SCIENTIFIC AMERICAN

OBJECT-PERCEPTION EXPERIMENT

ONE DOLLAR

October 1971

You have problems. We have solutions.

Pollution is industry's major problem and everyone is trying to get on the solution bandwagon.

However, at UOP, we were working on solutions long before it became popular. And, the results are helping industry right now.

For the petroleum and petrochemical industries we've developed processes to permit the production of nonpolluting products.

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We have the equipment and world-wide capabilities to design, construct and supply air, solid and water waste control facilities.

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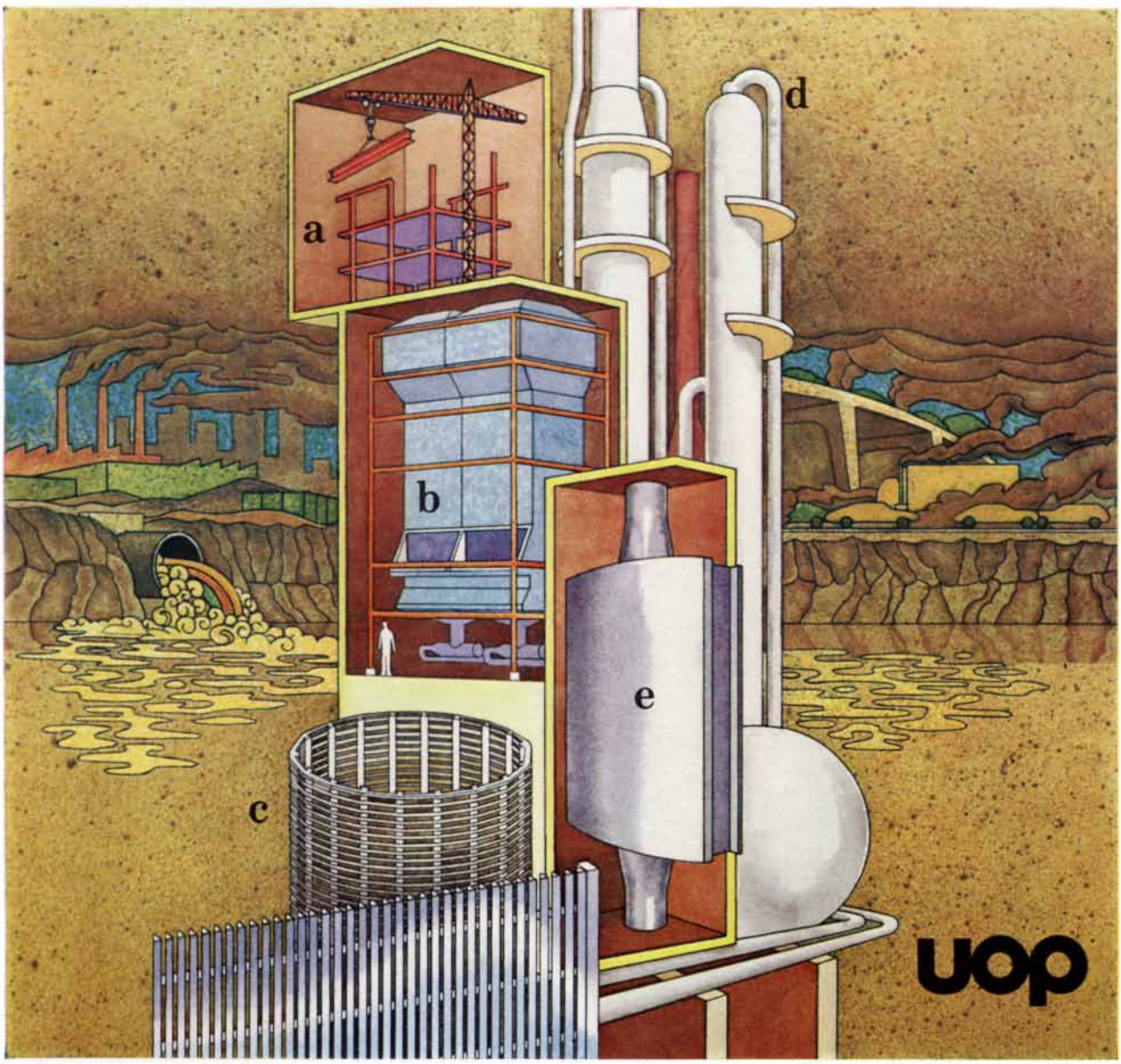

UOP serves environmental control through: (a) *Procon construction* including air, solid and water waste controls. (b) *Aircorrection by UOP*, air pollution control equipment. (c) *Johnson screens*, specialized screens and filters for water control. (d) *Processes by UOP*, advanced refining methods to help refiners solve their problems. (e) *UOP Research Center*, catalytic converters to cut exhaust pollution for all cars. **For solution of your pollution problems write, call UOP (Universal Oil Products Company), UOP Plaza, Des Plaines, Ill. 60016.**

super-micro-computer

Olivetti Corporation of America
Marketing Division, Department A10
500 Park Avenue
New York, N.Y. 10022

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from the company that invented the microcomputer.

In 1965, we introduced Programma 101. Today, it's the world's most popular microcomputer, with tens of thousands in use.

Now to complement the P-101, Olivetti introduces P-602. A powerful super-microcomputer to solve almost any scientific, technical, statistical and commercial problem that can be formulated mathematically.

The P-602 is clearly a logical extension of the Programma 101. All programs are recorded on small magnetic cards. The keyboard is simple. Program the P-602 yourself, or use the basic and application software developed by us.

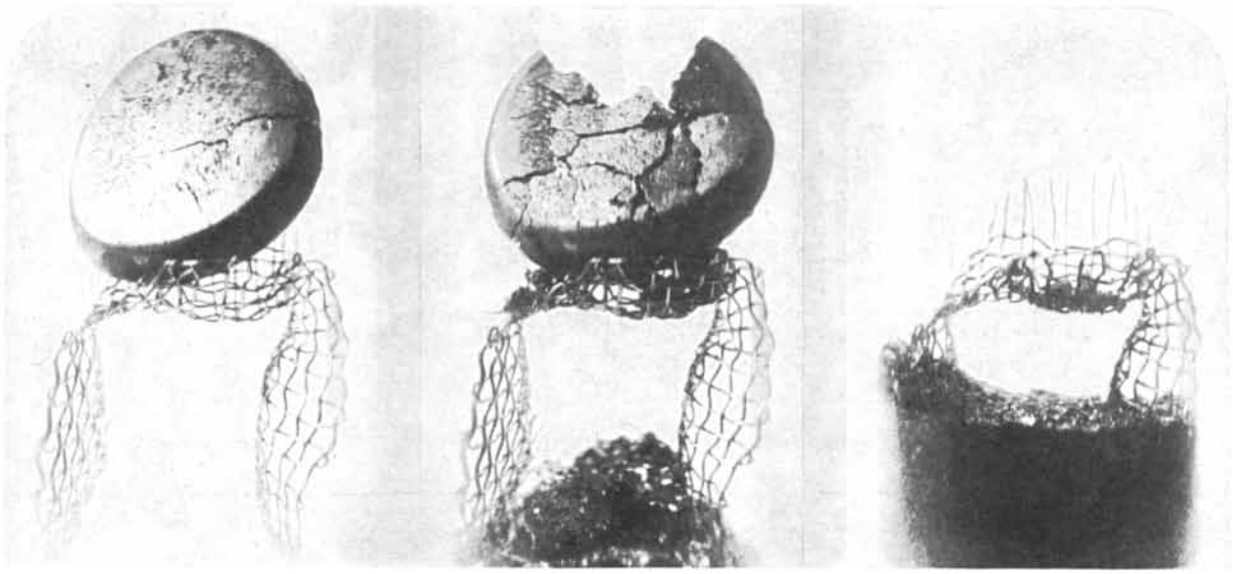
The P-602's power comes from many technical advances. Like read-only memory. Indirect addressing, as in large computers. Subroutines that can be created and called when needed. And single-step debugging.

But the P-602 is more than just a powerful machine. It can be integrated into a complete computing system through a magnetic cartridge unit, a paper tape reader, a tape punch, an XY plotter and scientific measuring instruments.

We admit we have something better than the world's most popular microcomputer. Small wonder we call the P-602 "super-microcomputer." To see the P-602 and Programma 101, simply call your local Olivetti representative (we're in the Yellow Pages) or fill in the coupon above.

We sell answers, not just machines.

The P-602 super-microcomputer is ideal for applications in numerical and statistical analysis, medicine, banking and finance, manufacturing, construction, civil engineering and surveying, aerospace, research, education, ecology, economic analysis, inventory and sales forecasting...and many more.



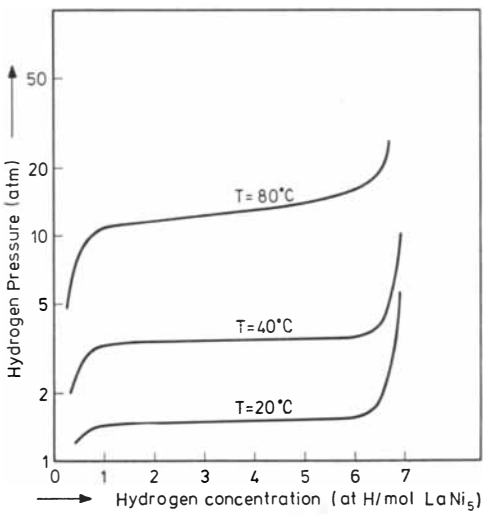
Our magnet attracts hydrogen

This is another example of the way in which relatively straightforward experiments occasionally produce surprising results.

In the research for more powerful permanent magnets, scientists have recently turned to intermetallic compounds like cobalt-rare earth. The properties of this new class of materials are markedly superior to those of conventional permanent magnets. For example, in 1969 Philips developed a samarium-cobalt ($SmCo_5$) magnet with a maximum energy product $(BH)_{max}$ of 20×10^6 gauss-oersteds and a high coercivity (10000 oersted). Etching of $SmCo_5$ powders has a noticeable effect on the coercivity H_c. This led physicists from Philips Research Laboratories, Eindhoven, the Netherlands, to believe that hydrogen had something to do with the H_c. So Dr. H. Zijlstra and Dr. F. Westendorp decided to investigate the coercivity in pressurized hydrogen. A sample of powdered $SmCo_5$ was compressed into a solid cube. This was enclosed in a thin stainless-steel tube. When the sample was subjected to a pressure of 20 atm. at room temperature, the scientists were surprised to find that the change in coercivity was much larger than they had expected; in fact it decreased by a factor of 10. Further experiments showed that large numbers of hydrogen atoms penetrated the lattice structure of the sample, transforming the original hexagonal structure into a hydride of orthorhombic structure, $SmCo_5H_{2\cdot6}$. When the pressure was reduced, the coercivity regained its initial value and the absorbed hydrogen was released. Pursuing this line of research with structurally related compounds like rare earth-nickel revealed even more exciting results. $LaNi_5$ in particular, a non-magnetic material, easily absorbs more than 6 hydrogen atoms per formula unit. The lattice expansion that goes with it (25% in volume) cracks the compressed pellet (see top picture). The hydrogen gas is as readily released as it is absorbed. A temperature difference of a few degrees or a pressure difference less than one atmosphere spells the difference between nearly saturated absorption and near desorption and it all happens at very practical temperatures and pressures (see bottom figure).

This spongelike property comes in handy for many applications. For example storage of hydrogen, for which the packing densities of H atoms at room temperature can be higher than in liquid H_2, or purification of hydrogen, as no impurities can penetrate the lattice of the material.

So who cares if $LaNi_5$ doesn't attract iron? It certainly attracts hydrogen!



In the Research Laboratories of the Philips group of companies, scientists work together in many fields of science. Among these are: Acoustics, Cryogenics, Information Processing, Mechanics, Nuclear Physics, Perception, Solid State, Telecommunications and Television.

PHILIPS

Established 1845 **SCIENTIFIC AMERICAN** October 1971 Volume 225 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover depicts an infant's response in an experiment on the perception of objects (see "The Object in the World of the Infant," page 30). The experiment begins with the infant's watching the red ball slowly move toward the screen, disappear behind it and emerge on the other side. On random trials the ball stops behind the screen. All the eight-week-old and 16-week-old infants who were tested in the experiment anticipated the reappearance of the ball. In the second stage of the experiment, which is the one that is illustrated on the cover, the ball stops in full view before it reaches the screen. Again all the infants who were tested looked to the other side of the screen as if they were expecting the ball to emerge.

THE ILLUSTRATIONS

Cover illustration by Birney A. Lettick

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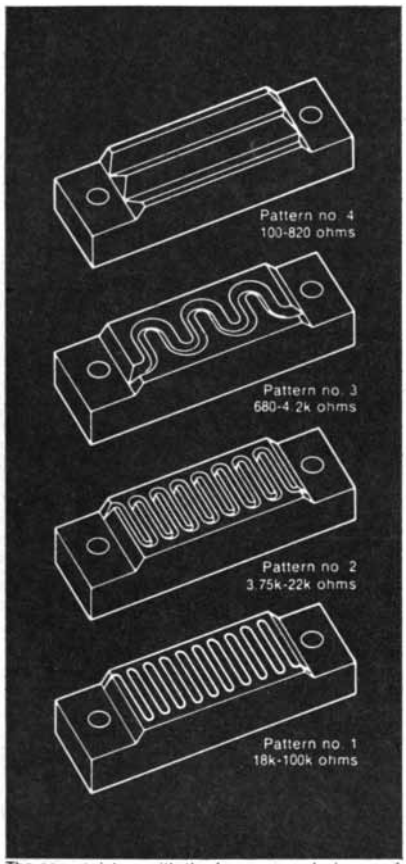
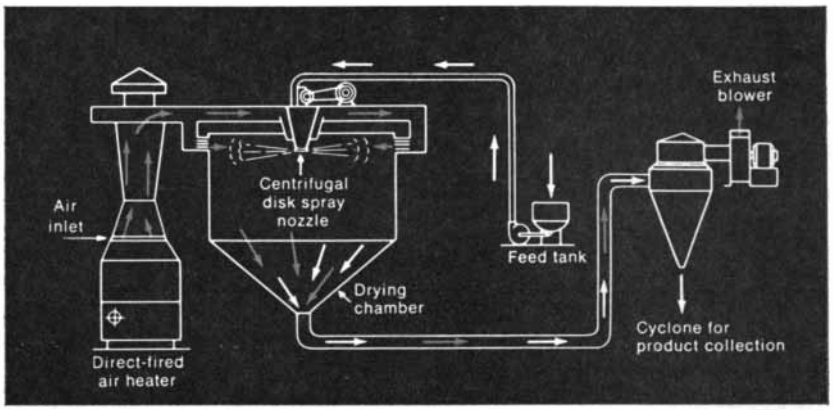
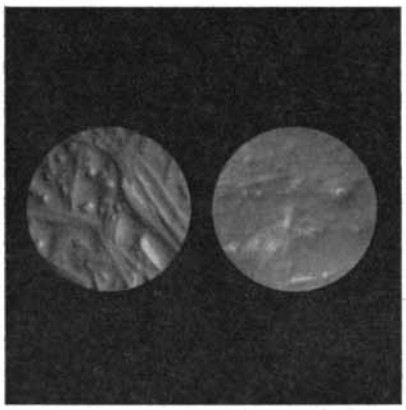
Putting resistance into new grooves.



The new resistors with the four groove designs and the range covered by each.



The spray-drying process that turns the wet ceramic into a fine powder with spherical granules.


Surface of original ceramic (left), and, (right), with finer grade of silica.

Everybody knows the virtues of tantalum for resistors in thin film circuits. Could these virtues be transferred to discrete resistors that would cover a wide range of values, and also be easy and economical to make?

That would involve, essentially, finding a way to deposit a resistor path — i.e., a strip of tantalum — on a ceramic substrate so that its length and width could be closely controlled.

The problem was given to engineers at Western Electric's Winston-Salem plant, and they solved it by designing a small ceramic rectangle which had a V-shaped groove on one surface. Coat that surface with tantalum and then grind it off: tantalum will be left in the groove, giving us our resistor path. Continued grinding keeps narrowing the resistor path. Hook the grinder up to an ohmmeter and it can be made to stop automatically at the desired resistance. With four groove designs we could cover the entire range from 40 to 100,000 ohms.

So far so good. But actually making these little ceramic rectangles with their little grooves presented another problem: what to make them out of. The most promising ceramic had two drawbacks. First, it developed needle-like crystals, giving it the surface you can see on the left of the picture, and tantalum sticks best to smooth, glassy surfaces. Second, the only way anybody had ever made anything out of this ceramic before was by a wet extrusion process. We couldn't extrude these little rectangles because of those wavy grooves.

Our engineers solved the first problem by changing the formulation of the ceramic, and the second by spray-drying it in a blast of hot air. Spraying broke it up into tiny droplets which were formed — by surface tension — into spheres, and that's the way they dried. So now we had a powder made up of spherical granules, which flowed almost like a liquid. That made it easy to get it into individual molds where each resistor substrate, complete with grooves, could be stamped out individually.

Development of even so homely a device as a new resistor is important to us at Western Electric because most of the electronic equipment we make is so complex—and because we make so much of it. Even a slight increase in long-range stability, and fractional reductions in initial cost, result in savings big enough to help the Bell telephone companies keep down the cost of your phone service.

Western Electric

AMERICAN MOTORS INTRODUCES THE GUARANTEED CAR.

If anything goes wrong with one of our 72's and it's our fault, we'll fix it free. Anything.

AMERICAN MOTORS 1972 BUYER PROTECTION PLAN.

For years, car buyers in this country have been saying that instead of shiny new chrome every year, what they really want is a good car they can count on.

That's why American Motors and its dealers put together their 1972 Buyer Protection Plan.

Here's how it works:

A STRONG GUARANTEE IN PLAIN ENGLISH.

When you buy a new 1972 car from an American Motors dealer, American Motors Corporation guarantees to you that, except for tires, it will pay for the repair or replacement of any part it supplies that is defective in material or workmanship.

This guarantee is good for 12 months from the date the car is first used or 12,000 miles, whichever comes first.

All we require is that the car be properly maintained and cared for under normal use and service in the fifty United States or Canada and that guaranteed repairs or replacements be made by an American Motors dealer.

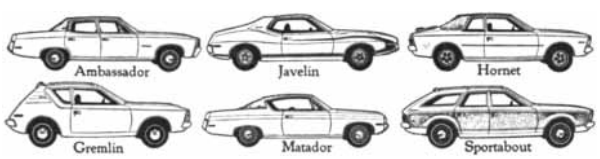
This guarantee gives you 12-month or 12,000-mile coverage on a lot of things most car warranties don't. It covers air conditioning, battery, radio, wiper blades, front end alignment, light bulbs—literally everything we put on the car except tires.

In other words, if something we did goes wrong with one of our '72's, you won't have to pay for the parts or the labor.

We will.

A MORE THOROUGHLY-CHECKED CAR. FROM THE FACTORY AND THE DEALER.

Naturally, we wouldn't be backing our cars like this if we weren't more sure of



them than we've ever been before. For 1972, we've put in more quality control steps, more tests and more people to see that every car leaving our factory is as perfect as man and machine can make it.

At the dealer's, it's checked over again.

Every car (not one of 50, one of 5, every one) is road-tested for starting, handling, braking and overall performance. When the serviceman completes the test, he signs his report and slides it over the sun visor, where you can see it.

And, when a man signs his name to something, you can be sure he's done his job. And done it right.

A LOANER CAR WHEN YOU NEED IT. FREE.

Not only do we offer you a strong guarantee, we've set up a system to back it up without inconveniencing you.

If you have to leave your '72 overnight for guarantee repairs, over 2,000 dealers will loan you one of their cars. A nice, clean, well-equipped car in good condition. Free.

A DIRECT LINE TO DETROIT. TOLL-FREE.

We're making some big promises, and we fully intend to keep them. But, just in case you have a problem, we have a way of handling it. When you buy a '72, you get the name and toll-free number of a person in Detroit.

If you call, we promise you you'll get results. And fast.

These aren't just fancy words. We mean it.

Nobody in the business does as much for you after you buy a car, and it takes a lot of time, men and money to do all of these things.

But we think it's worth it.

Since we're giving American car-buyers exactly what they say they want, we should sell more cars than we've ever sold before.

American Motors

LETTERS

Sirs:

In your "Science and the Citizen" note dealing with eutrophication [SCIENTIFIC AMERICAN, May] it is pointed out that in some cases nitrogen may be the controlling factor in eutrophication. While this is true in certain instances, it should not be used as an argument against phosphate control generally.

Perhaps an example will illustrate this point more clearly. If an intelligent person is given two cars, one without an engine and the other without fuel, he is not likely to suggest that in both instances they don't function because they need fuel. Similarly, if algal growth in the lower Great Lakes is phosphorus-limited and growth in coastal waters is nitrogen-limited, intelligent scientists should not recommend a continental policy of either phosphorus control or nitrogen control.

What is clearly needed here is a policy that takes into account regional environmental factors when dealing with environmental control. For example, when criticism was leveled at the International Joint Commission for blaming phosphorus rather than carbon for eutrophication in the lower Great Lakes, the critics did not take into account the high natural bicarbonate and carbon dioxide levels of those lakes and the low natural phosphorus levels. The suggestion of controlling algae by carbon reduction in the Great Lakes is as unwise as that of controlling algae in some coastal areas by phosphorus reduction.

It would be highly desirable if all authors commenting on environmental problems would be careful to present their data in such a way that readers could not reasonably transfer the information to different regions where other factors may be operating. It is imperative that legislation imposed to cure a pollution problem in one area of the continent not create a pollution problem in a different area.

D. JAMES KINGHAM

Ottawa

Sirs:

In their article "Eye Movements and Visual Perception" [SCIENTIFIC AMERICAN, June] David Noton and Lawrence Stark argue that the processing of visual information in the brain is serial and not parallel and they base this opinion on the tendency to periodicity of the eye movements when looking at a stationary picture. It is known, however, that a large fraction of the neurons of the cerebral cortex are in operation at any one time, so that the ultraparallel activity of the brain cannot be denied. It seems that some more careful definition of "serial activity" is required. It cannot be ascribed to conscious attention, otherwise the article by Noton and Stark would not have been written.

The approximately periodic motion of the eyes by no means implies an exactly analogous procedure in the visual cortex. Instead it seems more reasonable to suppose that neural impulses travel around in parallel in a number of circuits, and that this activity is reinforced in an economical manner by the signals sent from the optic nerves. This theory is consistent with all the experimental facts and also with the assembly and subassembly theories of the brain, where the subassemblies of neurons correspond to the features, and an assembly to a picture as a whole. The subassemblies keep the assembly reverberating and *conversely* (see, for example, D. O. Hebb, *The Organization of Behavior,* Wiley, 1949; I. J. Good, "Speculations Concerning the First Ultra-intelligent Machine," *Advances in Computers: Vol. VI,* 1965, pages 31–88; I. J. Good, "Creativity and Duality in Perception and Recall," *Conference on Pattern Recognition,* London: Institution of Electrical Engineers, 1968).

I. J. GOOD

University Professor
Virginia Polytechnic Institute
and State University
Blacksburg, Va.

Sirs:

A review of our article will show that our conclusion that visual recognition is a serial process was based not on our own results concerning scan paths ("periodicities") in eye movements but on the results of recognition-time experiments performed by others (page 35 of the article). Although we would not deny the existence of parallel processing in the brain, for example in the transmission of information to the visual cortex during a single fixation of the eye, we feel that these recognition-time experiments indicate serial processing of features during recognition. We interpret our scan-path results in the light of this conclusion, suggesting the feature ring as internal representation of an object in memory.

The feature-ring hypothesis is by no means incompatible with the "assembly and subassembly theories of the brain," if the individual sensory and motor memory traces are interpreted as subassemblies and the feature ring is interpreted as an assembly. However, in the absence of adequate neurophysiological data on the brain, we preferred to give a purely functional description of the memory traces and feature ring and to avoid speculation about their neural implementation. Suggestions that "neural impulses travel around in parallel" are interesting but without experimental support, whereas our hypothesis, although speculative, did in fact predict and explain the experimental finding of scan paths in eye movements.

DAVID NOTON

University of Colorado
Boulder

LAWRENCE STARK, M.D.

University of California
Berkeley

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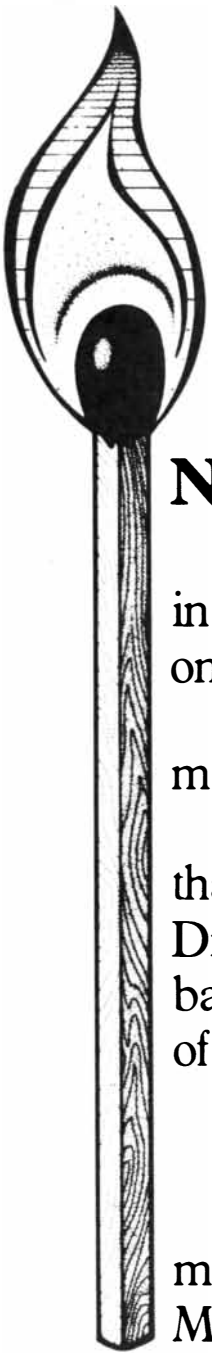
OLD ADDRESS



Now what starts fires, stops them.

Phosphorus used to seem like magic, back in Chemistry I. Expose it to air and it catches on fire, remember?

Now we've made phosphorus seem like magic again. We've turned it into a fire-retardant.

It's a Monsanto product called Phos-Chek,® that's used in fighting brush and forest fires. Dropped from a plane or copter, it produces a barrier that puts out the fire, then does a couple of nearly unbelievable things.

It helps keep the area safe from further fire.

It fertilizes the ground for new seedlings.

Phos-Chek® fire-retardant is just one of the many kinds of products coming from the new Monsanto Company. In areas as diverse as swine genetics and electronics, fashion fibers and steel, environmental engineering and plastic packaging. Ideas just seem to catch fire at **Monsanto: the science company.**

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1921: "As our readers well know, SCIENTIFIC AMERICAN is in favor of a judiciously regulated disarmament. The spirit of the forthcoming disarmament conference which has been called by President Harding will be determined very largely by the spirit with which we enter it. If we enter the conference with the conviction that the rest of the world is prepared to be just as honorable, just as fair, just as frank as ourselves, we shall give a tone to the whole series of discussions which will carry them through to a brilliant accomplishment. It should be for us to remember that the world which we have invited to meet us is a broken world, a world that is very sick and wounded almost to death. Our guests will enter the conference bearing a crushing load imposed by their naval and military armament, and we firmly believe that there is not one of them but will come to the conference eager to have that burden lightened."

"The age of artificial lightning appears to be close at hand, not as a mere stage effect but as a practical means of distributing electric power over nationwide areas. Only a few weeks ago the press announced the culmination of a series of tests aiming to raise commercial currents to one-million-volt potential and then to transmit that lightning-like current over a properly insulated transmission line. The final experiments would seem to indicate that such high potentials can be generated and handled, but there remains a vast amount of engineering work before we can begin to raise the potential of our electric power lines from the present high mark, 220,000 volts. The remarkable high-voltage tests in which the one-million-volt potential was reached took place at the high-voltage laboratory of the General Electric Company at Pittsfield, Mass. These experiments have been carried out by specialists in electrical transmission—men who have seen the distribution of electric current on a long-distance scale begin with 15,000 volts in 1891 and culminate with the creation of a 220,000-volt line in California."

"It used to be thought that the salt in the ocean was dissolved out of the rocks forming the continents by rain water and carried down to the sea by rivers. This theory is not tenable for various reasons. For one thing the salt contained in solution in the water of streams contains about 80 per cent of calcium carbonate and only 7 per cent of compounds containing chloride, whereas 89 per cent of the mineral compounds contained in sea water consists of salt. Furthermore, when rivers are cut off so as to form landlocked lakes which afterward dry out, the stratified layers of mineral salts which are formed differ in composition from sea salt. Modern geologists consider the salinity of the ocean as being an original instead of a derived condition. Suess has a theory that the mineral compounds found in the ocean water to-day proceed from the volcanic eruptions which took place in the early stages of the formation of our earth."

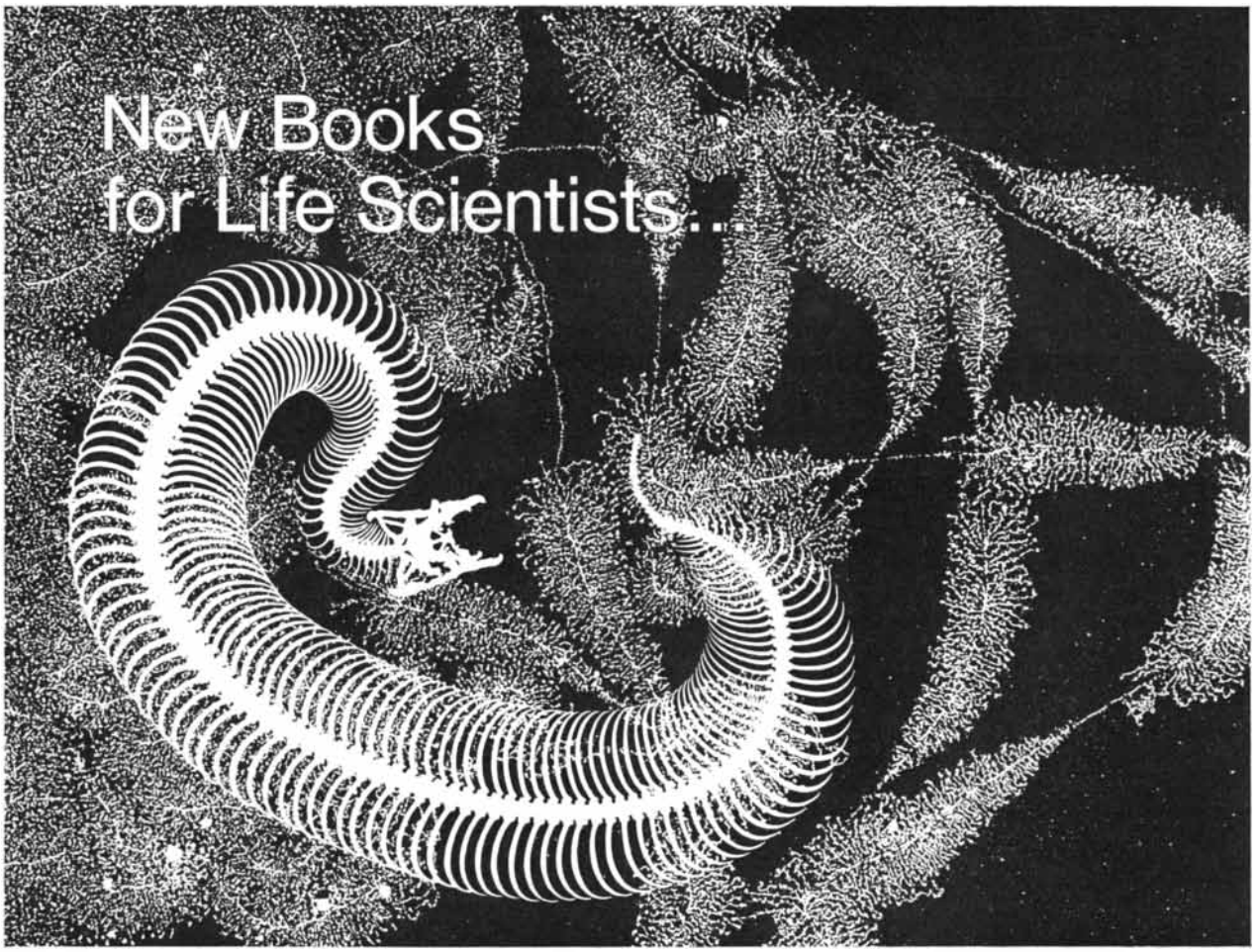
"The American women who raised the money to give Mme Curie a gram of radium have exceeded their goal by $60,000. Another fund of $50,000 is in process of collection. Those funds combined are to provide her with adequate laboratory equipment and a life income with which to carry on her researches."

SCIENTIFIC AMERICAN

OCTOBER, 1871: "The area burned over by the almost unparalleled fire at Chicago approximates four square miles. Ten thousand buildings were destroyed, 2,000 of which were business houses. The total loss cannot be at less than $200,000,000. The people rendered homeless by the disaster number probably not less than 100,000. Is there no useful lesson taught us in this dreadful catastrophe? There had been a long drought, and there were quarters in the city where fire could feed itself fat on wooden structures whose combined burning generated a heat too intense to be withstood by iron or walls of brick. The wooden sidewalks and pavements which abound in Chicago no doubt did much, in their excessively dry condition, toward spreading and adding fury to the flames. It is safe to infer from the careful general study of fires in cities that, were it not for wooden buildings massed together, there never could be such extensive conflagrations. The wooden buildings, sidewalks and pavements of Chicago will be replaced by more substantial structures, and in time the Garden City will perhaps be all the stronger for this purification by fire."

"Those who have believed the International Working Mens' Association of small account in its influence upon industrial affairs throughout the world may learn a useful lesson from the recent struggle between labor and capital in England. About four months since, a demand was made by the workmen in the workshops on the Tyne for a reduction of one hour's labor per day without a corresponding reduction in their pay. The demand was refused, and about the first of June the workmen, numbering some 10,000, struck. A significant feature of the strike has been the united attempt made by the prominent engineering firms in England to defeat it. These sided with the Tyne firms, and raised a large fund for the purpose of importing workmen from other parts of Europe. A large number of workmen were obtained from Belgium and others were secured from the Government Arsenal in Denmark. But the influence of the International, coupled with the threats and remonstrances of the English workmen, soon overpowered that of the manufacturers. We have thus the spectacle of united capital pitted against united labor on a scale to test the relative strength of each. Prone as is the American public to refrain from recognizing and preparing for approaching emergencies, there are among us some who see that the adjustment of the relations of capital to labor will soon force itself upon public attention."

"When glycerin is allowed slowly to trickle into a mixture of equal measures of nitric acid and oil of vitriol at a low temperature, two atoms of its hydrogen are replaced by two atoms of protoxide of nitrogen, and there results a heavy oily liquid known as nitro-glycerin, a body which has more than 10 times the explosive power of gun powder. It has come into extensive use for blasting, and a number of terrible accidents have resulted from it. Nobel claims that nitroglycerin can be rendered perfectly harmless and safe for transportation by mixing it with 10 per cent of wood spirits or methylic alcohol. Such a mixture, known as dynamite, may be exploded by means of fulminate of mercury, itself fired by the electric spark or by a slow match."



MOLECULAR GENETICS

An Introductory Narrative

GUNTHER S. STENT,
University of California, Berkeley

This book presents the essentials of molecular genetics in the historical sequence in which that body of knowledge evolved. Drawing upon his own experience and firsthand acquaintance with many of the scientists whose work he describes, Professor Stent traces the growth of the field from the esoteric specialty of a small, tightly-knit vanguard to an immense, ramified discipline. The book is copiously illustrated and contains portraits of many of the protagonists of its story.

1971, 650 pages, 282 illustrations, $12.00

INSECT HORMONES

V. B. WIGGLESWORTH,
University of Cambridge

"In the publication of his sixth book, Sir Vincent Wigglesworth continues the high standards he set in his earlier publications. . . . But unlike these previous works, this volume is written not for the specialist but for a more general audience. The result is a clear, interesting account of insect hormones which presents the main outlines without becoming bogged down in minute detail. . . . Biologists in general will profit from a thoughtful reading of *Insect Hormones.*" —*Science,* February 26, 1971

1970, 159 pages, 43 illustrations, $6.50

PLANT CELL PHYSIOLOGY: A PHYSICOCHEMICAL APPROACH

PARK S. NOBEL,
University of California, Los Angeles

". . . Written primarily for advanced undergraduate and graduate students of plant physiology and biophysics . . . As far as I am aware, there is no other textbook available which covers these topics of plant physiology and also deals with their physicochemical aspects. Consequently, Nobel has made available an excellent and needed textbook for those who teach in this field."
—J. Barber in *Nature,* April 9, 1971

1970, 267 pages, 34 illustrations, $7.75

INTRODUCTION TO HERPETOLOGY

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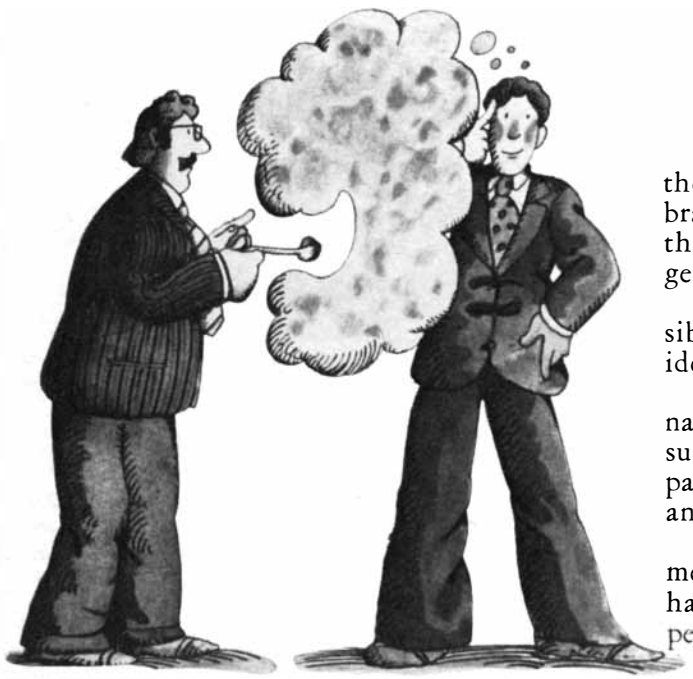
The Care and Feeding of the Bright Idea.



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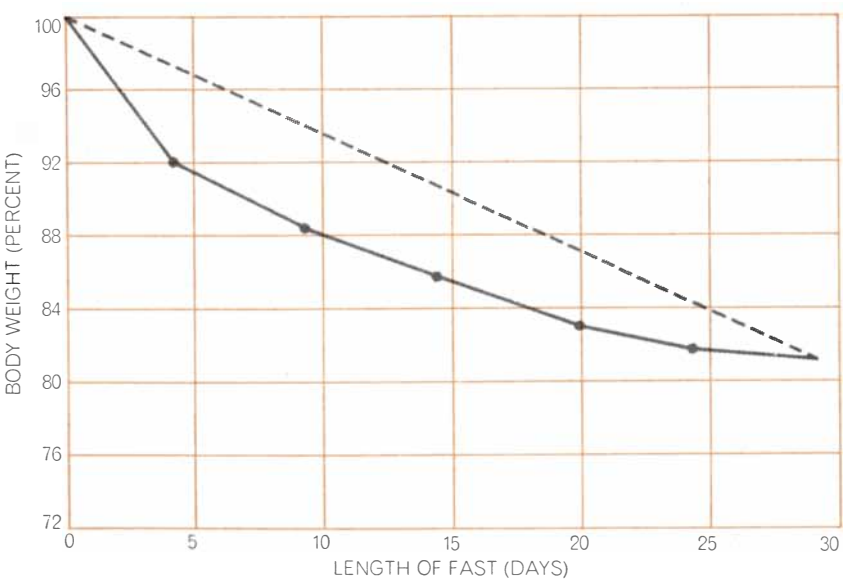
The Physiology of Starvation

How does the human body adapt to prolonged starvation? Studies of fasting subjects indicate how best to utilize food when food is scarce and also how protein and calorie requirements are related

by Vernon R. Young and Nevin S. Scrimshaw

The human body has a remarkable capacity for surviving without food for long periods. There is the well-authenticated case of Terence MacSwiney, the Irish revolutionist and mayor of Cork, who in his famous hunger strike in a British prison in 1920 survived for 74 days before dying of starvation. It has been shown many times that a fast for the biblical period of 40 days and 40 nights is well within the capability of a healthy adult. Recent tests of total fasting by obese persons for weight reduction have yielded remarkable results. Some obese individuals have gone without food for as long as eight months and emerged from the ordeal in good condition.

How does the body accommodate itself to prolonged starvation? Although a knowledge of how to survive though hungry could not do much to ameliorate the chronic hunger and the famines that afflict a large portion of mankind as a result of poverty and droughts and wars, the question does not lack practical importance. From investigation of the body's responses to food deprivation we can learn much about its specific nutritional needs. Studies of the physiological and biochemical adaptations to starvation have also thrown light on a wide range of other questions, from appropriate diets for reducing weight to more effective regimes of food use during a food-shortage emergency. Moreover, they have advanced the understanding of the starvation disease called marasmus, which is increasing in many developing countries because mothers are giving up prolonged breast-feeding and their infants are not receiving an adequate substitute diet during a critical time in development.



CLASSIC STUDY of a fasting man by L. Luciani in 1890 shows how body weight decreases with fasting time. The decrease is not linear (*broken curve*) but slows with time (*solid curve*). When subject began fast, he weighed 139.5 pounds; after 29 days he weighed 113.

Experimental studies of the effects of food deprivation over very long periods began around the turn of the century. One classic study was conducted in 1915 by F. G. Benedict of the Carnegie Nutrition Laboratory in Boston; he studied a volunteer subject who fasted for 31 days. In the 1940's Ancel Keys and his collaborators at the University of Minnesota tested a group of volunteer subjects kept on a semistarvation diet (about 1,600 calories per day) for 168 days. These experiments have been followed by trials of abstinence from food for the treatment of obesity, pioneered by Garfield G. Duncan of the University of Pennsylvania School of

Medicine and Walter Lyon Bloom of Piedmont Hospital in Atlanta.

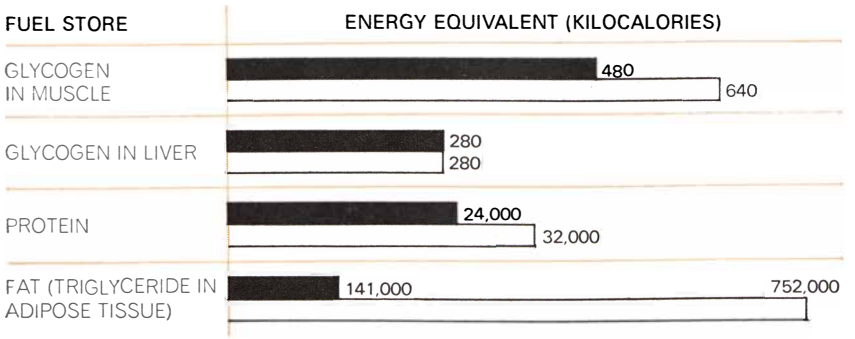
A large number of obese patients have now undergone the total-fasting treatment for extensive periods under careful observation at centers in North America and Europe, and in almost all cases there have been no serious complications. The longest reported fasts were by two women treated by T. J. Thompson and his coworkers at the Stobhill General Hospital and Ruchill Hospital in Glasgow. One was a 30-year-old woman who ate no food for 236 days and reduced her weight from 281 pounds to 184; the other patient, a 54-year-old woman, fasted for 249 days and reduced from 282 pounds to 208. Of 13 fasting patients in Thompson's group none showed any significant adverse side effects that could be attributed to lack of food.

There have been several deaths elsewhere among fasting obese patients, but in all but one case the deaths apparently were due to preexisting medical conditions that had been aggravated by the obesity rather than by the fasting itself. The one exception was a 20-year-old girl who in 30 weeks of total fasting cut her weight from 260 pounds to 132 pounds. On the seventh day after she had resumed eating, her heartbeat became irregular, and she died of ventricular fibrillation on the ninth day. E. S. Garnett and his co-workers at the General Hospital in Southhampton, England, found that this patient not only had lost fatty tissue but also had consumed, during her fast, half of the lean-tissue mass in her body, including part of the fibrous tissue of the heart muscle.

To explain the body's ability to mobilize its inner resources for survival in the absence of food intake we must begin with a review of its chemical needs. The primary need, of course, is fuel to supply energy for the vital functions. Normally the principal fuel is glucose, and its most critical user is the brain, for which glucose is fully as essential as oxygen. A rapid drop of the sugar level in the blood, which must continuously deliver glucose to the brain, brings about behavioral changes, confusion, coma and, if prolonged, structural damage to the brain resulting in death. In the body at rest the brain consumes about two-thirds of the total circulating glucose supply (compared with about 45 percent of the oxygen supply). Most of the remaining third of the glucose supply goes to the skeletal muscles and the red blood cells.

The human brain requires between

SEMISTARVED VOLUNTEER SUBJECTS rest in sun during an experiment undertaken in 1944 by Ancel Keys and his colleagues at the University of Minnesota. Volunteers were conscientious objectors of World War II. Their fast was only partial; they received a ration of 1,600 calories per day for 168 days. This photograph was made by Wallace Kirkland of *Life* and is copyrighted by Time Inc.



FUEL STORES in normal adult (*black bars*) and obese adult (*white bars*) are compared. Each pair of bars is on a different scale. The main store is fat, and in obese people this store is five or six times larger than in normal people. The data are from George F. Cahill, Jr.

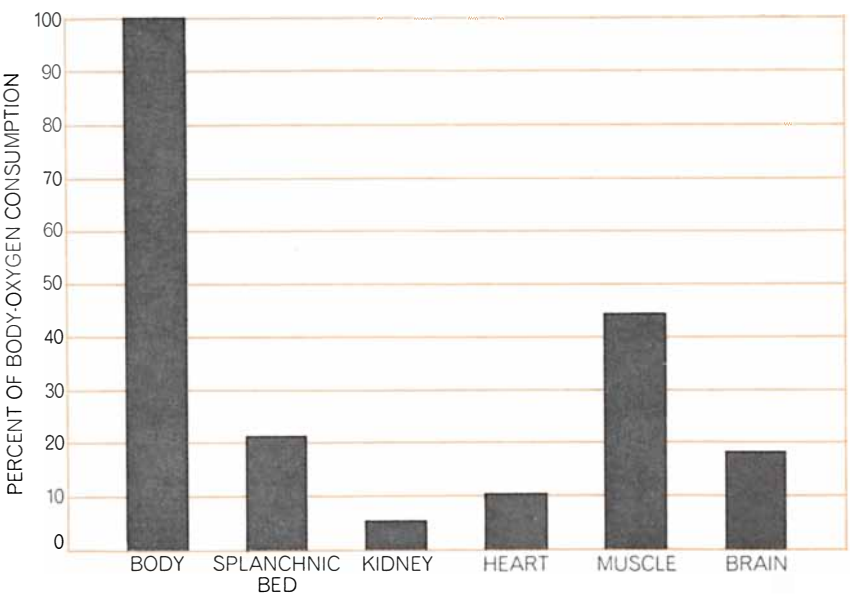
100 and 145 grams of glucose (equivalent to about 400 to 600 calories) per day. The body's main reserve of glucose, in the form of glycogen in the liver, amounts to considerably less than 100 grams, and part of this store is not ordinarily available because the liver tends to conserve some glycogen for stressful emergencies the body must be prepared to meet. As a result the liver's store of fuel can supply the brain's need for only a few hours. In fact, the stored glucose is not sufficient for the duration of the overnight fast between dinner and breakfast. Between meals the liver begins to draw on the tissues of the body for materials to synthesize the required glucose. We have found by examination of subjects in our laboratory at the Massachusetts Institute of Technology that after a person has eaten a meal at 10:00 P.M. certain amino acids that are precursors for the synthesis of glucose begin to accumulate in the blood plasma by 1:00 A.M., and they continue to increase until breakfast. The rise in amino acids is an indication that proteins in the skeletal muscles are being broken down to provide material for the production of glucose by the liver. Analysis of the blood also shows that at the same time the blood contains free fatty acids, which are derived from the breakdown of triglycerides in the fatty tissues and are capable of supplying energy to tissues other than those of the nervous system.

Clearly if the breakdown of protein continued at the initial rate, the skeletal muscles would rapidly waste away and the body could not survive for long. As starvation is prolonged, other sources of energy for the brain come into play, as we shall see. Let us first, however, follow the contribution of protein.

During the early period of starvation the body of an average man (143 pounds) synthesizes about 160 grams of glucose per day. Most of this is produced by the liver, but the kidney cortex also synthesizes an appreciable amount of glucose. The loss of protein involved and substantial losses of body minerals (such as calcium, potassium and magnesium) cause a loss of the water associated with these substances in the body, and this is mainly responsible for the initial loss of weight. As starvation continues, however, a progressively greater proportion of the weight loss is accounted for by the consumption of body fat. Gram for gram, fat is much richer in energy than other nutrients are: fat represents about nine calories per gram of weight in the body, whereas protein in the body carries only two calories per gram and carbohydrate one calorie per gram. Thus each unit of consumption of body fat donates much more energy to the starved body. This is probably a major factor in slowing the loss of weight as starvation is prolonged [*see illustration on page 14*]. Eventually the fat consumed during continued loss of weight in obese people provides for essentially all the energy needed by the body.

There is an interesting question concerning what the weight loss means in terms of cells. Does the loss take the form of shrinkage of the cells' size or reduction of their number? Animal studies have shown that total or nearly total starvation can reduce the number of cells or fibers in the skeletal muscles. Little direct study of this question has been conducted in man. Radiographs of the chest in persons on a starvation diet have indicated that the heart shrinks in size, but not whether this is due to a reduction of the cells' size or of their number. Jules Hirsch of Rockefeller University obtained somewhat more definite information. He studied a group of obese adults who had been fed only 600 calories per day and had lost upward of 100 pounds of body weight. Examining cells of their fatty tissues aspirated through a hypodermic needle, he found that the cells had shrunk by about 45 percent in size. The number of cells had not changed appreciably, however, except in a few people who had achieved particularly large losses of body fat.

George F. Cahill, Jr., of the Elliott P. Joslin Research Laboratory of the Diabetes Foundation, the leading investigator of the biochemical aspects of starvation in man, has looked into the changes in metabolism of obese people during fasting. Analyzing the blood's content of metabolites from skeletal muscle, he



OXYGEN UPTAKE after an overnight fast is apportioned among various organs as shown by bars at right. "Splanchnic bed" refers to viscera, mainly the liver. Pattern of oxygen uptake is quite different from that of glucose uptake (*see illustration on opposite page*).

finds that at the beginning of fasting (not long after a meal has been digested and absorbed) the blood shows an increase of amino acids released from the muscle cells. Of these amino acids, which provide the supply of substrate for the liver's synthesis of glucose, the principal one is alanine. Furthermore, it turns out that alanine given by injection can increase the production of glucose, as shown by a rise of the glucose level in the blood.

The amount of alanine released from the muscle cells is surprising, because alanine makes up only 7 percent of the total content of amino acids in the cell proteins. It appears that most of the alanine discharged from the cells during fasting is not produced directly from protein breakdown but must be synthesized from alanine's immediate precursor, pyruvic acid, by the addition of an amino group furnished by other amino acids liberated by the breakdown of protein.

Cahill has proposed a cycle for the conversion of alanine to glucose and reconversion to alanine; it is somewhat analogous to the Cori cycle for lactate [*see illustration on page 20*]. According to Cahill's model, the alanine cycle, like Cori's, merely recycles a fixed supply of glucose. In addition, however, the alanine cycle offers an efficient means of transporting to the liver the nitrogen derived from the amino acids liberated by the breakdown of muscle protein.

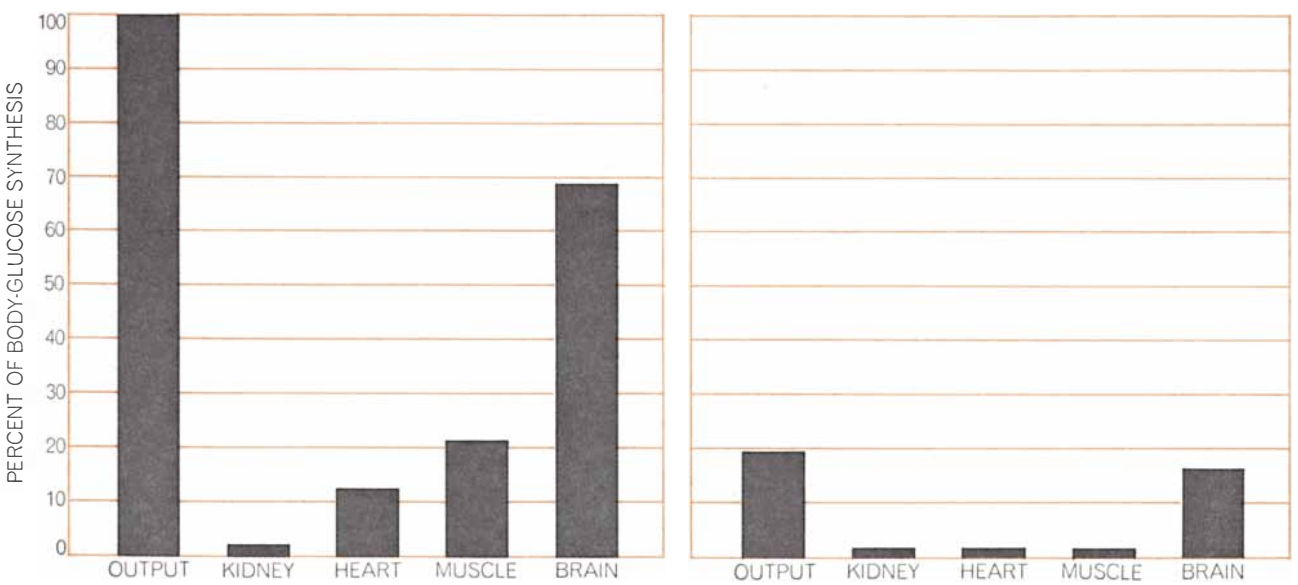
As starvation continues, a number of general factors come to the aid of the organism. The basal metabolic rate slows, and the body's need for calories is further reduced by the loss of metabolically active tissue. The starving person engages in less spontaneous activity and becomes more sparing in the expenditure of energy, so that he uses his available energy more efficiently in accomplishing a given work load. His ability to survive will also depend, of course, on individual variables such as his body size and his stores of fat, and on environmental ones such as temperature and humidity.

Paramount, however, is the matter of the expenditure of protein. The starving body soon resorts to strong measures to preserve its integrity. It is confronted with two seemingly irreconcilable demands. The brain still requires a daily supply of energy equivalent to at least 100 grams of glucose; yet the synthesis of glucose at that rate would quickly exhaust the protein on which life depends. The triglycerides of fatty tissue provide a source of synthesis for glucose, but they can furnish only about 16 grams per day. In order to obtain the rest of the daily glucose requirement, some 90 grams, the body would have to break down about 155 grams of muscle protein. This would involve a daily loss of 25 grams of nitrogen. The nitrogen content in the body of an adult amounts to about 1,000 grams, and a loss of more than 50 percent of that amount is lethal. Hence a starving man could not live longer than three weeks if he had to expend his nitrogen at that rate.

Actually the body takes steps to control its loss of protein. The skeletal-muscle cells reduce their release of alanine, and the liver's synthesis of glucose declines. Cahill and an associate, Oliver E. Owen, found that by the fifth or sixth week of an obese adult's fast the liver and kidney were producing only 24 grams of glucose per day, and that essentially all of this glucose was going to the brain.

Where and how did the brain obtain the rest of the energy it required? Cahill discovered that the deficit was made up by a substitute source of energy derived from the fatty tissues. The blood of the starved obese subjects showed an accumulation of ketone bodies: acetoacetic acid and two derivatives from it, acetone and beta-hydroxybutyric acid. These substances yield energy on oxidation, and the brain evidently had adapted to using them as energy substrates in place of glucose.

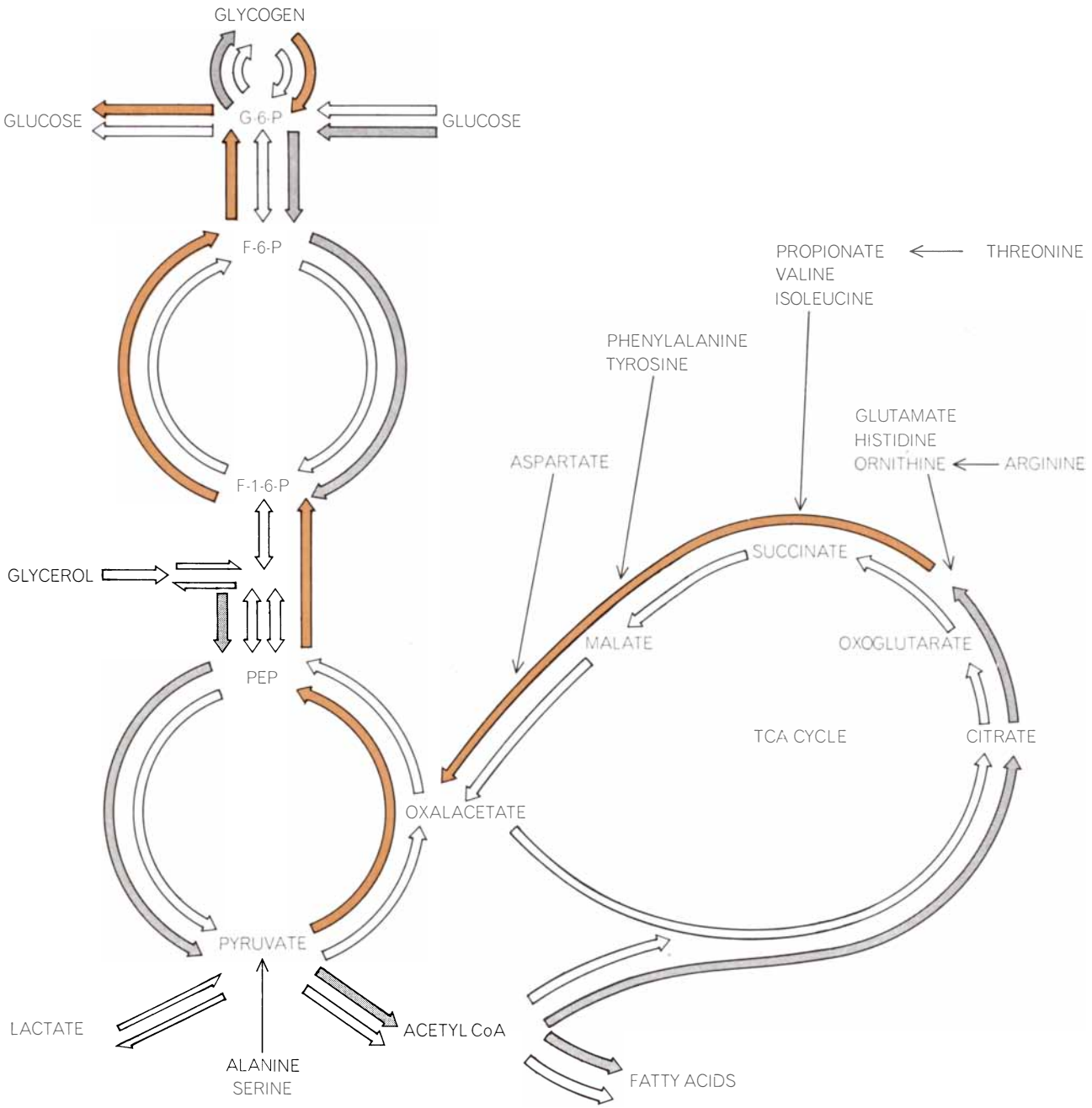
Ordinarily the metabolism of fatty acids does not create ketones. In response to starvation, however, fatty acids are released from the fat depots and are oxidized in the liver to acetoacetic acid, which is then transported by the blood to other tissues to provide them with energy. The accumulation of ketones in the blood during starvation—and indeed in people on a high-fat diet—has been known for some time as the condition called ketosis. It is now clear that the ketosis of starvation signals a response to depletion of the body's supply of glucose, as Hans A. Krebs of the University of Oxford suggested some years



GLUCOSE OUTPUT AND UPTAKE after overnight fast (*bars at left*) and after five weeks' starvation (*bars at right*) are compared. "Output" is glucose synthesis; the other bars indicate the uptake of glucose by various organs. After the overnight fast glucose comes mainly from the liver; after the five weeks' starvation it comes 50 percent from the liver and 50 percent from the kidneys.

ago. The evidence indicates that the brain promptly adopts the ketone bodies, particularly beta-hydroxybutyrate, as a substitute energy source, possibly within the first week of starvation. The Oxford group has recently shown (in studies conducted with experimental animals) that the brain has the enzymatic machinery to utilize ketone bodies. Their studies suggest that the human brain can probably begin to utilize ketone bodies for meeting its energy needs as soon as these metabolites in the blood supplying the brain reach a high enough level.

The breakdown of body protein is not completely eliminated. Even in prolonged starvation nitrogen in the form of urea and ammonia continues to be excreted in the urine. It reflects the basic turnover of proteins in the body that goes on at all times. In our laboratory we estimated the amount of this basic turnover by measuring the urinary-nitrogen output of subjects who were fed a diet containing no protein but adequate in calories. Comparing their daily nitrogen loss with that reported for starved subjects in the fourth week without food, we find that the starved obese subjects' loss is not markedly higher. This could mean that the starved subjects were producing some five more grams of glucose per day than can be obtained through the basic turnover of body protein. The body cannot do entirely without glucose, because most tissues need it for replenishing the tricarboxylic acid (TCA) cycle, which among other things synthesizes the energy-rich adenosine triphosphate (ATP) on which so much of the body's chemistry depends. Nevertheless, the very small extra loss of protein shown by obese people during prolonged starvation indicates that, thanks to the substitution of ketones for energy, their need



MAIN PATHWAYS in the utilization and production of carbohydrate in the liver are outlined in starvation (*dark-colored arrows*) and nonstarvation (*gray arrows*). "G-6-P" stands for glucose-6-phosphate; "F-6-P," for fructose-6-phosphate; "F-1-6-P," for fructose-1-6-diphosphate; "PEP," for phosphoenolpyruvate; "CoA," for coenzyme A, and "TCA cycle," for tricarboxylic acid cycle.

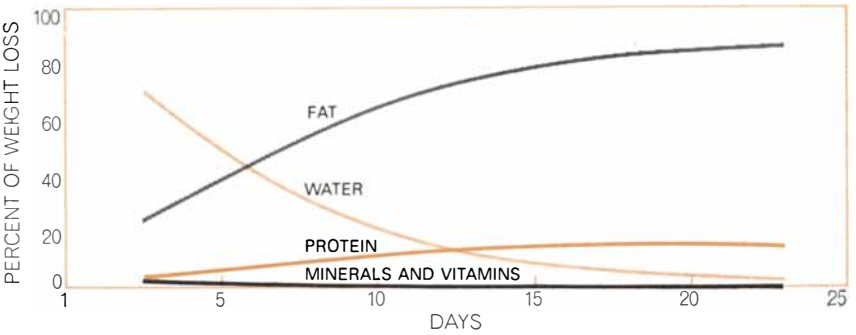
for glucose is limited to not much more than is provided by the ordinary turnover of protein in the body.

One of the consequences of the body's conservation of protein during starvation is that urination for the excretion of nitrogen is reduced. Hence a starving man needs less water intake. If his loss by sweating is minimal, a cup of water a day is sufficient to maintain his body's water balance.

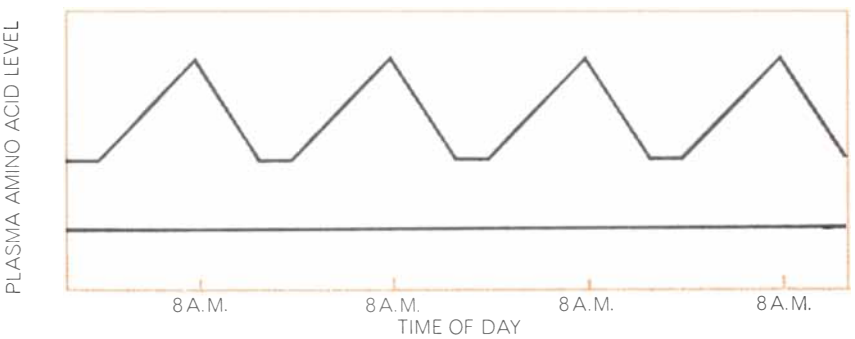
What are the mechanisms that bring about the adaptive changes in metabolism during prolonged starvation? This question remains to be explored. No doubt hormones will be found to play an important part. It is known that the pancreatic hormone insulin is an important regulator of chemical activity in the body's ordinary daily cycle of eating and fasting. During the digestion of a meal the absorption of glucose and amino acids from the intestinal tract stimulates the secretion of insulin; the hormone in turn stimulates the synthesis of fat and inhibits its breakdown, promotes the uptake of glucose and amino acids by the muscle cells and inhibits the synthesis of glucose by the liver. After the meal has been absorbed the insulin level in the blood falls, and during prolonged starvation it stands at a level lower than normal. Cahill has found that during prolonged starvation glucagon, the pancreatic hormone whose effect is opposite to that of insulin, is at a higher level in relation to insulin. Glucagon normally acts to stimulate the liver's synthesis of glucose. It is possible, therefore, that the alteration in the balance between the two hormones in the blood during starvation serves to heighten the activity of the liver in forming glucose and in metabolizing fats. The possible participation of other hormones, notably the growth hormone of the anterior pituitary gland and the glucocorticoid hormones of the adrenal gland, is being investigated, but so far it does not appear that these play primary roles in the metabolic adaptation to starvation.

There is a striking change in the role of the cortex of the kidney during prolonged starvation. It is promoted from a relatively minor partner of the liver in the synthesis of glucose to the main producer; by the sixth week of an obese person's fast the kidney cortex is synthesizing more glucose from amino acids than the liver is. This shift is believed to be attributable, at least in part, to the change in the acid-base balance in the blood caused by the increase in the body's production of ketone bodies.

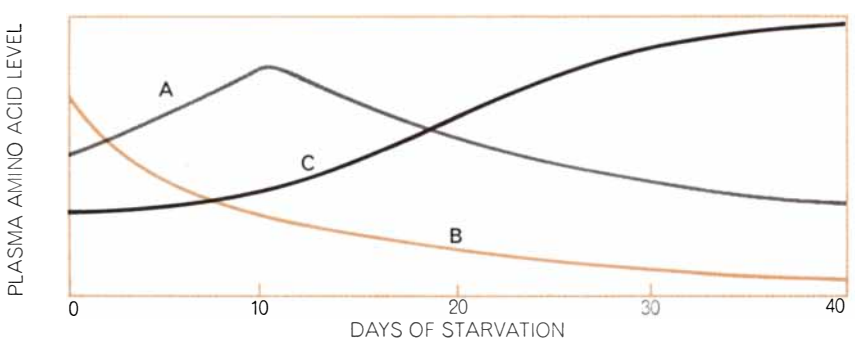
The ability of an adult to survive pro-



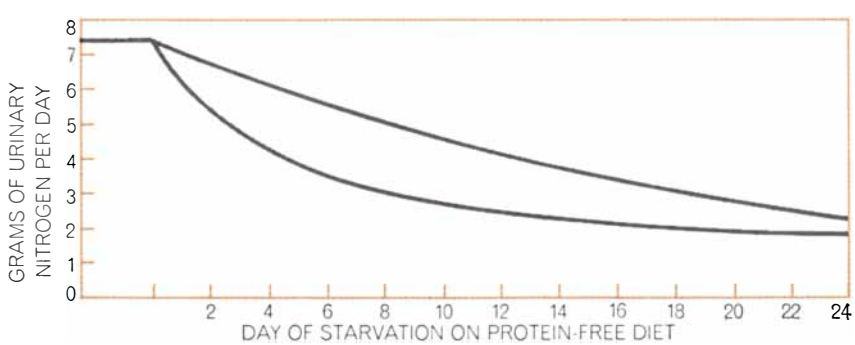
DAILY WEIGHT LOSS in prolonged starvation is analyzed by constituents of the body. Data are from Josef Brožek, Ancel Keys and their co-workers at University of Minnesota.



LEVELS OF AMINO ACIDS IN THE BLOOD normally follow these generalized curves. The level of certain amino acids (for example tryptophan, leucine and valine) rises and falls daily (*top curve*). The level of others (for example aspartic acid) remains steady.



LEVELS OF AMINO ACIDS IN STARVATION follow different curves. Certain of the amino acids (for example valine) rise and then fall (*A*). Other amino acids (for example alanine) fall steadily (*B*). Still others (for example glycine) show a delayed rise (*C*).



NITROGEN LOST IN URINE by starved subjects (*top curve*) and by subjects fed a protein-free but otherwise adequate diet (*bottom curve*) are compared. The difference between curves reflects starved person's need to synthesize glucose out of his own protein.

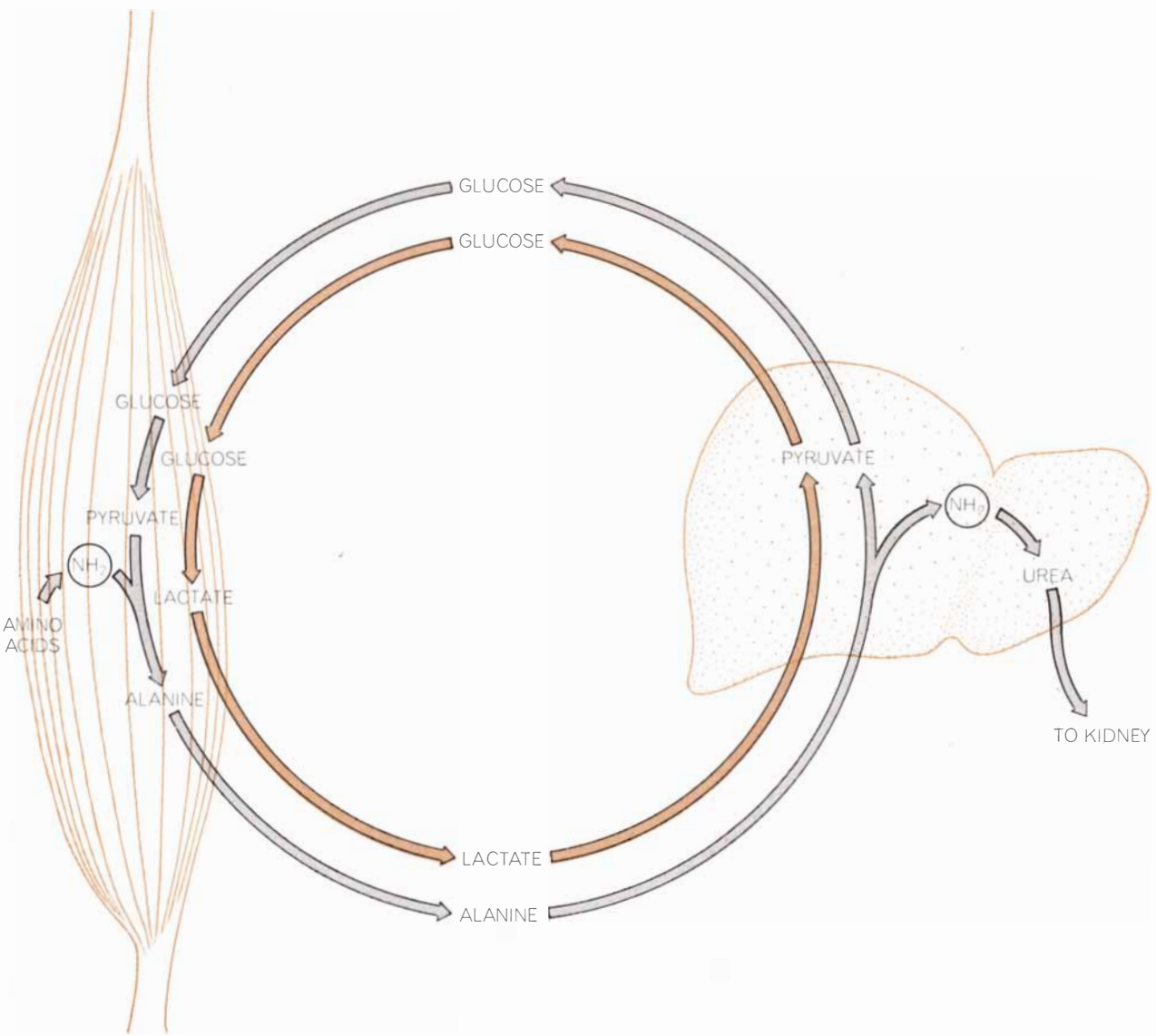
longed starvation is not shared by children, particularly very young children. In a child deprived of food growth stops almost immediately, because of the high requirement of energy necessary to build protein. The child develops the emaciated condition known as marasmus. In cases where a deficiency of protein is more pronounced than a deficiency of calories the child shows the symptoms of the disease called kwashiorkor. A child who has suffered undernourishment very early and for an appreciable length of time will never reach normal size for his age, even though he is later fed well enough to restore a normal rate of growth. This is part of the reason for the small body size of many people in impoverished countries.

Particularly critical is the first year or so of life, the "preweaning" period. Because the brain is still growing and developing during this time, underfeeding is likely to result in permanent physical stunting of the central nervous system. Myron Winick of the Cornell University Medical Center in New York City found in experimental studies of rats, and in analysis of the brains of children who had died of marasmus, that the underfed brain had a subnormal content of DNA. Starvation had interfered with cell division and left the animal or child with a permanent deficit in the number of cells in the brain. Winick's experiments with rats also showed that when the mother was underfed during pregnancy, malnutrition of the offspring after birth had an even more devastating effect on the brain.

In the burgeoning cities of the less developed countries many mothers in low-income families are now abandoning breast-feeding early, either in order to go to work or in imitation of the more affluent classes. As a result infantile marasmus is becoming common in a number of countries. A particularly well-documented report of this trend, and the cause, has been made by Fernando Mönckeberg of the University of Chile, who studied the situation in that country.

What useful conclusions can we draw from the studies conducted so far on the body's adaptations to starvation? First, let us consider the best way of coping with emergency situations in which the food supplies are very limited.

A little food, of course, is better than

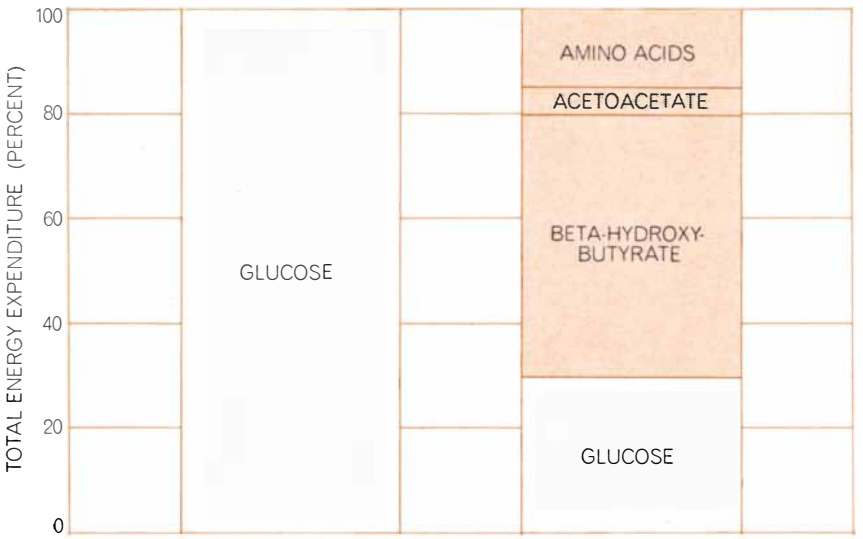


TWO METABOLIC-SUBSTRATE CYCLES operate between muscles (*left*) and the liver (*right*) through the blood. Lactate cycle worked out by Carl F. Cori (*color*) results in a net gain for muscle of two molecules of adenosine triphosphate (ATP). Alanine cycle proposed by Cahill would also facilitate the removal of nitrogen from amino acids liberated by the breakdown of muscle protein.

no food at all. Yet there is a paradox here. The edema of famine is hardly ever seen in cases of total starvation but develops often in semistarvation. Moreover, a semistarved person's survival time may actually be shortened if he tries to subsist on a diet consisting mainly of carbohydrate and deficient in protein. In such circumstances a child may quickly fall victim to kwashiorkor. Why is it that, although a person can be stricken with this disease when he eats a little food, it never shows up in total starvation, when the person gets no protein intake at all?

The typical clinical signs of kwashiorkor are apathy, loss of appetite, edema and changes in the skin and hair. On close examination of the blood and other tissues it is found that there is a marked drop in the concentration and activity of key enzymes. In the light of the known facts about the body's adjustment to a lack or shortage of food we can deduce the reason for the enzyme deficiency. In a semistarved child or adult the brain probably continues to depend mainly on glucose for energy. With some glucose being supplied by way of food, the need to synthesize glucose from body proteins would be reduced. Consequently there is only a modest release of amino acids from skeletal muscle into the bloodstream. If the semistarved individual is receiving little or no protein in his food, the amount of free amino acid in the blood is not sufficient for the body's synthesis of essential enzymes and other tissue proteins. Therefore the body shows the devastating results of protein deficiency. This is precisely what was observed during the recent famine in Biafra. The population was subsisting almost solely on the starchy roots of the cassava plant. Edema and other symptoms of acute protein deficiency were most conspicuous in the children. A high frequency of kwashiorkor is now being found among the East Pakistan refugees in India because many of the young children are not receiving protein foods.

We are seeing in such phenomena an indication of the conditions that gave rise to the evolution of man's present metabolic resources. In the hunting and plant-gathering phase of his early history his hungry periods took the form of general undernourishment, and the body evolved adaptations to improve metabolic efficiency for that contingency. It is only recently that human populations have come to depend heavily on a single cultivated plant staple for food—a situation with which the human body is not prepared to cope.



ENERGY NEEDS OF THE BRAIN are met differently in normal circumstances (*bar at left*) and after five to six weeks of starvation (*bar at right*). Glucose normally suffices, but in starvation it can meet only 30 percent of the requirement and other substances fill in.

We do not yet have precise knowledge about the mechanisms that cause the brain to switch from glucose to ketone bodies as its main energy source to induce this switch artificially for preservation of the body's integrity. All that can be suggested is that in a food-shortage emergency it may be best to spread out the consumption of the limited supply of protein and/or carbohydrate over the day, taking nibbles at frequent intervals, so that the periods of fasting and consequent breakdown of body protein for glucose synthesis will be shortened.

More information of practical usefulness is available on dieting for weight reduction, since most of the studies of adaptation to starvation have been carried out in obese subjects. It is quite clear that there is no way of achieving a permanent weight reduction without reducing the intake of calories to less than the outgo. The greater the difference between the intake and the expenditure of caloric energy, the faster one will lose weight. What about the various special diets that have become popular?

A high-protein or high-carbohydrate diet in theory should tend to minimize the body's loss of protein. It has also been argued that part of the protein and carbohydrate intake is spent in generating body heat after a meal and therefore does not go into the building of body fat. In practice, however, these considerations are probably too small in effect to be significant in preserving health or reducing weight.

On the whole it must be said that bizarre reducing diets have no scientific basis; any apparent success they may have appears to be due solely to their poor palatability or, as in the case of low-carbohydrate, high-protein diets, a rapid initial weight loss due to loss of body water. The best diet for reducing is still one that is balanced in food ingredients and sufficiently low in total calories to produce weight loss at the desired rate.

From a purely biochemical standpoint the most efficient way to lose weight, as the starvation tests have shown, is complete fasting into the stage where body fat is being consumed as the main source of energy for the brain and other tissues. Total fasting for an extensive length of time can be dangerous, however. It should not be prescribed for high-risk patients, and in all cases one must take care to avoid too much exercise in the initial phases and refrain from continuing the fast too long. Duncan of the University of Pennsylvania School of Medicine, who has perhaps had the most experience with this method of dealing with obesity, has treated fasting patients in a total of more than 1,300 hospital admissions without a fatality. Each fast has been limited to 10 days or two weeks, with patients returning for repeated fasts at varying intervals. Duncan cautions that any total fast for more than two weeks should still be considered in the category of a research enterprise. It must be emphasized that no one should undertake total fasting for weight reduction without prior medical screening, hospitalization and continuous medical supervision.

CABLE TELEVISION

In two decades the system has acquired more than five million subscribers. The technology is available for the cable network to provide many communication services in addition to television

by William T. Knox

At the beginning of 1952, when reliable statistics on the three-year-old cable television industry in the U.S. were assembled for the first time, 70 operating systems were serving a total of 14,000 subscribers. At the beginning of 1971 there were 2,500 systems serving 5.5 million subscribers. Besides growing rapidly, cable television has evolved technologically. At first it was a simple arrangement for bringing a good television signal into a home that received a poor one or none; the system was often called "community antenna television," which both described the service and supplied the acronym CATV by which the system is still widely known. Now cable television is a versatile broad-band communications system that can provide a subscriber with many more channels than there are programs to fill them. The technology has reached a point where, if the demand arose, a cable system could bring into the home not only conventional television signals but also facsimile service, access to data-processing equipment and almost any other kind of service having as its key feature the use of telecommunications. If, as has been proposed, cable television is linked to communications satellites, separate cable systems could be cheaply and flexibly interconnected in regional, national and international networks.

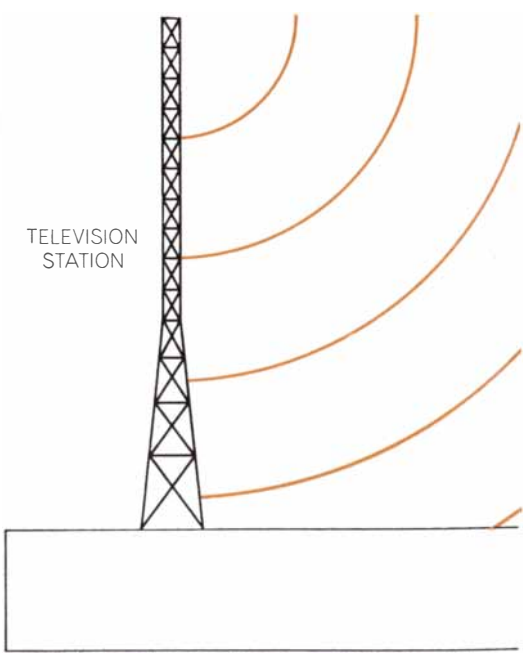
During its rapid growth cable television has been involved in controversy over the competition that it gives television stations and telephone companies and over the extent to which various levels of government should undertake to regulate the industry. Since it is probable that within a decade at least 60 percent of the homes in the U.S. will be wired with cable systems providing 20 or more channels, still more issues are bound to arise. Among them are the questions of what form the cable communications system should take and what kinds of information it should carry.

The first two cable television systems in the U.S. were built in the late 1940's in Lansford, Pa., and Astoria, Ore. They had the simple purpose of providing better television reception in small towns and rural areas that were prevented by distance or obstructions from receiving broadcast television signals of good quality or that could receive at most the signals of only one or two television stations. The technology of the early cable systems entailed erecting an antenna or a set of antennas on a high point where the reception of television signals was good and then relaying the signals over coaxial cable to television sets in individual homes and other locations in the community. Signal amplifiers placed at intervals along the cable kept the signal strong. This is still the basic method of operation of cable television systems.

Where possible a cable system catches the signals of a television station by means of a directional antenna tuned to the correct broadcast frequency and aimed directly at the broadcasting station. A separate antenna is used for each station received. A common type of antenna is the yagi, which resembles the kind usually seen on homes. It is a sharply tuned antenna that is particularly useful for receiving a single channel. Another design is the log-periodic antenna, which receives signals over a broader frequency range than the yagi. The corner-reflector antenna, which employs a mesh or tubing reflector to concentrate the signal on the dipole elements of the antenna, is also widely used [*see illustration on page 27*].

Today a number of cable systems have sources of signals other than the transmissions of television stations that are picked up directly. One source is programs that the cable systems originate themselves. Another is microwave radio signals that some cable systems use to relay television programs picked up so far away from the cable system's processing center that it is cheaper to use microwave than cable.

Whatever the source, the signals go into the "head end," which is the master control station and nerve center of a cable system [*see top illustration on page 28*]. There various kinds of electronic equipment amplify, filter and sometimes change the frequency of the



TYPICAL ARRANGEMENT of a cable television system centers on a receiving an-

signal. If the signals are exceptionally weak, they are usually boosted by a preamplifier so that the head-end equipment can process them satisfactorily.

In nearly all U.S. systems the output of the head end is carried to local delivery areas by a fairly large coaxial cable, typically three-quarters of an inch in diameter. Amplifiers are installed about every 3,000 feet. In underground installations a special cable is required with such features as a stainless-steel sheath to protect the cable against damage from moisture and biological attack.

Most cable systems hang their cables on existing utility poles or put them inside existing utility conduits. This procedure avoids the expense of obtaining a separate right-of-way or installing a conduit solely for cable transmission. Cable companies at first paid fees of about $1 per year per pole; now in some cases the fee is as high as $5.

Once the main trunk cable reaches a local delivery area a branching network of distribution cables is set up. The cables are usually .412 inch in diameter and extend up to about 1,500 feet in length. Final connection to the user's television set is usually made with flexible coaxial cable about a quarter of an inch in diameter.

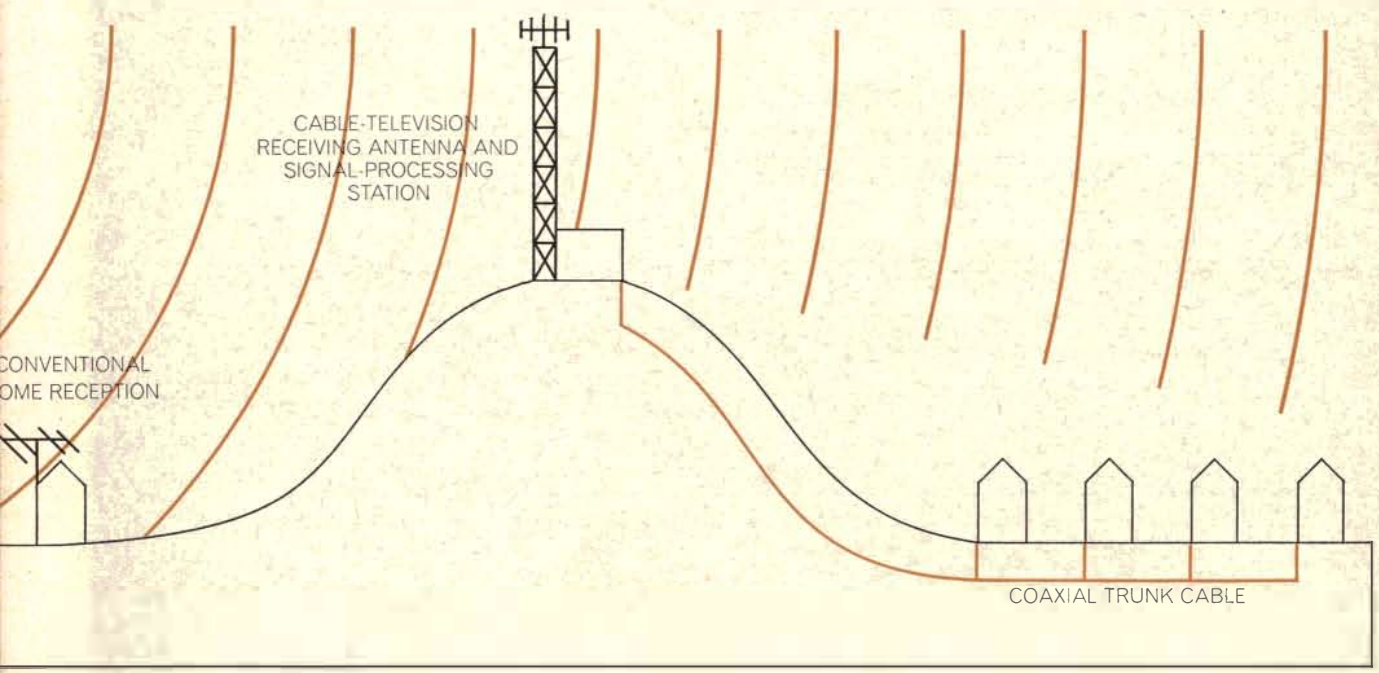
An entirely different kind of cable television system has been developed in Britain under the name of Rediffusion. A similar American system called Discade is being developed. Both systems avoid the cost of running wide-bandwidth cables over long distances by having a number of local distribution centers from which homes are served by simpler cables. This arrangement is possible because only one television program at a time goes into a home, in contrast to the conventional arrangement where all the programs carried by a cable system are brought to the home by wide-bandwidth coaxial cable and the subscriber chooses from them at will by operating the tuning dial on his television set. In Rediffusion the subscriber can likewise change programs by turning a knob on his set, but in doing so he is not choosing from several programs that are already at the house; instead he is notifying the local distribution center that he wants a different program sent to his house.

The local distribution centers are interconnected by a trunk network, which distributes the signals to them either by conventional coaxial cable or by means of microwave transmission. Each center provides up to 36 programs to 336 subscribers. An area with a larger number of subscribers will have more than one distribution center. In practice the average distance between the center and a subscriber is less than 1,000 feet. Rediffusion transmits in the five-megahertz to 10-megahertz band, that is, at frequencies of from five million to 10 million cycles per second.

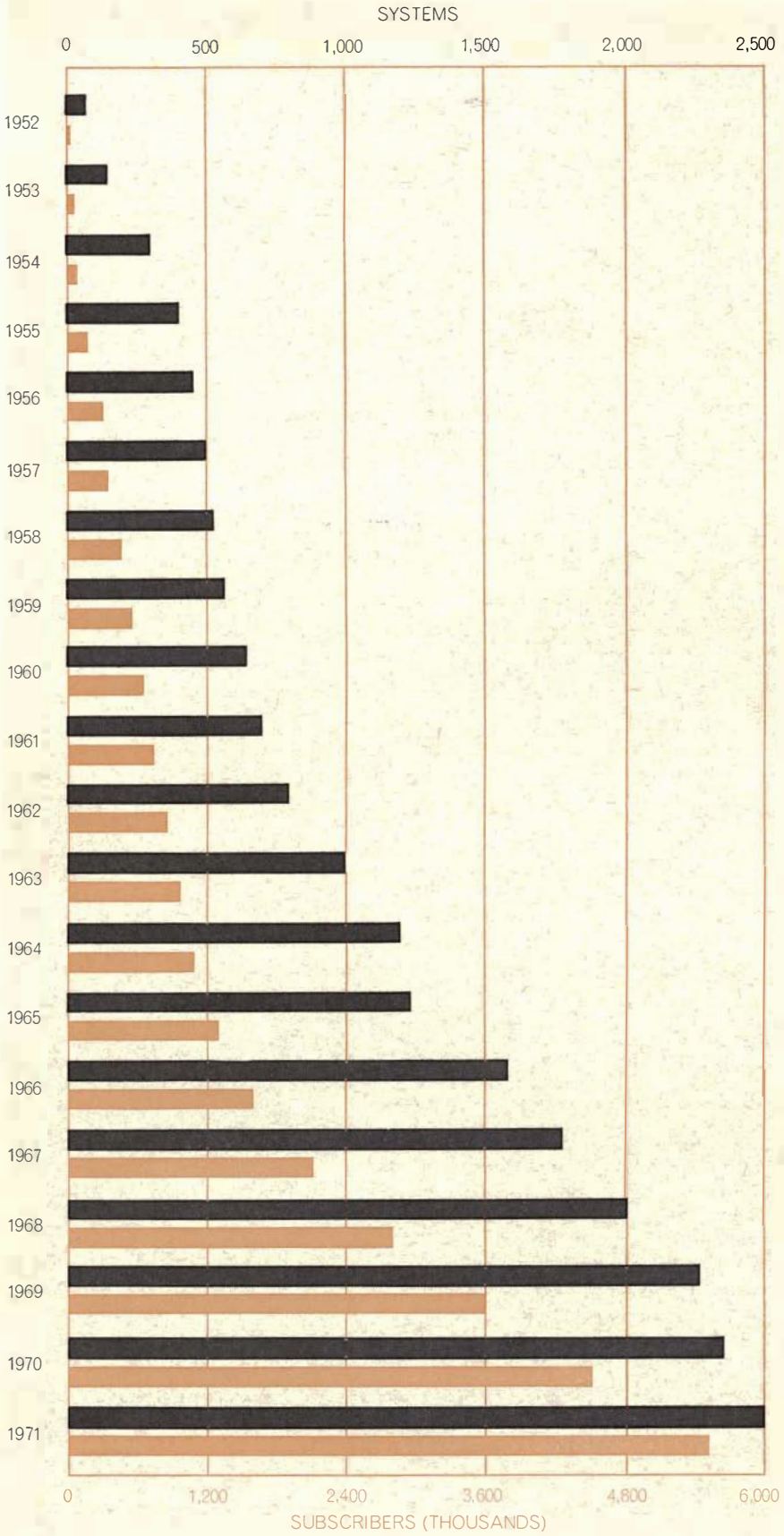
Discade is similar except that it employs narrow-bandwidth coaxial cables instead of the telephone type of wire used by Rediffusion. Discade's programs are sent in the seven-megahertz to 13-megahertz band. Both systems obviate the need for the costly wide-bandwidth amplifiers needed in conventional systems.

Since the British system transmits a much less complex signal than the conventional system, the receiving set in the home does not need the conventional tuner and intermediate-frequency amplifier. Rediffusion is therefore particularly advantageous from a cost point of view in areas that do not already have large numbers of standard television sets. The system claims that savings of about 30 percent in the cost of television receivers can be achieved. On the other hand, installation costs are $100 or more per subscriber compared with $25 for the typical U.S. system.

The comparative merits of the U.S. and British systems involve considerations of the kind that have long concerned communications engineers. The basic question is whether over long distances it is better to put more of the total cost on distribution lines and less on terminals or vice versa. In the U.S. system the trend is toward single lines of increasing bandwidth (that is, toward



tenna that is at a place, such as a hilltop, where the signals broadcast by a television station come in clearly. A separate antenna is used for each station that the cable system picks up. Signals thus received are sent to subscribers' homes by coaxial cable.



GROWTH OF CABLE TELEVISION is portrayed in terms of the number of operating systems (*gray*) and the number of subscribers (*color*) since 1952, which was the first year that reliable statistics were assembled. Cable television industry was then three years old.

wide-bandwidth coaxial cables) and more expensive and complicated terminals to sort out the signals. Terminals account for a bigger share of the cost than lines. In Rediffusion, which brings a single signal to a simpler television set, lines account for a bigger share of the cost than terminals.

Cable television originated at a time when there were few television stations in the U.S., most of them in big cities, and no new stations were being built because the Federal Communications Commission had imposed a "freeze" on new construction until it could develop a national plan for allocating television channels. In the circumstances the areas that got the poorest television reception were mostly outside the cities, and so it was in such areas that cable television got its start. It is still predominantly a nonurban phenomenon: 35 percent of the television homes in small towns and 23 percent of the television homes in rural areas receive their television signals by cable, whereas only 1.6 percent of the homes in major metropolitan areas have cable television. An example is the small community of Elmira, N.Y., where 21,000 households (out of 25,000 having television) pay $4.50 a month to subscribe to cable television.

Other factors are probably at work in the small-town orientation of cable television. The major broadcasters have been more concerned with the advertising markets in the 100 largest cities than in the rural and small-town markets. Moreover, people in large cities tend to be satisfied with the quality of the broadcast television signals they receive, since the stations are nearby. It also costs more to lay cables in large cities than it does in small ones.

In addition to the 2,500 cable television systems that were operating at the beginning of this year (in 4,000 communities) some 3,200 franchises for cable systems have been granted by municipalities. It is unlikely that all of them will develop into operating systems. The trend is toward consolidation of systems and growth in the number of subscribers within a system. Although the growth in the number of cable television systems is about 8 percent per year, the number of subscribers rises by about 20 percent per year.

During the early 1960's the average number of subscribers per system was about 1,000. Now it is about 2,000. As systems combine the average will rise quickly, perhaps reaching 4,000 sub-

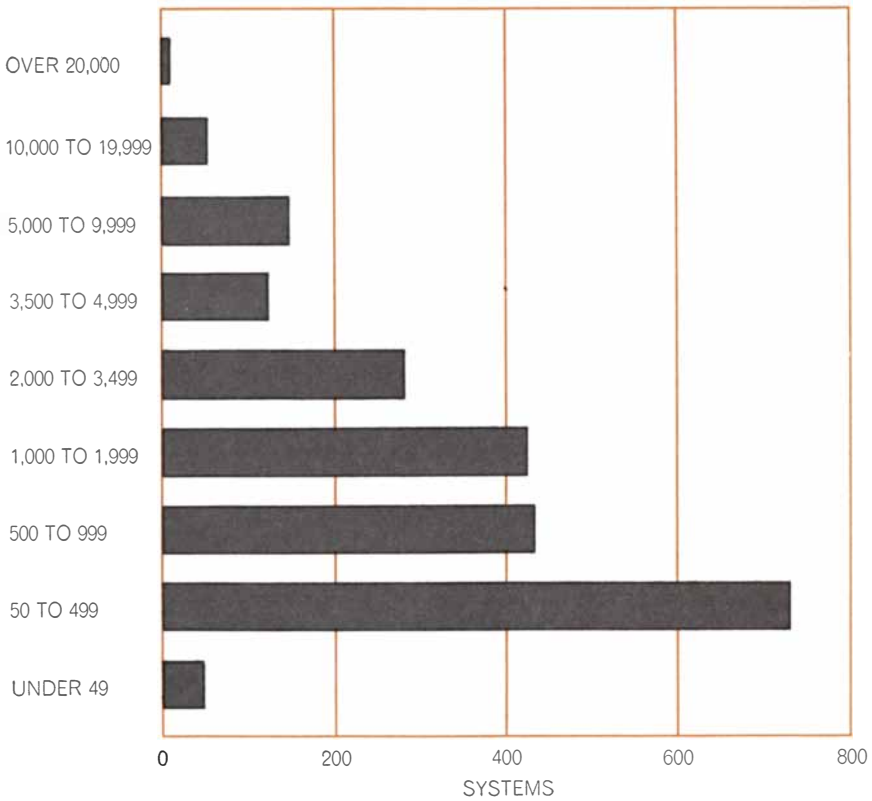
scribers per system by 1975. (The largest system, which is in San Diego, has about 40,000 subscribers, giving it an audience comparable to the one served by a small television broadcasting station. About a third of the systems have between 50 and 500 subscribers, and some 50 systems have fewer than 50 subscribers each.)

As sales of color television sets increase, pressures for the spread of cable television rise. The reason is that color television signals require more bandwidth than black-and-white signals and are more easily impaired by the echoes, barriers and reflections typical of urban areas. Some 60 million households in the U.S. have at least one television receiver, and 20 million of them have color television.

Most of the programs offered by cable television systems are of course pickups of what is sent out by television broadcasting stations. The systems also frequently originate time, weather and news broadcasts. These offerings are easy to produce: a television camera is focused on a clock, a thermometer, a barometer or a teletype news ticker.

To make sure that cable television does not come under the dominance of the broadcasting networks the FCC has encouraged cable systems to originate and control programs locally. Indeed, since last April 1 the commission has required cable television systems with more than 3,500 subscribers to originate programs on at least one channel. Programs that offer merely time or weather do not qualify. Many of the 350 or so systems affected by this order were already originating at least one program, and a few systems too small to be included in the order also originate programs.

If cable television systems are required to originate a substantial part of their program offerings, the present average monthly charge of $5.50 per subscriber may rise. The FCC order on original programming, however, was coupled with permission for the cable-system operator to insert advertising at "natural breaks or intermissions." If the revenue from advertising were high enough, a rise in the monthly charge to subscribers would presumably be unnecessary.



SIZE OF CABLE SYSTEMS in the U.S. is indicated according to the number of subscribers. The largest group of systems has from 50 to 499 subscribers per system. The largest single system has about 40,000 subscribers. Average charge to subscribers is $5.50 per month.

Much has been said about the possibility of having cable television systems offering from 40 to 100 channels. It is true that the technology for carrying up to 80 black-and-white channels has been developed, but an increasing amount of television reception is in color. Here the limitation resides in the television receiver. Standard home television sets in the U.S. cannot receive more than 12 color channels without added electronic equipment.

All cable television systems built during the past three years have had at least 12 channels. Of the 105 systems begun in 1969, 22 will have a capacity of more than 12 channels. A few systems are installing 20-channel equipment, which represents the frontier of present field experience.

In two places, however, operators are planning to install systems of larger capacity, looking toward a time when it will be feasible to offer a number of cable services in addition to television programs. A system of 30 or more channels is planned in San Jose, and a 40-channel system is being sought in Akron. If a system wants to provide more than 40 channels, it probably will be best technologically for some years to come to simply add another 30-to-40-channel coaxial cable.

Broadcast television cannot obtain such large channel capacities. Each color television channel needs a frequency allocation of six megahertz. Slightly more than 4.5 megahertz of the allocation is actually required to transmit the signal; the remaining channel width affords protection against overlapping and interference. A single color television channel requires the equivalent of 240 frequency-modulation radio channels or 600 amplitude-modulation radio channels.

Allocation of relatively few channels to broadcast television therefore uses up a large part of the radio-frequency spectrum. Cable television does not use any part of the broadcast spectrum. Even though each channel still requires six megahertz, the channel is inside a cable and so does not enter the competition for airwave space. With steadily increasing demand for mobile-broadcast frequencies and for educational broadcasting and other forms of public-service broadcasting, the role of cable television versus broadcast television has become a major issue of public policy.

An attempt to deal with this issue was made in 1968 by the President's Task Force on Communications Policy. The task force put forward the concept of the "wired city," where all television signals would be placed in cable systems, thus freeing for other uses the space in the spectrum now taken up by broadcast television. That would not be all.

System	Subscribers
1. San Diego, Calif.	39,135
2. Allentown, Pa.	32,580
3. Altoona, Pa.	22,300
4. Santa Barbara, Calif.	22,000
5. Elmira, N.Y.	20,000
6. New York, N.Y.	20,000
7. Harrisburg, Pa.	20,000
8. Williamsport, Pa.	20,000
9. New York, N.Y.	19,541
10. Lima, Ohio	19,000
11. Cumberland, Md.	18,609
12. Mahanoy City, Pa.	18,550
13. Los Angeles, Calif.	17,658
14. Melbourne, Fla.	17,498
15. Atlantic City, N.J.	16,500
16. Johnstown, Pa.	16,500
17. Binghamton, N.Y.	16,211
18. Concord, Calif.	16,031
19. Santa Cruz, Calif.	16,000

System	Subscribers
20. Everett, Wash.	15,684
21. Easton, Pa.	15,500
22. Bakersfield, Calif.	15,000
23. San Francisco, Calif.	15,000
24. Eugene, Ore.	15,000
25. Parkersburg, W.Va.	15,000
26. Toledo, Ohio	14,500
27. Florence, Ala.	14,000
28. Ambridge, Pa.	13,865
29. Tyler, Tex.	12,950
30. Austin, Tex.	12,900
31. Bakersfield, Calif.	12,800
32. Dubuque, Iowa	12,544
33. Huntsville, Ala.	12,300
34. Gainesville, Fla.	12,000
35. Ithaca, N.Y.	12,000
36. Northampton, Pa.	12,000
37. Kingsport, Tenn.	12,000
38. Charleston, W.Va.	12,000

System	Subscribers
39. Rochester, Minn.	11,875
40. Macon, Ga.	11,699
41. Lafayette, Calif.	11,500
42. Pottsville, Pa.	11,301
43. Lafayette, Ind.	11,107
44. New York, N.Y.	11,000
45. Clarksburg, W.Va.	10,950
46. Palm Desert, Calif.	10,890
47. Pittsburg, Calif.	10,700
48. Fort Walton Beach, Fla.	10,502
49. Aberdeen, Wash.	10,500
50. Palm Springs, Calif.	10,300
51. Seattle, Wash.	10,300
52. York, Pa.	10,300
53. Hazleton, Pa.	10,250
54. Santa Maria, Calif.	10,000
55. Key West, Fla.	10,000
56. Kalamazoo, Mich.	10,000
57. Utica, N.Y.	10,000

LOCATION OF LARGEST CABLE SYSTEMS is shown by a key wherein a number on the map refers to the corresponding number in the list below the map. Following each number in the list are the name of the city and the number of cable subscribers there as of a year ago. A few cities have more than one system. One reason for cable television's orientation toward smaller cities is that such areas were remote from the first television stations and needed cable systems in order to receive satisfactory television signals.

The task force proposed a two-way system, so that in addition to carrying television signals the cable network would carry telephone and data traffic. Indeed, the cable system would provide all of a city's telecommunication facilities.

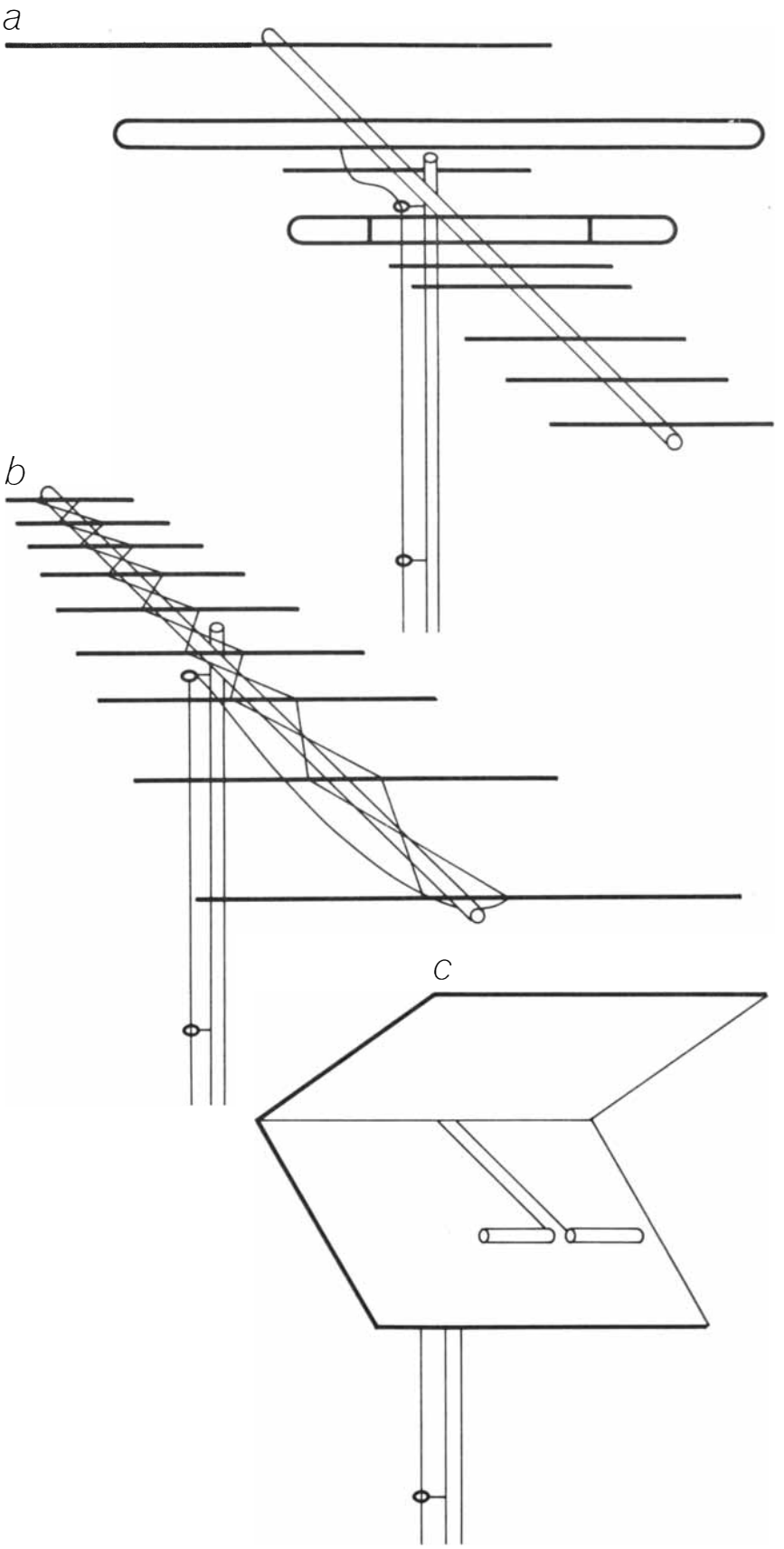
As would be expected, the proposal raised a storm of protest from television broadcasters and the telephone companies. Technical and economic arguments were also raised against the large capital expense required for a broadband, coaxial, switched cable system. (Switched systems, which are characteristic of telephone operations, make it possible for a user of a system to communicate with any other user.) The most significant force behind the wired-city concept has been the Electronic Industries Association, which is of course not uninterested in new markets for communications equipment. Rediffusion, Ltd., has also pointed out that the British development of inexpensive, telephone-like wires capable of operating at frequencies as high as 13 to 15 megahertz, together with the necessary switching equipment, makes the wired city much more feasible economically than would be the case with coaxial cables.

The wired-city concept broadens the familiar telephone network into a system that carries both audio and video signals. Part of the promise of the wired city is the choice made possible by two-way communication for individually selecting a television program. The recent development of relatively inexpensive television cameras, costing about $1,500 each, raises another possibility: the use of the cable network for sending television signals generated by individuals or groups in homes, schools, offices and plants.

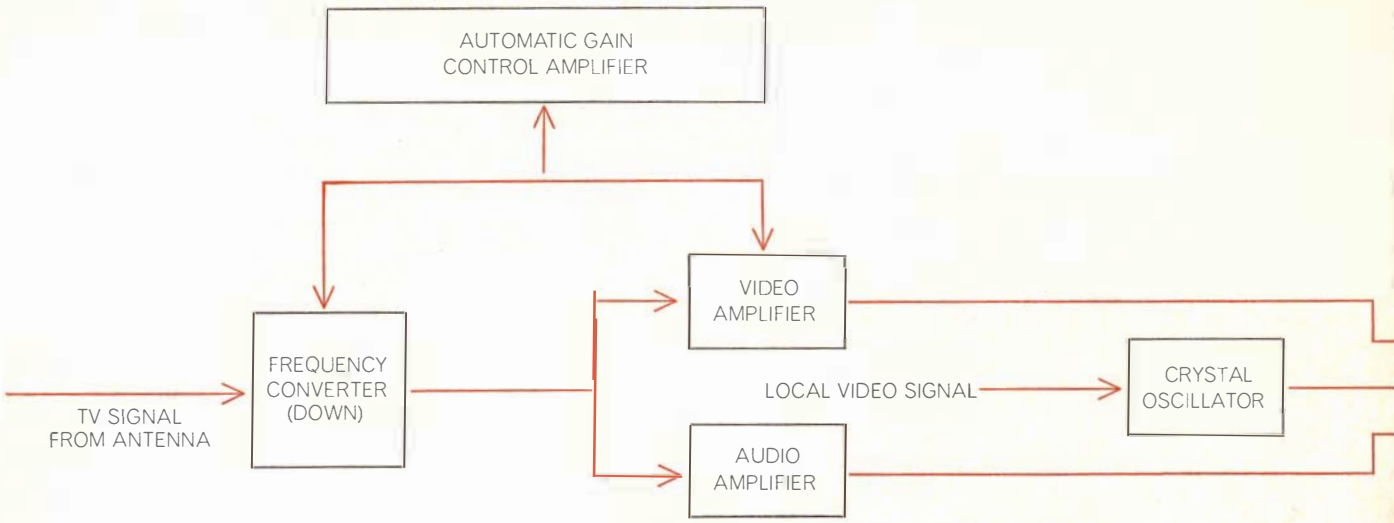
If cable television evolves in this direction, it can provide many services in addition to the television programs that are its standard fare now. The possibilities are best considered under two headings: discrete-address services, where messages go from one point to another single point, and multiple-address services, where messages go from one point to a number of other points simultaneously. Under the first heading a nonswitched cable network could carry first-class mail to the home from the post office, texts originating in the library, business or personal transactions, merchandise displays and information, press services and computer data, and could provide a watching service that would sound an alarm in case of trouble at the subscriber's premises. A switched network could provide video-telephone service (a replacement for the mail system) and an exchange of computer data between individual users. A nonswitched multiple-address network could carry third-class mail, instructional material, press releases and data of limited public interest, and a switched multiple-address network could provide video-telephone conference calls.

Cable television also offers interesting and possibly far-reaching prospects in the political field. With cable a political candidate could direct a television appeal to his constituency alone, thereby greatly reducing the cost of television campaigning. Indeed, campaigning by television might turn out to be cheaper than any other form of campaigning. It is even possible to envision rapid polling of opinion in an area by means of two-way cable communication.

Peter C. Goldmark, who retired last year as president of the Columbia Broadcasting System Laboratories, foresees still further developments arising from a marriage of domestic satellites and cable television. He believes such a union would outmode the present broadcast networks. With a community wired from one or more terminal points to in-



TYPES OF ANTENNA used by cable television systems to receive signals broadcast by television stations include the yagi (*a*), which can be tuned sharply and is most suitable for receiving a single channel, the log-periodic (*b*), which can receive signals over a broader frequency range than the yagi, and the corner-reflector antenna (*c*), where the reflector of mesh or tubing is used to concentrate the signal on the dipole elements of the antenna.



PROCESSING CENTER of a cable television system is called the "head end." It has components, here depicted schematically, that amplify and filter the signal received from the broadcasting television station and sometimes change the signal's frequency. Not

dividual homes the local pickup would not be limited to the channels of the commercial television networks; instead participants could receive through the satellite a number of services to meet individual tastes. The system could also provide a good deal more than entertainment. For example, it could put both national and local channels at the disposal of government agencies—Federal, state and municipal—concerned with education, health and crime control.

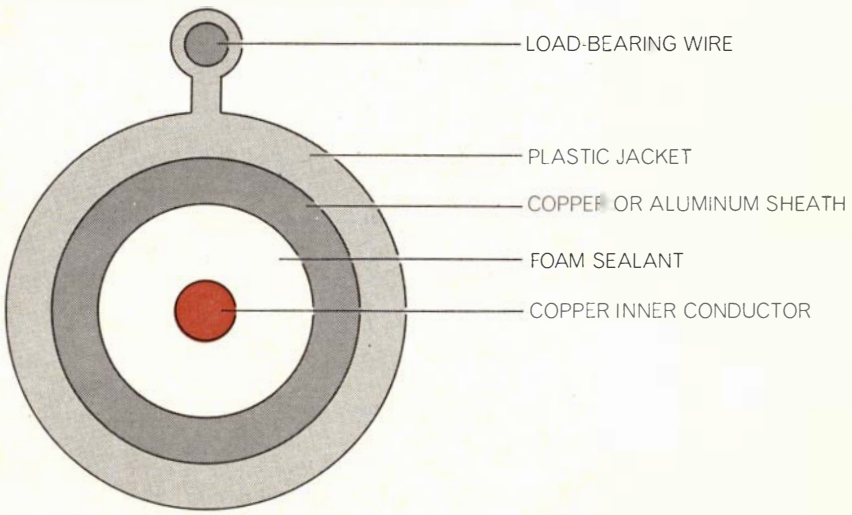
Even in reaching its present stage of development, cable television has raised a number of issues that remain to be finally resolved. Among them are the questions of regulation, ownership and copyright. If cable television evolves along the lines I have indicated, a number of other issues will be raised.

In its early days cable television was subjected to little government regulation. Municipalities required franchises for cable television systems, but the main reason for the franchise was to raise revenue. Some franchises are still granted with revenue mainly in mind. Occasionally a community will take into account the financial stability of the applicant. Seldom, however, do the programming or communication possibilities of a cable system enter into the franchising considerations.

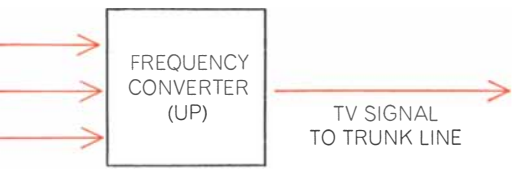
The first independent analysis of cable television franchising was recently completed in New Jersey by the Center for the Analysis of Public Issues, a privately financed consumer-research organization. In its report the center said that municipalities have failed to protect the public interest in issuing franchises for cable television. The center recommended that the cable television industry be regulated by the state.

The FCC at first took the position that it had no authority to regulate cable television. Under pressure from television stations and networks, which felt the competition of cable systems, and with final approval from the U.S. Supreme Court, the commission has gradually exerted a considerable amount of control over cable television. In August of this year the commission issued a statement of policy for the development of cable television in big-city markets. The statement was based on study and negotiations with interested parties that the commission conducted over a period of several months. Under the policy a cable operator in a major city would be allowed to import the signals of at least two out-of-town channels. He would also be required to keep at least one of his 20 or more cable channels open as a free public forum for anyone who wanted to speak on it. Moreover, for each channel carrying television broadcasts he would have to provide another channel for lease, facsimile printing or original programming. He would also have to provide two-way facilities so that subscribers could send as well as receive messages. The FCC has not yet imposed these policies. It said it would not do so until Congress had reviewed the recommendations.

The copyright issue, arising from the fact that cable television systems could



COAXIAL CABLE used in cable television systems typically has four layers. The main cables are about three-quarters of an inch in diameter; the cables into the home, less than half an inch. In most systems the cable is suspended in utility conduits or on utility poles.



shown is a preamplifier sometimes added to boost unusually weak incoming signals.

ignore copyright on the material they picked up from broadcast television stations, has been an irritant in relations between the broadcast television industry and the cable television industry. Broadcast television systems must obtain permission from copyright owners and pay fees for the right to transmit copyrighted materials. In 1968 the U.S. Supreme Court issued a qualified ruling that cable television operators should be allowed to retransmit such material freely to their subscribers. The grounds for the decision were technical: the court held that the cable television operator merely provided for his subscribers a better antenna than individual subscribers could afford. Legislation pending in Congress would establish a copyright-licensing scheme covering cable television. The stakes are high in this proceeding, and the broadcasting industry, the cable industry, the copyright owners and the FCC are all seeking to influence the final form of the legislation.

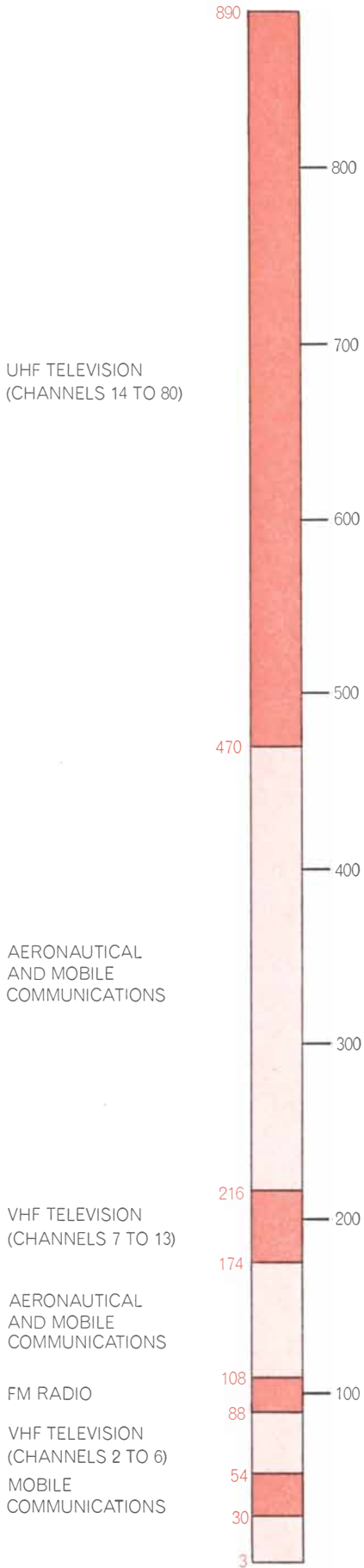
Ownership of cable television systems is one means that broadcast television interests and telephone companies have undertaken to a certain extent to meet the competition of cable television. Of the 2,490 cable systems operating on March 9, 1970, radio and television broadcasters owned 36.5 percent and telephone companies owned 5.8 percent. Newspapers and other publishing organizations owned 8.2 percent. The FCC has adopted a policy prohibiting television stations from owning cable television in their own communities. In 1969 the U.S. Department of Justice endorsed this policy and suggested that the rule apply to newspaper owners as well. In 1970 the FCC ruled that telephone companies could not furnish cable television facilities directly or through an affiliated cable television system within the company's operating territory. The major telephone companies are appealing the ruling.

Notable among the issues that can be expected to come up as cable television develops is the question of who will pay. If cable television becomes a common carrier of telecommunications, as the telephone companies are, it will be the first carrier with a proprietary right to the information that it carries. Should questions of its financing be decided by the users, the operators, the groups concerned with the information content or the suppliers of hardware?

Another question concerns the future of the ultrahigh-frequency (UHF) television stations, which occupy channels 14 through 80 in the broadcast spectrum. Considering the need for more mobile-broadcast facilities, which use the same region of the spectrum, the encouragement of cable television might be a better policy than further support of the UHF stations. It may be that the spread of cable television will mean the end of the UHF stations.

Several other issues can be envisioned. What is the best combination of government regulation and free competition in the development of cable television and the wired city? How should control over the system be distributed at the several levels of government? If a single entity owns a cable television system in a city, should other entities have access on a nondiscriminatory basis? Is it necessary or desirable to have one cable system in a community, or should there be multiple facilities? How is the transition between the present state and the future system to be managed?

Noticeably lacking in the issues presented by the various government and private interests so far is much concern about the social, psychological and cultural consequences of a nationwide broad-band communications network capable of handling all of an individual's communication needs. Yet this may be the area where the most unforeseen events will materialize.



RADIO-FREQUENCY SPECTRUM extends from three million megahertz, or three million cycles per second, to 890 megahertz and is used for a number of purposes. The upper and lower operating limits of cable television transmission are respectively 300 megahertz and three megahertz.

The Object in the World of the Infant

At what stage of development does an infant begin to associate qualities such as solidity with objects that he sees? Experiments with infants reveal that this occurs much earlier than expected

by T. G. R. Bower

According to most traditional theories of how we come to perceive the world around us, the quality of solidity belongs to the sense of touch in the same way that the quality of color belongs to the sense of vision or the quality of pitch to the sense of hearing. Only the sense of touch has the intrinsic ability to distinguish solids from nonsolids. The ability to identify solid objects visually is the result of learning to associate visual clues with tactile impressions, or so the traditional arguments have asserted. The classic version of the theory was presented by Bishop Berkeley. It was espoused in the 19th century by Hermann von Helmholtz and more recently by J. McV. Hunt, Burton White and Richard L. Gregory.

If the ability to associate touch and sight is learned, then at what stage of human development does the learning occur? Since young children clearly exhibit a unity of the senses, such learning must take place at some early stage of infancy. The infant who has not yet made the association must therefore live in a world of clouds, smoke puffs and insubstantial images of objects rather than in a world of solid, stable objects.

A similar situation holds when we observe an object move behind another object and disappear from sight. An adult knows that the object is still there, that it has not ceased to exist. This can be verified simply by removing the obstructing object or looking around it. It is hard to understand how an infant could know that the object is still there by using vision alone; how can vision provide information about the location of an invisible object? Touch must play a critical role in the development of the ability to deal with hidden objects. The hand can go around obstacles to reach such objects, and only as a result of such explorations can an infant come to know that the object is still there. So, again, goes the traditional argument, and very plausible it seems.

These aspects of objects—solidity and permanence—present deep problems to the student of human development. Not the least formidable of the problems is finding ways to measure a naïve infant's response to objects. The infant, with his limited repertory of responses, is a refractory subject for psychological investigation. Recent advances in techniques of studying space perception and pattern recognition in infants are inherently unsuitable. These methods mostly determine whether or not the infant discriminates between two presentations, for example a regular pattern and an irregular one. One could present a solid object and, say, a bounded air space with the same external contour to an infant. Undoubtedly an infant of any age could discriminate between the two objects. The mere fact of discrimination would not tell us that the infant knew the object was solid, tangible and would offer resistance to his touch. There are visual differences between solids and nonsolids, and the infant could pick up these differences without realizing that they signify solidity. Indeed, according to some theories there must be such a stage, where the infant does perceive differences but is not aware of their significance.

The methods I adopted to measure the infant's expectation of solidity involve the element of surprise and the use of an optical illusion. The illusion is produced with a binocular shadow-caster, a device consisting of two light projectors with polarizing filters and a rear-projection screen. The object, made of translucent plastic, is suspended between the lights and the screen so that it casts a double shadow on the rear of the screen. The small subject sits in front of the screen and views the shadows through polarizing goggles that have the effect of making only one shadow visible to each eye. The two retinal images are combined by the normal processes of binocular vision to yield a stereoscopic percept of the object. This virtual object appears in front of the screen and looks very real and solid. It is nonetheless an illusion and is therefore intangible. When the infant attempts to grasp it, his hand closes on empty air. To reach out for a seemingly solid object and come in contact with nothing is startling for anyone. The surprise clearly is a consequence of the nonfulfillment of the expectation that the seen object will be tangible.

Since even very young infants display the startle response, it can serve as an indicator of surprise. If the infant is startled by the absence of solidity in the virtual object, that can be taken as an index of an expectation that the seen object will be tangible. In contrast, a startle response on contact with the real object could be taken as an indication that the seen object is not expected to be tangible.

In the first experiment the infant sat before a screen and was presented with the virtual object or the real object. The two situations were presented several times, always beginning with the virtual object. We looked for evidence of startle behavior. The startle response can be measured in numerous ways, some of which are sophisticated and expensive, but in this experiment we used very simple indicators: facial expression and crying. These measures, so simple as to seem unscientific, are in fact as reliable as the more complex ones we used later.

Our subjects were infants between 16 and 24 weeks old. The results were quite unambiguous. None of the infants showed any sign of surprise when he touched the real object in front of him. Every infant showed marked surprise when his hand failed to make contact with the perceived virtual object. Whenever the infant's hand reached the place where the virtual object seemed to be, within a fraction of a second he emitted a coo, a whoop or a cry, accompanied by a change in facial expression so marked as to seem a caricature. The older infants reacted even more: they stared at their hand, rubbed their hands together or banged their hand on the chair before reaching again for the virtual object. All of this supports the idea that the infants expected to be able to touch a seen object and were very surprised when their attempts to do so produced no tactile feedback.

Although these results are interesting, they do not resolve the problem under investigation. They merely indicate that learning to coordinate vision and touch must take place, if it takes place at all, before the age of 16 weeks. We therefore attempted to study coordination between vision and touch in even younger infants, hoping to find a period of noncoordination. The communication problem is intensified in very young infants, since their behavioral repertory is even more limited than that of older infants.

Some investigators have reported that an infant less than six weeks old will not show defensive or avoidance behavior when an object approaches him. Other studies, however, have shown that an infant can discriminate changes in the position of objects in space well before the age of six weeks [see "The Visual World of Infants," by T. G. R. Bower; SCIENTIFIC AMERICAN, December, 1966]. The lack of defensive behavior may indicate the absence of the expectation that the seen object would produce tactile consequences, and it seemed to us that the infant's response to approaching objects would be a promising area to investigate.

Our preliminary investigations were highly encouraging. We took infants in their second week of life, placed them on their back and moved objects toward their face. We used objects of a wide variety of sizes and a wide variety of speeds. Some objects were moved noisily, some silently. All of this was to no avail. The infants, more than 40 of them, did not even blink. These two-week-old infants certainly did not seem to expect a seen object to have tactile consequences. It appeared that we had indeed found a period when vision and touch were not coordinated.

At this point in the research I became aware of the work of Heinz Prechtl, who

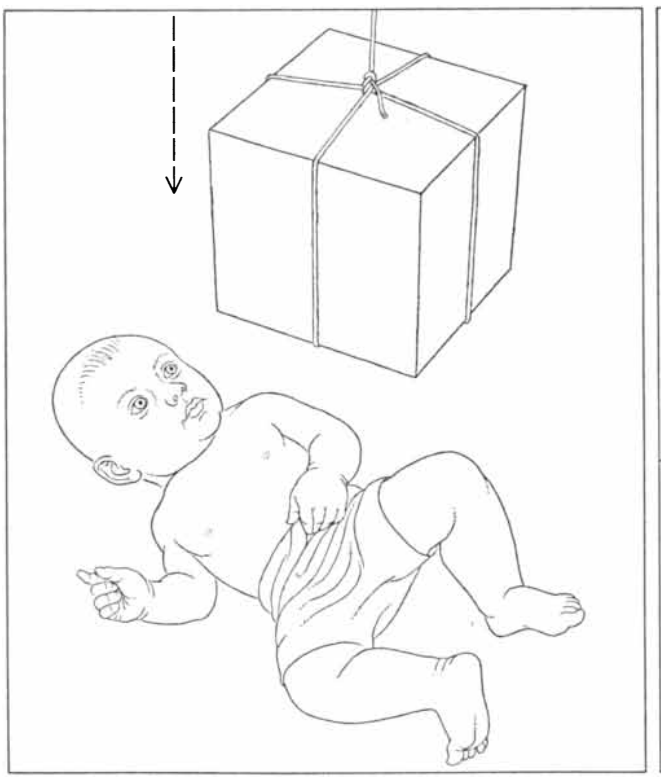
INTANGIBLE OBJECT is produced by a shadow-caster, in which two oppositely polarized beams of light cast a double shadow of an object on a rear-projection screen. An infant views the double shadows through polarizing goggles that make a different shadow visible to each eye. The innate processes of stereopsis fuse the two images to make the infant think he is seeing a solid object in front of the screen. When the infant tries to grasp the virtual image, he is startled when his hand closes on empty air; within a fraction of a second he cries and his face expresses marked surprise. When a real object is placed in front of the screen, none of the infants show any signs of surprise when they touch it. These results indicate that the infants expect a seen object to be solid and tangible.

had gathered evidence that implied infants under two weeks old are never fully awake while they are lying on their back. Since one could not expect defensive behavior from infants who were half-asleep, we repeated the experiment with infants of the same age who were held in an upright or semiupright position. With this modification the results were totally different. The infants clearly showed a defensive response to an approaching object. They pulled their head back and put their hands between their face and the object. These responses were accompanied by distress and crying so intense that the experiment had to be terminated earlier than had been planned. We were nonetheless able to try a few variations. We found that the defensive behavior was specific to an approaching object; if an object moved away, it produced neither defensive behavior nor crying. Moreover, the response was specific to a seen object. A moving solid object displaces air, which presumably causes pressure changes at the surface of the skin. In order to rule out the possibility that such pressure changes were the effective stimulus, we had a group of infants view an approaching virtual object produced by a shadow-caster. An object behind a translucent screen was moved away from the infant toward a projector. When the infant is placed at the same distance in front of the screen as the projectors are behind it, a shadow on the screen produces an image on the infant's retina that is identical with the image produced by a real object moving toward the baby, without the displacement of air and other nonvisual changes that accompany the movement of a real object.

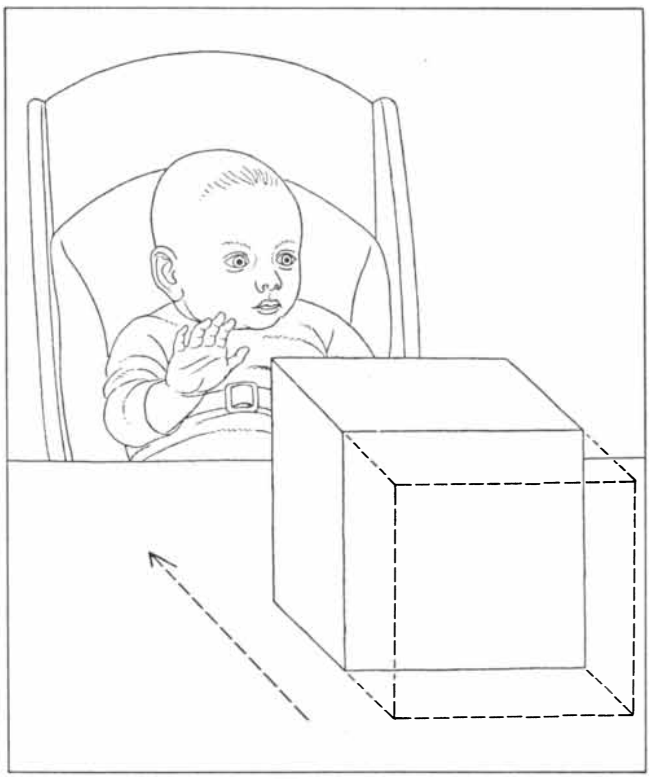
The results were that seven out of seven infants in their second week of life exhibited defensive behavior when they saw the approaching virtual object. In our study the intensity of the infant's response to the virtual object seems somewhat less than the response to the real object, but a replication of the experiment by E. Tronick and C. Ball of Harvard University showed that the two responses are not that different. As a further check on the role of air movement another group of infants was presented with air displacement alone (produced by an air hose) with no object in the field of vision. None of these infants exhibited any defensive behavior or marked distress.

Taken together, these results suggest that by the second week of life an infant expects a seen object to have tactile consequences. The precocity of this expectation is quite surprising from the traditional point of view. Indeed, it seems to me that these findings are fatal to traditional theories of human development. In our culture it is unlikely that an infant less than two weeks old has been hit in the face by an approaching object, so that none of the infants in the study could have been exposed to situations where they could have learned to fear an approaching object and expect it to have tactile qualities. We can only conclude that in man there is a primitive unity of the senses, with visual variables specifying tactile consequences, and that this primitive unity is built into the structure of the human nervous system.

In an effort to further test this hypothesis we repeated the original virtual-object experiment with a group of newborn infants. It was not easy to do this, since the infants had to meet the criterion that they would wear the polarizing goggles without fussing. Newborn infants do not reach for objects in the same way that older infants do. They will, however, reach out and grasp ob-



NO RESPONSE was observed when objects were moved toward the face of two-week-old infants who were lying on their back. At first this was taken to mean that infants at this age do not expect seen objects to have tactile qualities, but the author learned later that very young infants are never fully awake when on their back.



DEFENSIVE RESPONSE and marked distress to an approaching object was exhibited by upright two-week-old infants, even when the approaching object was an illusion produced by a shadow-caster. This evidence contradicts the theory that the perception of solidity is learned by associating tactile impressions and vision.

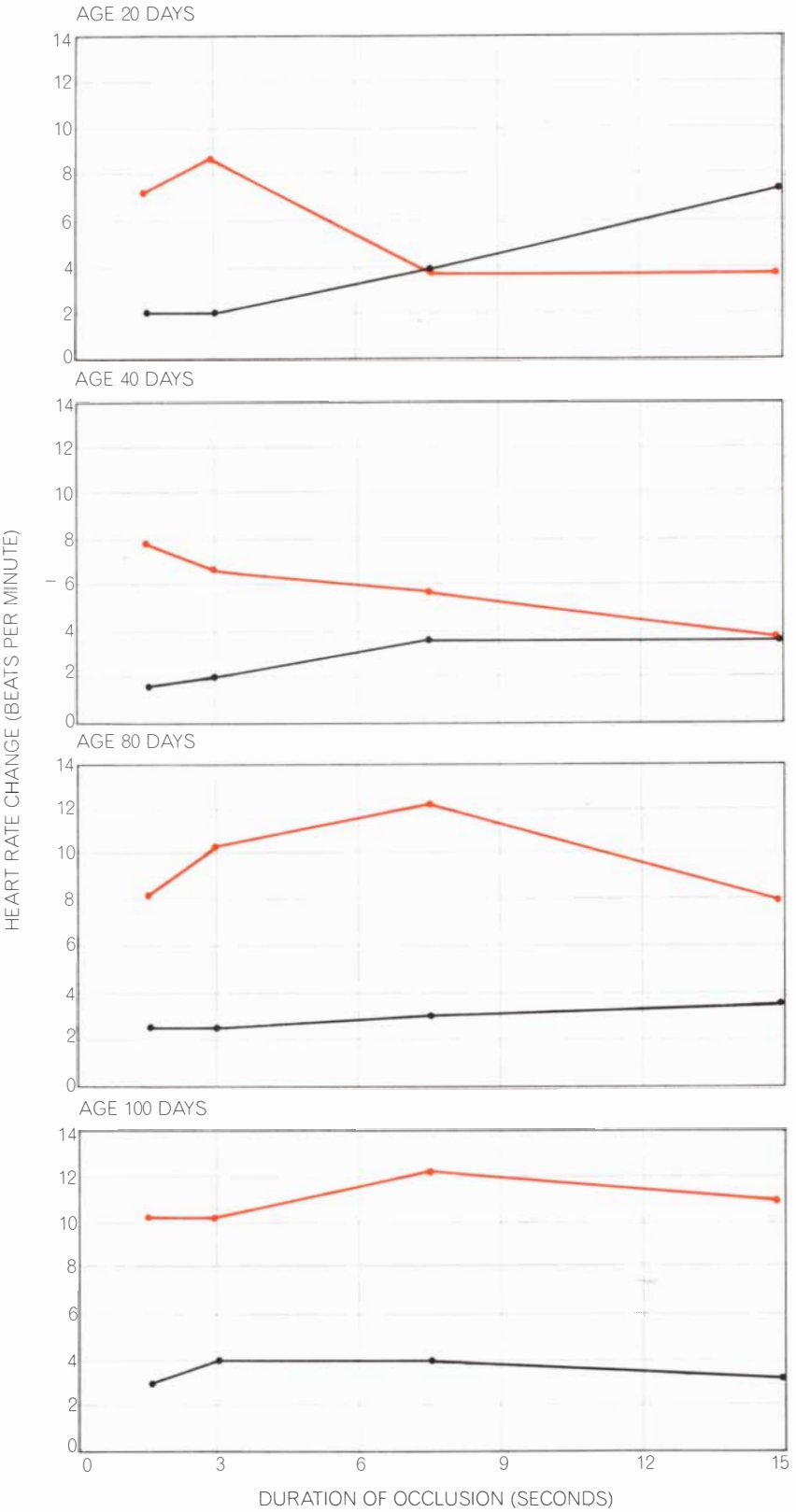
jects if they are supported so that their hands and arms are free to move to the objects in front of them. (They also reach out and grasp at empty air, but that does not affect the argument.)

We found that all the newborn infants touched and grasped real objects without any sign of being disturbed. The virtual object, however, produced a howl as soon as the infant's hand went to the intangible object's location. Here too, then, in dealing with the absence of tactile input in a situation where it normally would be expected, we have evidence of a primitive unity of the senses. This unity is unlikely to have been learned, given the early age and the history of the infants studied.

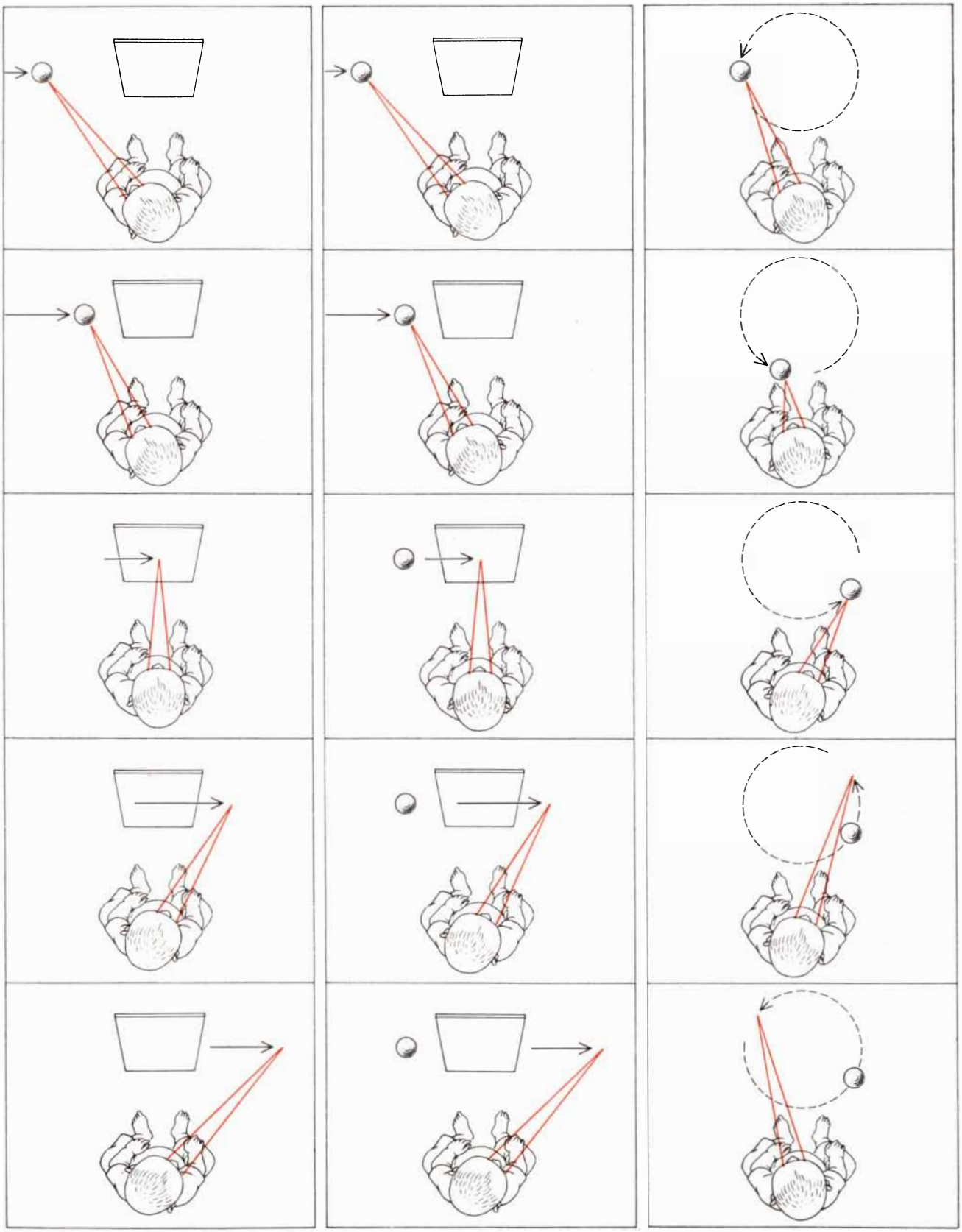
These results were surprising and interesting. They showed that at least one aspect of the eye-and-hand interaction is built into the nervous system. If it is built in, might not a more complex aspect of objects, namely permanence, also be built in? Is it possible that inborn structural properties ensure that an infant knows an object moving out of sight behind another object is still there? In order to find out we again used the startle response as an indicator of surprise. We sat an infant in front of an object. A screen moved in from one side and covered the object. After various intervals (1.5, 3, 7.5 or 15 seconds) the screen moved away. In half of the trials the object was still there when the screen moved away. In the other trials the object was no longer there when the screen moved away. If the infant knew that the object was still there behind the screen, its absence when the screen moved should have surprised him. If, on the other hand, the infant thought the object had ceased to exist when it was covered by the screen, its reappearance when the screen moved away should have been surprising.

In this experiment surprise was determined by a more quantitative index: a change in the heart rate. It is well known that the heart rate of an adult changes when he is surprised, and the same is true of infants. We measured the change in the heart rate of an infant by comparing his average heart rate over the 10 seconds after the moment of revelation with the average heart rate over the 10 seconds before the object was covered with the screen. Our subjects were infants who were 20, 40, 80 and 100 days old.

The results revealed an interesting pattern. When the object had been occluded for 1.5 seconds, all the infants manifested greater surprise at its nonreappearance than at its reappearance.



CHANGES IN HEART RATE reveal the degree of surprise in infants at the reappearance or disappearance of an object after it has been covered by a moving screen for various periods of time. Older infants are not surprised at the reappearance (*black curves*) of the object when the screen moves on, regardless of the duration of occlusion, and show little change in their heart rate. They are surprised when the object does not reappear (*colored curves*) from behind the moving screen. The youngest infants also are surprised by the object's failure to reappear when the occluding period is brief; when the time is increased to 15 seconds, they seem to forget about the object and show surprise at its reappearance.



INFANT'S ANTICIPATION of the reappearance of an object that moves behind a screen and stops (*left*) seems to prove that the infant knew the object was still behind the screen. When the object stops before it reaches the screen, however, the infant continues to track the path of motion as if he could not arrest his head movement (*middle*). Next the infant was shown an object moving in a circle. If inability to arrest head movement were responsible for the continuation of tracking, then when the object stops halfway up the arc (*right*), the infant's gaze should continue tangentially to the circular path. Instead the infant's gaze paused on the stopped object for half a second and then continued along the circular path. It seems that the eight- and 16-week-old infants did not identify an object as being the same object when it was moving and when it was stationary and so they continued to look for the moving object.

In short, they expected the object to still be there. When the object failed to reappear, the change in the heart rate was about seven beats per minute; when the object did reappear, the change was very slight.

The oldest infants expected the object to reappear even after the longest occlusion period; when the object did not reappear, the change in their heart rate was 11 beats per minute. Curiously, the youngest infants exhibited a reverse effect after the longest occlusion period. They showed more surprise at the object's reappearance than at its nonreappearance. It seems that even very young infants know that an object is still there after it has been hidden, but if the time of occlusion is prolonged, they forget the object altogether. The early age of the infants and the novelty of the testing situation make it unlikely that such a response has been learned.

If object permanence is a built-in property of the nervous system, then it should show up in other situations. If the object was moved behind a stationary screen instead of the screen's moving to cover a stationary object, the same neural process should inform the infant that the object was behind the screen. We tested this assumption by having an eight-week-old infant watch an object that could be moved from side to side in front of him. A screen hid the center segment of the object's path. We reasoned that if the infant knew that the object had gone behind the screen rather than disappearing into some kind of limbo, he should be able to anticipate its reappearance on the other side of the screen. On the other hand, if the infant did not know that the object was behind the screen, he should not look over to the place where it would reappear; his eye movement should be arrested at the point of disappearance.

Two television cameras were lined up with the infant's face in order to record what side of the screen the infant was looking at. In the first part of the experiment the object would begin at one side, move slowly toward the screen, go behind it, emerge and continue to move for some distance. Then on random trials the object stopped behind the screen. Would such eight-week-old infants look over to the side where the object was due to emerge, or would they halt their gaze at the point of disappearance? The answer was quite straightforward: all the infants anticipated the reappearance of the object. Their behavior supported the hypothesis that a built-in neural process had informed them the object was behind the screen.

Unfortunately this result might have been an artifact of the experiment. Perhaps the infant following the object could not stop the movement of his head and the movement simply continued after it had begun. In order to test this possibility we ran a comparison series of experiments in which the object stopped in full view before it reached the screen. We reasoned that if the infant's apparent anticipation of the object's reappearance had been the result of the continuing movement of his head, the movement should continue after the object had stopped. On the other hand, if the infant had been genuinely anticipating the reappearance of the object, he would not look at the other side of the screen for an object he had just seen stop before reaching the screen. To our great disappointment the infants all looked over to the other side of the screen. This result seemed to rule out the hypothesis that eight-week-old infants seeing an object go behind a screen know that the object is still there and will reappear. Further studies indicated that infants up to 16 weeks old also were likely to look for the object to reappear in both experimental situations.

The inability to arrest head movement is an intrinsically unsatisfying explanation, particularly since it does not explain the results from the experiment with the stationary object and the moving screen. We therefore tried a variety of other experiments. In one test infants were presented with an object that moved in a circular trajectory at right angles to their line of sight. After a time the object stopped in full view at a point halfway up the arc. If the continuation of tracking was the result of an inability to arrest ongoing movement, a pause in the object's movement on a circular path should have produced head movements tangential to the path. Every infant, however, continued to look along the circular trajectory. Furthermore, frame-by-frame analysis of motion pictures of the head movements and eye movements revealed that the infant's fixation on the object was held for about half a second before the tracking movement continued. This bizarre behavior, continuing to track a moving object after seeing it stop, cannot be the result of an inability to arrest head movement. Every infant was able to momentarily hold his gaze on the object when it stopped. Therefore the infants must at least have noticed that the object had stopped. Yet they continued to track the path the object would have taken had it continued to move.

The explanation of this behavior was not, and is not, obvious. Superficially the infant's behavior appears to reflect an inability to identify a stationary object with the same object when it is moving. It was as if the infants had been tracking a moving object, had noticed the stationary object that the moving object had become, had looked at it for a while and then had looked farther on to find the moving object again. It seems that they had not been aware that the stationary object was in fact the same as the moving object.

Could the converse be true? Would infants look for an object in the place where it had been stationary after seeing it move off to a new location? In order to find out we seated an infant in front of a toy railroad track that had a train on it. The train carried flashing lights to attract the infant's attention. At the beginning of the experiment the train was stationary in the middle of the track. After 10 seconds the train moved slowly to the left and stopped at a new position, where it remained for 10 seconds, and then returned to its original position. The cycle was repeated 10 times.

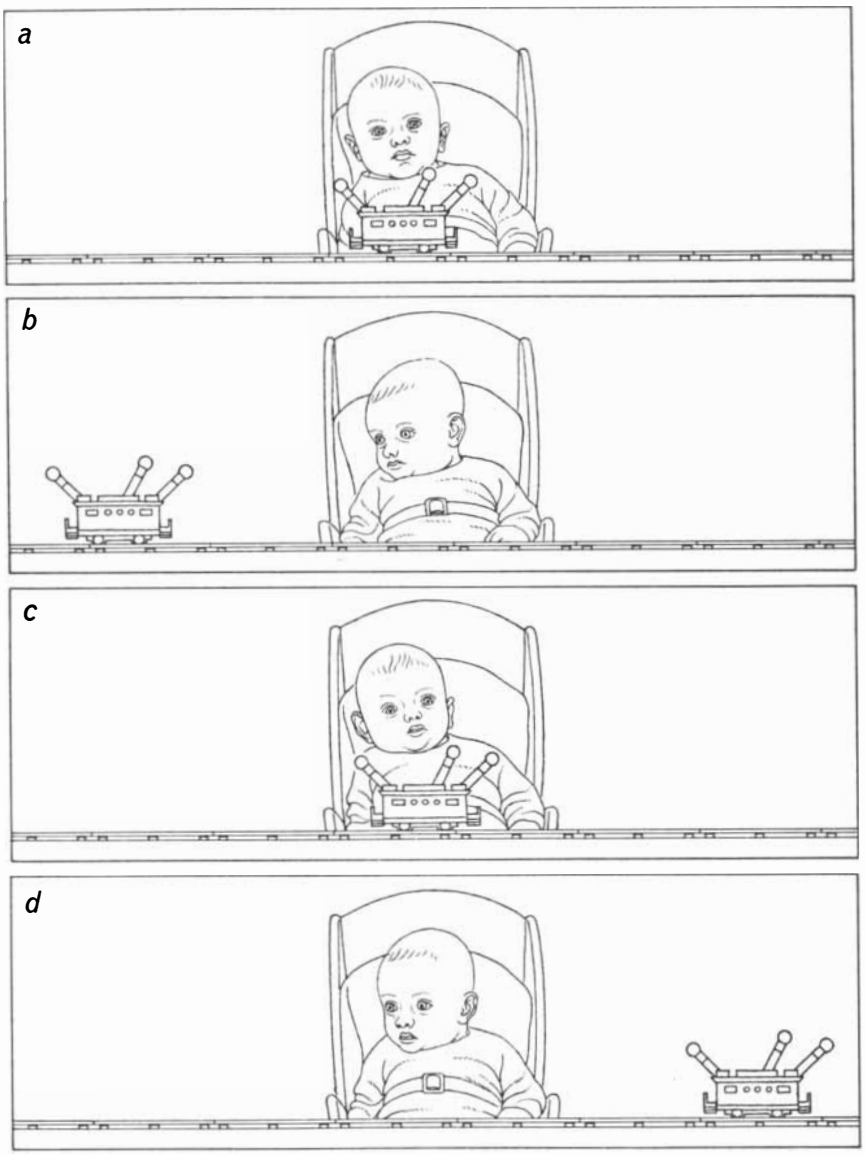
How would this simple to-and-fro movement be seen by a three-month-old infant? Our hypothesis was that an infant of this age fails to recognize the identity of a moving object and the same object standing still. Initially the infant should see a stationary object in a particular place. Then the object would disappear and a new moving object would appear. Then the moving object would disappear and a stationary object would appear in a new place. After a time that too would disappear and a new moving object would appear, which in turn would give way to the original object in the original place again. To the infant the cycle would seem to involve perhaps four objects, whereas in reality there is only one. An infant quickly learns to look from one place to another as an object moves between them. If our hypothesis is correct, the infant is not following an object from place to place; rather he is applying a rule in the form, "Object disappears at *A*, object will reappear at *B*."

Suppose now that after the 10th cycle the train moves to the right to an entirely new position instead of moving to the left as usual. A subject who was following a single object would have no trouble. If an infant is applying the rule

above, he should make an error. Specifically, when the stationary object moves to the right for the first time, thereby disappearing at the middle, the infant should look for the stationary object to the left in the place where it has reappeared before. When we tested three-month-old infants, every infant made the error predicted by our hypothesis. That is, when the train moved to the right, the infant looked to the left and stared at the empty space where the train had stopped before. Meanwhile the train with its flashing lights was in full view in its new place to the right.

This last result, together with those from our earlier studies, confirms the hypothesis that three-month-old infants do not recognize the identity of an object at a standstill and the same object in motion, and vice versa. Note that I am using "identity" in a rather special sense, meaning to recognize an object as being the same object rather than another identical object. If an infant does not identify a stationary object with a moving object when they are the same object, how does he identify a stationary object with itself when it is stationary in the same place later? How does he identify a moving object with itself when it is moving along a continuous trajectory? We began a new series of experiments to answer this fundamental question. The most obvious features of an object are its size, shape and color. These seem to serve as identification elements for adults. For an infant their role would seem to be somewhat different.

We presented infants with four situations: (1) An object (a small white mannikin) moved along a track, went behind a screen, emerged on the other side, moved on for a short distance, stopped and then returned to its original position. (2) The object moved along the track, went behind a screen and at the moment when the object should have emerged on the other side of the screen a totally different object (a stylized red lion) emerged, moved on for a short distance before reversing and repeating the entire cycle in the opposite direction. In this sequence there were differences of size, shape and color between the two objects, but there was only one kind of movement in any one direction. (3) The object moved along a track as before, except that at a time when, according to its speed before occlusion, it should still have been behind the screen, an identical object moved out. Here the objects were identical but there were two kinds of movement and evidence that there were two different objects since a single object could not have moved quickly enough to get across the screen in such a short time. (4) The object moved along a track as before, and at a time when it still should have been behind the screen a totally different object moved out. Here there were two kinds of difference in movement and features to indicate that there were two different objects. In all the situations only one object was visible at a time.



DISAPPEARING TRAIN confirms the hypothesis that infants 12 weeks old do not watch a single object when the object is at first stationary, then moves and stops. They do not follow the moving object from place to place but rather apply a cognitive rule that can be stated: "Object disappears at *A*; object reappears at *B*." In the experimental test the infant sat watching a toy train with flashing lights at rest in the middle of the track (*a*). After 10 seconds the train moved to the left and stopped (*b*) and remained there for 10 seconds before returning to the center again. The cycle was repeated 10 times. On the next cycle (*c, d*) the train moved slowly to the right and stopped. If the infant had been following the moving object, he would have looked to the right, but if he had been following the hypothesized cognitive rule, he would have looked to the left in the place where the train had stopped before. Every 12-week-old infant tested made the error predicted by the hypothesis.

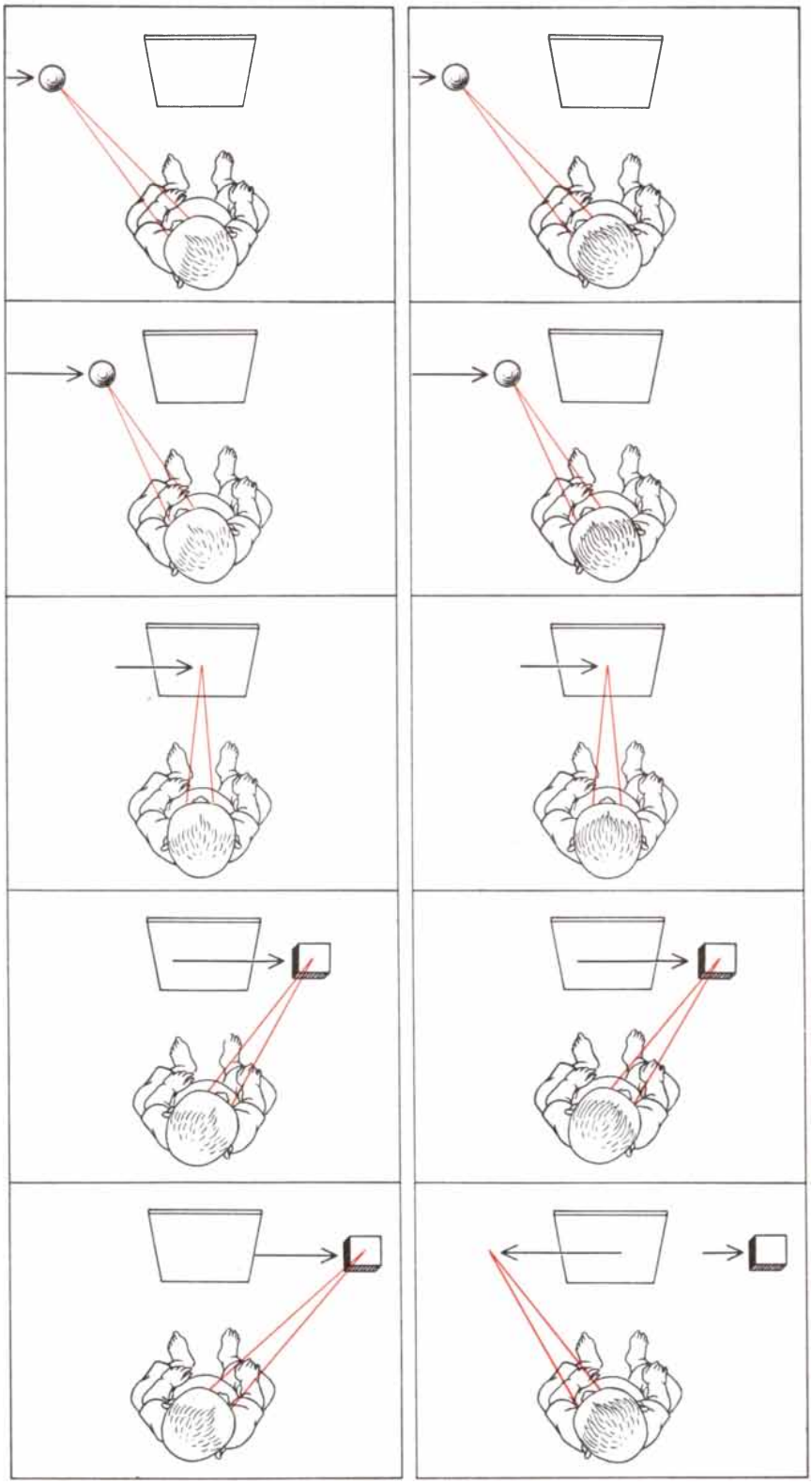
We conducted the experiment with groups of infants between six and 22 weeks old. The older infants tracked the moving object in Situation 1 quite happily; when the object stopped, they stopped tracking it. In Situation 2, where a different object emerged, they also followed the object in motion, although some glancing back and forth between

the sides of the screen was noticeable. When the object stopped, at least 25 percent of the time they looked to the other side of the screen as if they were looking for the object that had disappeared. Their responses in Situation 3 and Situation 4 were similar, with the difference that when the object stopped, on every trial the infants looked to the other half of the track in apparent anticipation of the appearance of the other object.

Infants less than 16 weeks old showed a complete contrast in behavior. In Situation 1 they followed the moving object with no sign of being disturbed. When the object stopped, they continued to follow its path of movement. In Situation 2, when a different object emerged, they also continued to track it with no sign of being disturbed. When the object stopped, they continued to track it. In Situation 3, however, where the object came out from behind the screen sooner than it should have, they were upset and refused to look any more. They also refused to look in Situation 4. In both cases when the object stopped, the infants did not continue to follow its path as they had in the first two situations. This was largely due to their refusal to track at all.

These results show that younger infants are not affected by feature differences. For them movement is predominant. They respond to a change in motion but not to a change in size, shape or color. They ignore features to such an extent that I would suggest they respond not to moving objects but to movements. Similarly, I would suggest that they respond not to stationary objects but to places. In contrast, older infants have learned to define an object as something that can go from place to place along pathways of movement. They identify an object by its features rather than by its place or movement. For them different features imply different objects that can move independently, so that the stopping of one does not imply the stopping of the other.

This attainment is obviously one of tremendous significance. It transforms the perceptual world of the infant at one stroke into something very close to the perceptual world of the adult. According to these studies it seems that infants less than 16 weeks old live in a world articulated in terms of solids that are stably arranged in space according to their location, with a constancy of existence when they occlude one another. It is, however, a grossly overpopulated



MOVEMENT AND FEATURES mean different things in the perceptual worlds of young and older infants. Infants less than 16 weeks old tracked a moving object (*left*) until it went behind a screen and anticipated its reappearance; when a different object emerged, they continued to track its motion with no sign of surprise. Older infants also tracked the object in motion when a different object emerged from behind the screen (*right*), but when the object stopped, the older infants often glanced to the other side of the screen as if they were looking for the first object. This indicates that the younger infants do not respond to moving objects but to movements, and not to stationary objects but to places. Older infants have learned to recognize an object by its features rather than by its place or movement.

world. An object becomes a different object as soon as it moves to a new location. In this world every object is unique. The infant must cope with a large number of objects when only one is really there.

In the last experiment I shall describe infants sat in front of an arrangement of mirrors that produced two or three images of a person. In some instances the infant was presented with two or three images of his mother; in others he would see his mother and one or two strangers who were seated so that they were in a position identical with the earlier additional images of his mother.

In the multiple-mother presentation infants less than 20 weeks old happily responded with smiles, coos and arm-waving to each mother in turn. In the mother-stranger presentation the infants were also quite happy and interacted with their mother, and they normally ignored the strangers. This demonstrates that young infants can recognize features in recognizing their mother, but they recognize the mother as one of many identical mothers. They do not recognize the identity of the multiple mothers in the special sense in which I have used the word "identity," that is, they do not identify the multiple images of the mother as belonging to one and the same person.

Infants more than 20 weeks old also ignored the strangers and interacted with their mothers. In the multiple-mother situation, however, the older infants became quite upset at the sight of more than one mother. This shows, I would argue, that the younger infants do identify objects with places and hence think they have a multiplicity of mothers. Because the older infants identify objects by features, they know that they have only one mother, and this is why they are upset by the sight of multiple mothers.

The discovery of the object concept must simplify the world of the infant more than almost any subsequent intellectual advance. Two pressing questions arise from this research. We do not know why the object concept must be discovered rather than being built into the neural system (as so many other kinds of perceptual knowledge are), nor do we know how the discovery is made. There are indications that built-in analyzers are limited to the initial input areas of the brain and their cross-connections. It is known that place and movement are separately coded in the visual system. Moreover, errors of the kind made by young infants persist in adults in some form. The late Baron Albert Michotte of the University of Louvain found that adults who are shown an impossible sequence such as the one described in Situation 3, where an object reappears from behind the screen sooner than it should, will say something like, "It looks as if it is the same object, but I know...." This kind of response indicates that the infant's error persists in the adult's perceptual system and is overcome by a cognitive rule. We do know that particular environments can speed or slow the acquisition of such conceptual behavior. In line with this fact there is evidence that nonhuman primates never overcome perceptual errors and remain much like the young infants we studied. The object concept may thus be outside the limits of intrinsic neural specification.

MULTIPLE MOTHERS were presented to infants by an arrangement of mirrors. In other instances the infant would see his mother and two unfamiliar women seated in the same position as the mirror images of the mother. Infants less than 20 weeks old waved their arms, smiled and called to each of the mother images in turn. Older infants, however, became quite disturbed by the sight of more than one mother. All the infants ignored the strangers and interacted only with the mother. It seems that the younger infants think they have a multiplicity of mothers because they identify objects with places. Older infants identify objects by features and know they have only one mother. Learning to identify objects by features is one of the major intellectual advances made by infants.

We want to be useful ...and even interesting

Kodak

The protein in the products and the protons in the protein

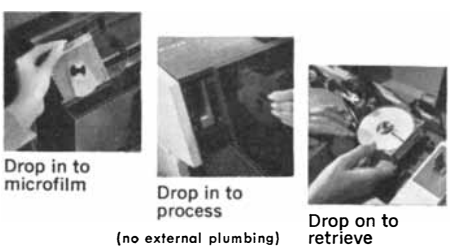
While merely minding our own business—photo materials—we have come up with a way of analyzing a proton magnetic resonance spectrum of protein that may merit attention elsewhere. Like sausage makers, we have yet to find a good replacement in our products for protein. In our case it's the protein gelatin. We think we are beginning to understand the signals from the variously situated protons in the macromolecule. The sausage business can probably get along without our contribution, but investigators of metal-activated enzymes may be interested.

As reported earlier this year in *Science 171*:573-4, P. I. Rose of the Kodak Research Laboratories first obtained spectra from model compounds like homopolypeptides and amino acids. This provided a glossary useful in analysis of the complicated gelatin spectrum. He then observed changes from the introduction of the paramagnetic Co^{++} ion. Aspartyls and glutamyls are the two protein building blocks that have carboxyls on their side chains. The PMR spectrum clearly shows that's where the Co^{++} gets bound.

Microfilm, the information medium that advances when expected to retreat

While our own and many other laboratories labor toward more sophisticated information storage devices than the familiar gelatin dispersions of silver halide, the photographic process continues to entrench itself all the deeper.

Wet chemistry? *What* wet chemistry? Film? *What* film? Oh, there is reputed to be film inside those cartridges, but you never touch it. Meet the newest Kodak microfilm system:



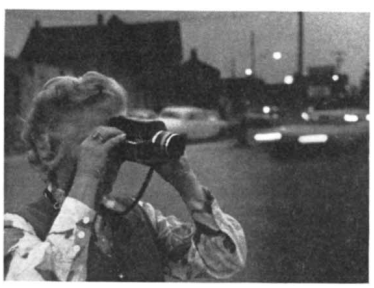
Wouldn't "Instamatic" be a good trademark to put on such equipment? Darn right.

To talk about it, look for Kodak in the Yellow Pages under "Microfilming."

The little orange light that signals a long and somewhat metaphysical message

We are pleased to announce a new generation of movie cameras intended, when loaded with the new KODAK EKTACHROME 160 Movie Film (Type A), to dispense with photographic lights when shooting at indoor social or athletic events.

To allow movie-making at the same light level as suffices for the eyes of the participants in such events, KODAK XL Movie Cameras come with *f*/1.2 EKTAR Lenses. All the light from the lens reaches the film. The shutter has a 230° opening instead of the usual 165°. Choice is provided of 18 or 9 frames/sec. Steadiness is provided by making you use your forehead for support. The same film is also OK in full sunlight when used in these cameras.



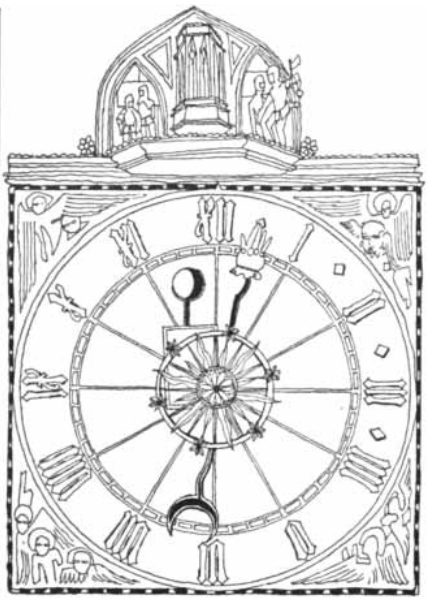
Quite apart from social gatherings, there may be applications for unobtrusive movie-making at very low light level. You point the camera at what you want to film. Perhaps an orange disk lights up above the scene in the viewfinder.

The signal light goes on somewhere between roughly 6 and 8 footcandles of illumination on the scene. Half that if you are willing to shoot at 9 frames/sec. The following message is thereby conveyed:

"What you will get if you press the button right now will look darker than what is generally expected in good pictures. On the other hand, it may be no worse than what you are seeing in the viewfinder at this moment. Indeed, if the picture you will see projected on the screen were to look brighter than what you are now seeing, it would no longer be a truthful representation, would it? Remember that the photographic process integrates light but your visual mechanism does not. Remember that on the darkest of nights still pictures can be forced by sufficient exposure to look like full daylight. In one sense, such a picture is a lie, of course; but if it happens to be a picture of your house, the house looks genuine enough.

"Now you are trying to make movies, and we are warning you that unless you can turn off this orange light by getting more illumination on this scene or by finding some brighter scene to photograph, you may not be satisfied with your results. But if you prefer subjective realism to objective delineation, you may like them very much."

SCIENCE AND



Optimism and Population

A comprehensive study of world population growth by a committee of the National Academy of Sciences under the chairmanship of Roger Revelle of Harvard University takes the basically optimistic position that "the natural resources available to present technology are sufficient to allow a vast improvement in the standard of living of all the people who will inhabit the earth 20 to 30 years from now." The committee's report, *Rapid Population Growth: Consequences and Policy Implications,* took three years to prepare. The two-volume work, just published by the Johns Hopkins Press, is concerned with "the most fundamental event of our times—the enormous growth of the world's population during the last 3 decades, and the prospects for continued growth in the future."

The authors observe that "apocalyptic visions of the future are based on simple, mathematical extrapolation of present rates of population growth." They have adopted the modest goal of examining "the population problem as it affects us now—and for the next 5 to 30 years." They acknowledge that if present fertility rates and mortality trends continue, the world population could reach 7.5 billion in the year 2000. Making "reasonable allowance for reductions in fertility," however, they suggest that seven billion is a more likely figure. They do not believe that "uncontrolled population growth in the earth's poor countries is leading to catastrophe." They write: "It is possible... to take a different view, based on what we know about the history of human populations and on the behavior of many people at the present time—a view that social inventions will lead to a deliberate limitation of fertility by individual couples." As evidence that sharp changes in fertility are possible in a short time, they point to Japan, where birthrates decreased by nearly 50 percent between 1948 and 1960. Decreases nearly as large in Taiwan and South Korea show that a high level of development is not a necessary precondition.

Volume I of the report, subtitled *Summary and Recommendations,* issued in paperback, reviews the history of world population growth, describes the different rates of growth in different regions of the world, presents the economic and social consequences of uncontrolled population growth and outlines a "population policy" with specific recommendations. The authors refer to surveys showing that there is an almost universal desire among parents to have a limited number of children but that in poor countries children are "the poor man's capital." Moreover, this capital is highly perishable. In East Pakistan, for example, the average 45-year-old woman has had 7.6 children, a third of whom have died. "Another important reason for the excess of live births over the number of desired children," the report continues, "is undoubtedly the ineffectiveness, difficulty, and hardship of preventing births with the methods now available to the people of poor countries." The authors state their conviction that "a full range of acceptable, easily used, and effective means of preventing births" are available today and could be provided by governments to everyone "at nominal or no cost."

The report analyzes the arguments sometimes put forward that rapid population growth can be economically beneficial for poor countries under certain circumstances. The authors believe this thesis is almost always misguided if all social costs are considered. Although the report emphasizes that couples must be "given full freedom of choice" on family size, it concludes that a full accounting of "benefits and costs for society as a whole" will "justify social intervention to influence the fertility behavior of the parents.... Many special-

THE CITIZEN

ists are convinced that governmental population policies to limit fertility must go beyond furnishing contraceptive materials, services, and information.... The freedom of husbands and wives to make reproductive decisions must, therefore, be tempered by concern for the rights and interests of others."

The report recommends a number of policies to help the nations of the world lower fertility rates. It observes that "over a billion births will have to be prevented during the next 30 years to bring down the world's population growth rate from the present 2 percent per year to an annual rate of 1 percent by the year 2000. The task may well be the most difficult mankind has ever faced, for it involves the most fundamental characteristic of all life—the need to reproduce itself."

Food and Population

Food production in the Far East rose 5 percent last year, a rate of increase that the Food and Agriculture Organization of the United Nations describes as "comfortably ahead of the population growth." Progress was also made in a number of other developing countries, but a larger number failed to increase their food production fast enough to supply their growing population with more and better food from their own output. Summarizing the situation in a preliminary version of its annual study titled *The State of Food and Agriculture 1971,* the FAO cited "the continued progress of rice and wheat production in the Far East, the world's most concentrated food-deficit zone," but added that "there was little or no increase in the total food production of the developing countries of Africa and the Near East," so that in per capita terms their output declined, and that although food production rose in Latin America, the increase "was just sufficient to keep pace with population growth."

In a foreword to the study Addeke H. Boerma, director-general of the FAO, attributed the gain in rice and wheat output in the Far East to "steadily increasing use... of improved seed varieties" and noted that governments there "are taking measures to spread the new technology over still larger areas and to bring it to farmers who thus far have

not been able to profit by it." He advised caution, however, in speaking of "the green revolution as if it were already an accomplished fact." Although the new technology now applied to cultivating rice and wheat in a number of countries has brought many benefits, Boerma said, "this is not yet a green revolution." Even in the most successful countries the increases in rice and wheat production have not been matched by similar increases in the production of other foods, and in many other countries intensive programs to raise yields "are only at a very early stage, if they have been started at all." What is required, he said, is "a widespread introduction of improved agricultural technology... in the developing world as a whole."

Cause and Effect

In the year since a liberalized abortion law went into effect in New York State (on July 1, 1970), New York City has had a distinct decline in birthrate, in the number of babies born out of wedlock and in the number of maternal deaths related to abortion. The law allows a physician to perform an abortion on any consenting woman who is not more than 24 weeks pregnant; previously an abortion was legal only if it was thought necessary to preserve the life of the mother. The effects of the new law are reported by Jean Pakter and Frieda Nelson of the New York City Department of Health in *Family Planning Perspectives,* a publication of the Planned Parenthood Federation of America. Pakter and Nelson found that the number of births in the first six months of 1971 was 60,695, compared with 64,667 in the first half of 1970; that births out of wedlock, which had been rising since they were first recorded in 1954, were 9,805 in the first four months of 1971 and 10,180 in the same period of 1970, and that the number of maternal deaths related to abortion during the first quarter of 1971 was, at seven deaths per 100,000 live births, only 40 percent of the figure for the first four months of 1970. "If this downturn in maternal deaths continues," they write, "New York City will experience for 1971 its lowest ratio of maternal deaths ever recorded."

Pakter and Nelson take note of predictions at the time the new law was passed that "the state and, more particularly, an unprepared New York City would be subjected to social and medical catastrophe" from an inundation of women seeking abortions. "None of these dire predictions," they find, "has come to pass." About 164,300 legal abortions were performed in the city during the first year under the new law, and most of them were "at costs considerably lower (and, of course, under conditions immeasurably safer) than were prevalent among illegal practitioners." The authors also report that poor women and black women in particular have benefited from the new law. "New York's experience," they write, "indicates that when abortion is made available and accessible at low cost it will be used to terminate unwanted pregnancies by all ethnic and racial groups."

The Cost of Cleanliness

The second annual report of the Federal Council on Environmental Quality examines at length the cost and economic impact of achieving national standards in controlling air and water pollution and in managing solid wastes. The council estimates that in the six-year period 1970–1975 the total bill for cleaning up the nation's air and water and disposing of wastes will come to about $105 billion. The average annual cost of $17.5 billion will be nearly twice the outlay in 1970 for such purposes.

The increase in cost will vary considerably with the medium involved. The six-year expenditure to abate air pollution will total $23.7 billion, representing an increase of 840 percent on an annual basis. For controlling water pollution the 1970–1975 total will be $38 billion, for an annual increase of 87 percent. Waste management will cost $43.5 billion over six years, representing an annual increase of only 37 percent.

The sharing of cost between public and private sectors will also vary widely. It is estimated that private industry will have to supply about $40 billion of the total six-year figure of $105 billion. State and local governments will have to provide about $26 billion of the cost of cleaning up the air and water plus an unspecified fraction of the $43.5 billion forecast for waste management. The largest single burden will fall on the buyers and users of automobiles. The council estimates that pollution controls will add at least $240 to the cost of 1975 automobiles, or a total of $2.4 billion if 10 million vehicles are sold in that year. Operating and maintaining the control devices will cost perhaps $20 per car, or another $2 billion per year for owners of the nation's more than 100 million vehicles.

One way or another virtually the entire $105 billion will be borne by private individuals in the form of increased cost of products, direct charges or taxes. In return the public can expect both tangible and intangible benefits. For example, it is estimated that the annual toll levied by air pollution on health, vegetation, materials and property values comes to more than $16 billion per year.

The $105-billion expenditure in six years will amount to only 1.6 percent of the cumulative gross national product of some $6.7 trillion. The council observes that the "environmental control costs of one firm represent income and revenues to other firms and workers.... The net result... would generally be only a change in the mix of total output, not a reduction in total employment. The Nation can lose economic welfare only by making choices on abatement levels or methods which incur costs larger than the benefits derived."

Gold in a Silver Mine

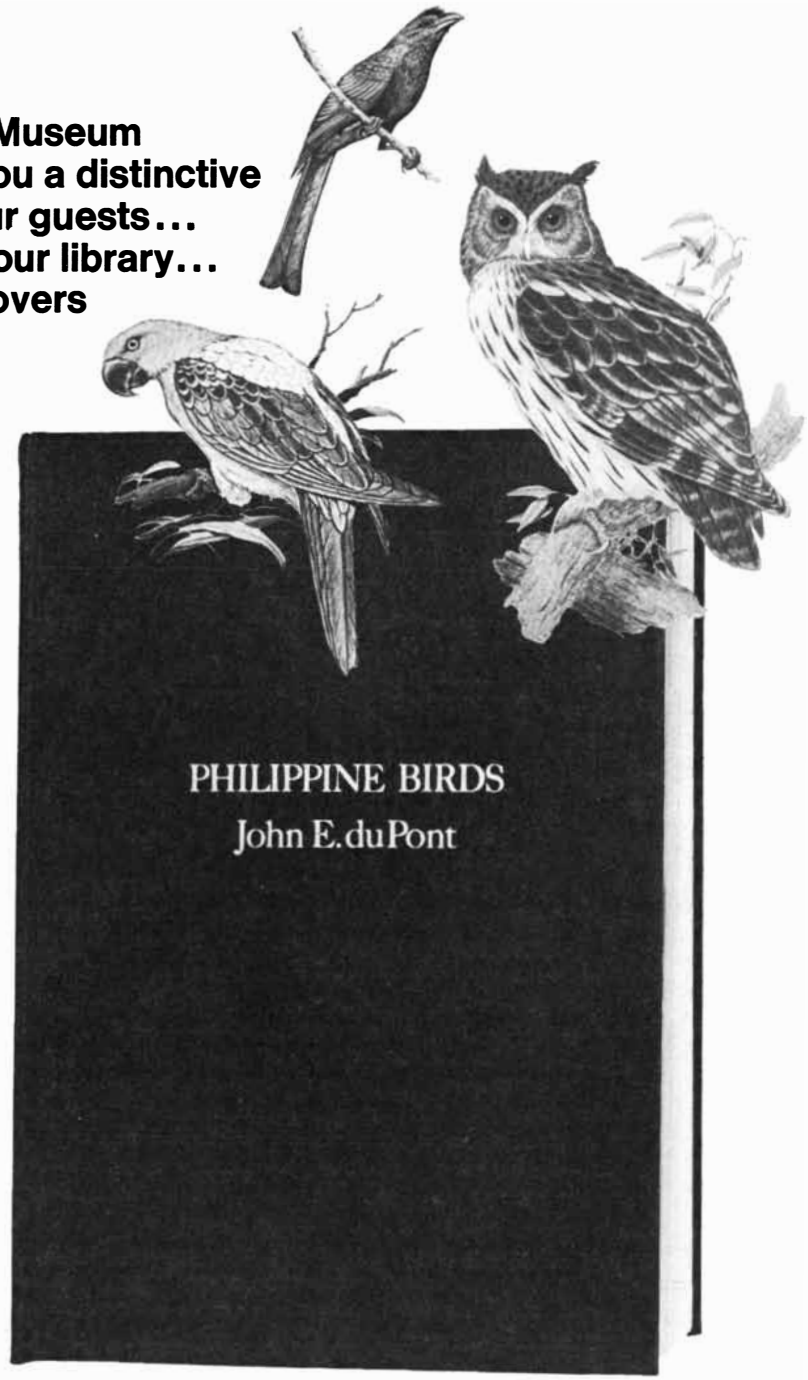
Evidence of the existence of a hitherto hypothetical subatomic particle—the intermediate boson, or *W* particle—has been found in an abandoned silver mine in Utah. The finding, made by a group of physicists from the University of Utah led by Jack W. Keuffel and Haven E. Bergeson, was reported recently at the 12th International Conference on Cosmic-Ray Physics, held in Tasmania.

The intermediate boson was originally postulated by theoretical physicists as the quantum of the weak force, in analogy to the pion (the quantum of the nuclear force), the photon (the quantum of the electromagnetic force) and the graviton (the proposed quantum of gravity). Up to now no firm evidence of the intermediate boson's existence had been reported.

The Utah physicists obtained their evidence with the aid of a large cosmic ray detector housed in a mine shaft three miles inside a mountain near Park City, Utah. The detector, a 2,000-ton array of concrete water tanks, light-collecting tubes and gas-filled cylinders, was designed to record the arrival of muons, or mu mesons, produced as a result of collisions between high-energy cosmic rays and atomic nuclei in the earth's upper atmosphere. (The detector was located underground to screen out relatively low-energy particles produced in the atmosphere.)

Such high-energy cosmic ray collisions produce a shower of secondary particles, principally kaons (*K* mesons) and pions (pi mesons), which in turn decay spontaneously into muons, provided that they can travel far enough without colliding with other particles.

Now the famed Delaware Museum of Natural History offers you a distinctive conversation piece for your guests... a prestigious addition to your library... a fascinating gift for bird lovers



Since 1958, John E. du Pont, world traveler, internationally known author and Director of the Delaware Museum of Natural History, has been a frequent visitor to the Philippine Islands. He spent much of his time observing, cataloging, studying and photographing the more than 950 different species and sub-species of beautiful and exotic birds that inhabit the islands.

Now, after more than a decade of exhaustive research and study, including continuing consultation with ornithological authorities in major museums of the world, John du Pont has assembled the results of his work between the covers of this authentic and beautifully bound book.

"PHILIPPINE BIRDS" contains 569 illustrations in all the colors of the rainbow, each faithfully portraying the multi-hued birds. Accompanying the illustrations are the modern classifications, descriptions, measurements and island occurrences of the birds. Both popular English and scientific names make accurate identification easy for the serious ornithologist as well as for students, librarians and just plain bird lovers. The 85 magnificent color plates are the work of two renowned artists, George F. Sandstrom and the late John Pierce. Dean Amadon, Lamont Curator of Birds and Chairman, American Museum of Natural History says in his foreword to PHILIPPINE BIRDS, "The book will speak for itself. Anyone who knows John du Pont will realize that once in the islands, he heads for the mountains and jungles; he is not one to dawdle about in the gardens of a lot of local officials."

The Monkey-Eating Eagle, one of the world's rarest

You will find hours of relaxation with the magnificent book, written in John du Pont's familiar and distinctive style. Handsomely bound, it will be an outstanding addition to your library, and an instant "conversation starter" whenever you have guests. PHILIPPINE BIRDS will make a unique gift for any occasion—for young and old alike.

ORDER NOW AND SAVE. If you order now, you can take advantage of the special pre-publication price of only $27.50 (plus a few cents for handling and mailing). This special price will apply only to orders received by the December 1, 1971 publication date.

Delaware Museum of Natural History, Dept. PB-2, Greenville, Del. 19807

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Particles entering the earth's atmosphere at oblique angles have a better chance of avoiding further collisions, and it was assumed by the Utah experimenters that they would detect more muons coming from directions near the horizon than from directions near the zenith. Out of more than 200,000 muons detected in the past three years, however, the proportion arriving from vertical directions has turned out to be higher than it should be; moreover, the ratio increases with depth below the earth's surface, reaching a peak at about 4,000 feet.

The Utah physicists believe these anomalous high-energy muons are produced by the decay of intermediate bosons formed in the upper atmosphere by cosmic ray protons; such unusual muons would presumably be selectively absorbed underground in a way that the ordinary pion-produced and kaon-produced muons are not. The experimenters point out, however, that final acceptance of this interpretation will depend in the first instance on confirmation of their results, which may be difficult since no other detector as large as the Utah one exists.

Pioneers to Jupiter

Two 560-pound spacecraft are being prepared for the longest space flight yet attempted: a mission to Jupiter. Designated *Pioneer F* and *Pioneer G*, each will be equipped with 11 scientific instruments, more than have ever been carried on a planetary mission. *Pioneer F* is scheduled to depart in late February or early March, 1972; *Pioneer G* will be launched 13 months later. The voyages will take somewhere between 19 and 32 months, depending on the exact departure date, and will cover between 600 million and 900 million kilometers. Each spacecraft will spend about four days in the vicinity of the solar system's largest planet. The craft will be launched by Atlas-Centaur vehicles provided with a new solid-propellant third-stage motor. They must attain a final speed of about 32,000 miles per hour, a new record for spacecraft. The initial velocity required for a trip to Mars is only about 25,600 miles per hour.

Great ingenuity has been used to minimize the weight and power requirements of the 11 instruments; their combined weight is 61.5 pounds and none draws more than 4.2 watts. Since each Pioneer will spend more than six months in the asteroid belt that lies between Mars and Jupiter, each will carry two instruments for detecting and counting meteoritic material. One device will record punctures made by particles weighing more than 10^{-9} gram; the other will detect larger particles by the amount of sunlight they reflect. Another group of six instruments will analyze the composition of the solar wind, measure magnetic fields in interplanetary space, count charged particles and cosmic rays and measure the intensity of particles trapped in Jupiter's magnetic fields. The Jovian atmosphere will be analyzed by an ultraviolet photometer and an infrared radiometer; the latter will also record temperatures on the surface of the planet. Finally, the disk of the planet will be photographed by a novel mechanism: an imaging photopolarimeter. It will consist of a telescope of one-inch aperture that will sweep out a cone as the spacecraft spins slowly at about five revolutions per minute. The light entering the telescope will be split to produce separate red and blue images. The images will be obtained in the form of scan lines along the viewing cone and will provide an image of the raster type with a resolution of 200 kilometers.

Digital data will be returned to the earth at the rate of 1,024 bits per second and received by three dish antennas with a diameter of 210 feet: one in California, one in Australia and one in Spain. The power of the transmitter aboard the spacecraft is only eight watts. The power for operating the instruments and the transmitter will be supplied by two plutonium thermoelectric generators, each capable of producing 40 watts at the start of the mission and 30 watts at the end of five years.

One Mile Down

A diver can do useful work at depths down to 5,000 feet—far in excess of all previously predicted limits—according to the results of an experiment just completed at the University of Pennsylvania's Institute for Environmental Medicine. For the purposes of the test four specially trained subjects, two university students and two recent graduates, spent 25 consecutive days in one of the Institute's high-pressure chambers being exposed to simulated extreme depths. A "major aspect" of the record 5,000-foot test dive was that neon was used for the first time as a respirable gas at high pressure. The experiment is part of a continuing series of studies being carried out at the Institute under the direction of Christian J. Lambertsen to predict the ultimate physiological limits of deep-sea activity by man.

The most recent simulated dive began on August 7, when the four subjects (Ronald Billingslea, Timothy J. Carson, Thomas R. Liebermann and Stephen C. Kowal) entered the chamber complex. The men were exposed to a series of progressively deeper environments until the hydrostatic equivalent of 1,200 feet of seawater was reached. A helium-oxygen atmosphere was used in the chamber system at all levels, but neon and nitrogen mixtures were "superimposed" for repeated short periods through a face mask to simulate the increasing density and narcotic influence to be expected when helium is breathed at depths of more than 2,000 feet. During the experimental exposure, the longest ever made at the 1,200-foot level, extensive respiratory, neurophysiological and performance tests were carried out "to separate the major variables that develop with each combination of gases at various depths and pressures."

One of the principal findings reported by Lambertsen was that "no significant limiting physical or mental influences of hydrostatic pressure or helium occurred at the 1,200-foot exposure even though the men spent six days doing continuous work at that depth." Nor were there any severe limiting respiratory or intellectual influences during periods of rest or light work when neon was added as a respiratory gas at the 1,200-foot depth to simulate helium densities found at 2,000, 3,000, 4,000 and 5,000 feet.

Heavy work could be accomplished down to a depth of 700 feet and moderate work down to 900 feet. At the 1,200-foot depth, with neon being used to achieve the greatest density exposure, the central nervous system still functioned normally during heavy exercise but the respiratory task of moving the dense, neon-rich air in and out of the lungs made it impossible for the subjects to complete the programmed work. Lambertsen points out, however, that "this was extreme exertion at a respiratory-gas density equivalent to breathing helium at a depth of 5,000 feet of seawater." In contrast, he adds, nitrogen-rich air induces such distinct narcosis at the 400-foot level that useful physical or mental work becomes impractical.

According to Lambertsen, the current studies will make possible the selective mixing of inert gases to provide the best combinations for economy, voice communication, safe decompression and protection against respiratory and central-nervous-system impairments. The results obtained so far "now make essential detailed investigations of the influences of water pressure itself, independent of the effects of the gases breathed at high pressure."

When the Atlas was retired as an ICBM it was the beginning of a new career.

To make a rocket fly, you really have to find out how to do three basic things.

Find a way to guide it. Find a way to hold it together as it flies. And find a way to keep down its weight, so it carries more than itself.

Finding a way to solve all that was, to say the least, one big problem. We know.

We build the Atlas rocket.

First, how do you steer a rocket?

We invented a new way. We made the main engines do two things at once: besides pushing the rocket up, the engines swivel on their axes and control flight.

The effect is like this: balance a baseball bat upright in the palm of your hand. To keep it stable, your hand is constantly correcting for the motion of the bat.

The engines do about the same thing for the rocket.

How do you build a structure strong enough to withstand the pressure of leaving the atmosphere?

Until Atlas, the hardest material around was boiler plate.

We developed another idea. Roll steel so thin that it almost reaches its breaking point. This steel will take four times the pressure per square inch of ordinary steel, but will not take an ounce more stress.

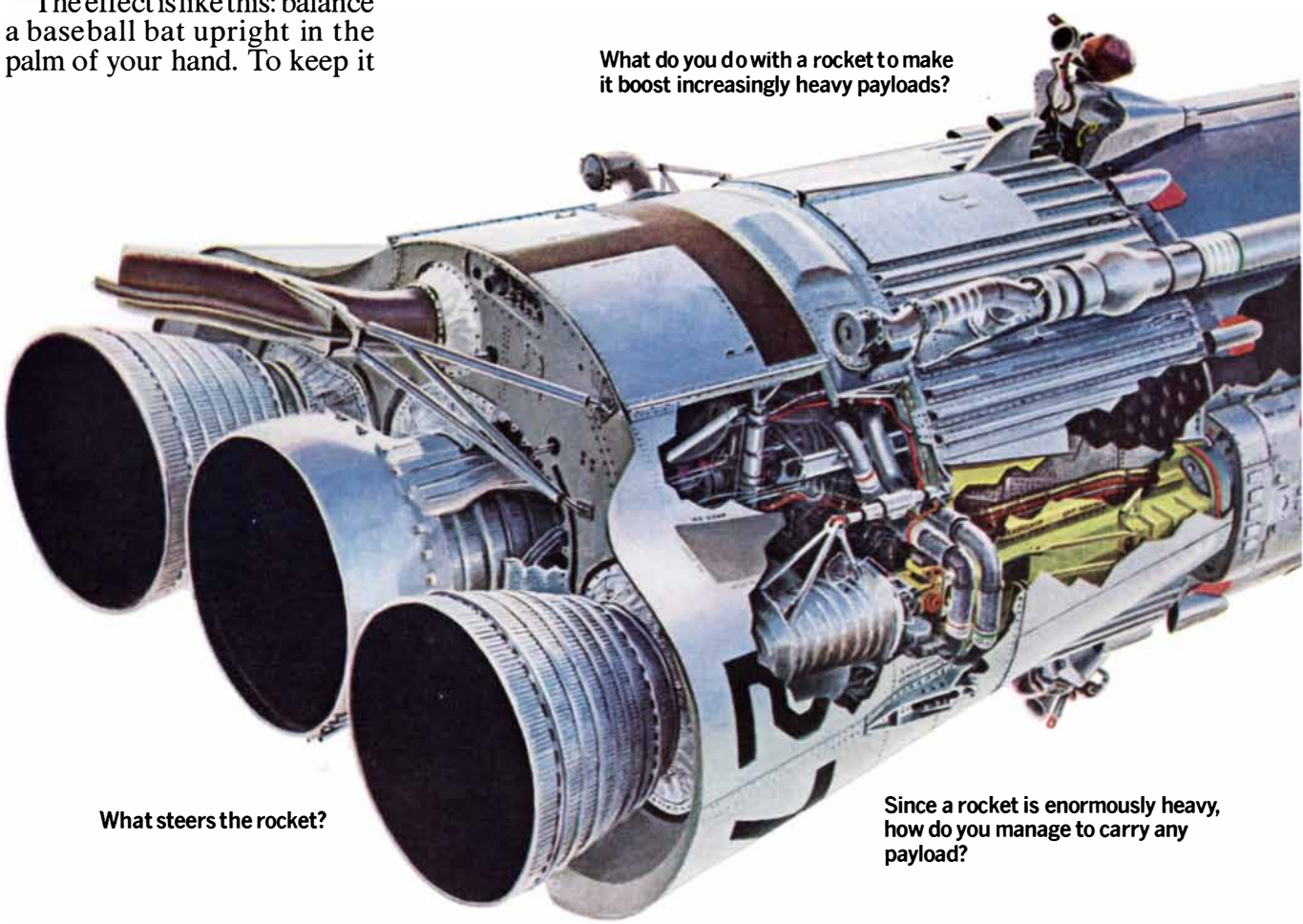
This thin steel, thin as a dime, became the outer skin of the Atlas. It reduced weight. It also let us do one other important thing.

It let us design a fuel tank like a balloon, so the fuel not only provided power but also held the tank rigid, and reduced structural weight even more.

In 1954, after all this work by our Convair Aerospace Division, we began to develop the Atlas under government contract.

In 1957, the first Atlas flew.

It was ready for mass production as our first ICBM. Happily, Atlas was never called on to



What do you do with a rocket to make it boost increasingly heavy payloads?

What steers the rocket?

Since a rocket is enormously heavy, how do you manage to carry any payload?

carry out this mission.

But as new requirements developed, the booster was modified to handle them.

To date, Atlas has fulfilled dozens of different missions for NASA and the U.S. Air Force. So far, Atlas has been launched more than 390 times.

These launchings include putting the first American into orbit; boosting our first unmanned payload to the moon; sending our first orbiting spacecraft around the moon; and launching the first close-up probes of Venus and Mars.

After all this, Atlas is far from a museum piece. Through the years, the addition of its second-stage mate, Centaur, has helped enlarge Atlas' capabilities.

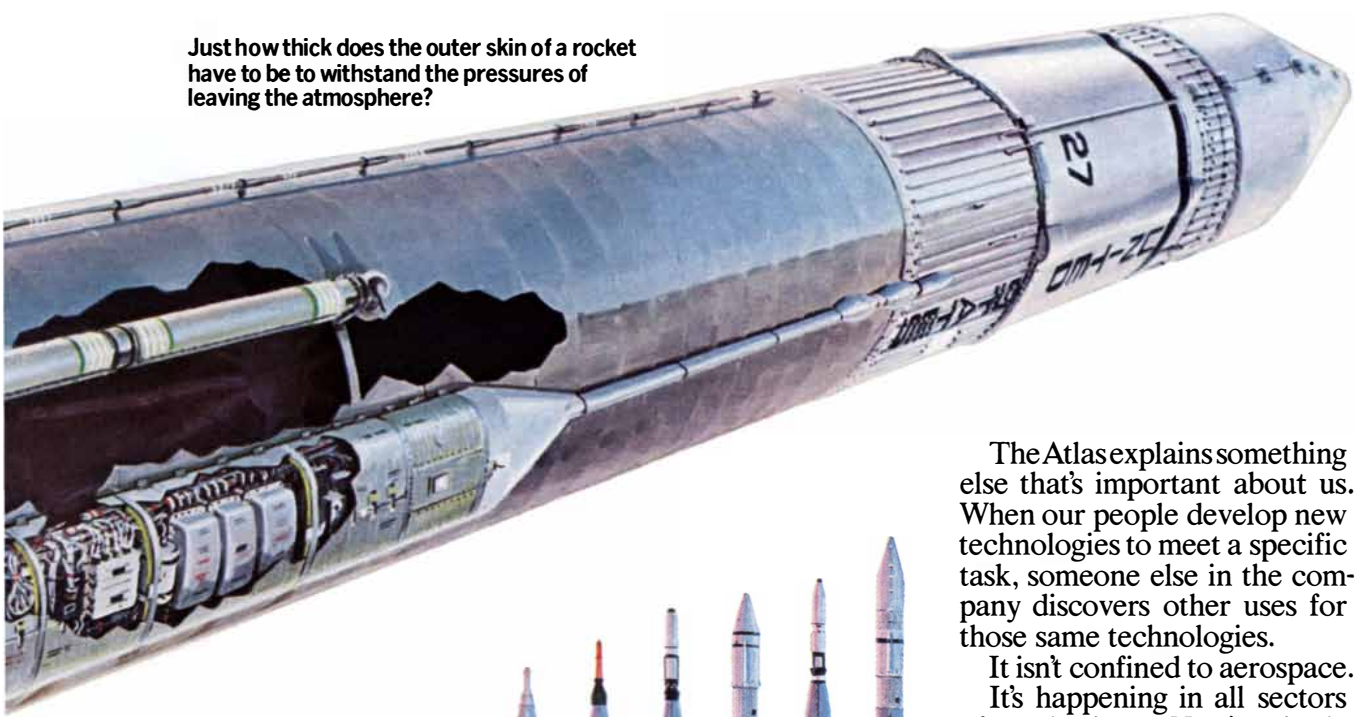
In this decade, Atlas-Centaur has been selected to send probes on their way to Venus, Mercury, Mars and Jupiter.

Recently, Atlas-Centaur boosted the first of a series of the heaviest, most complex communications satellites ever put into orbit: Intelsat IV. It can relay more than five thousand telephone conversations at once, greatly expanding world communications.

When we first began designing the Atlas, we couldn't have foreseen all its uses.

But we designed in the basic adaptability that has accounted for its varied missions through the years.

Just how thick does the outer skin of a rocket have to be to withstand the pressures of leaving the atmosphere?



Doesn't the fuel tank have to be very rigid to hold all its fuel?

The booster Atlas has been modified, upgraded, and changed through the years to handle missions ranging from ICBM to communications satellite booster.

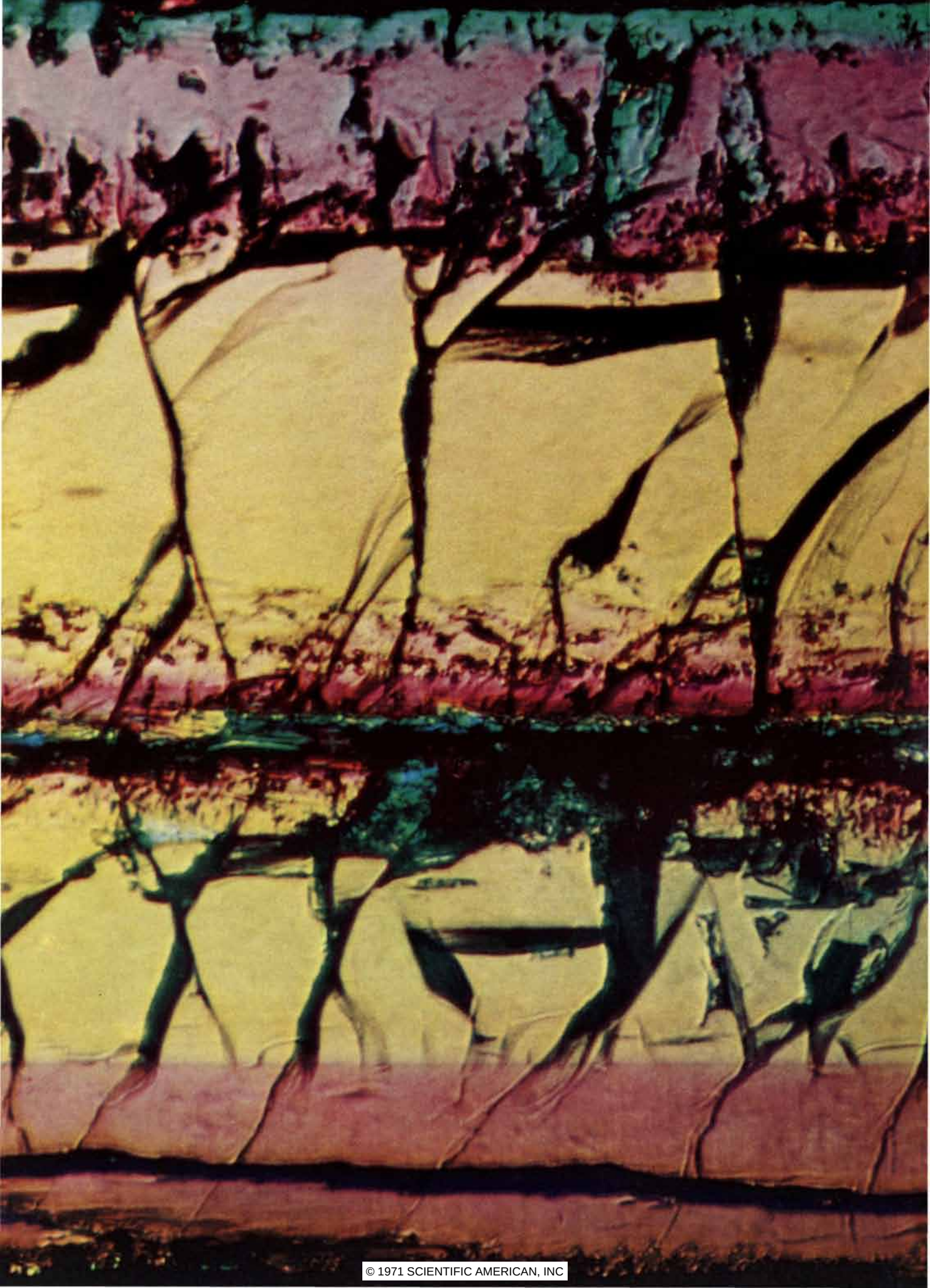
The Atlas explains something else that's important about us. When our people develop new technologies to meet a specific task, someone else in the company discovers other uses for those same technologies.

It isn't confined to aerospace.

It's happening in all sectors of our business. Not just in defense work, but in growing commercial markets: shipbuilding, telephone systems, electronics and natural resources.

It's productive technology that makes us a company that keeps making things no one ever made before.

GENERAL DYNAMICS



THE LUNAR ROCKS

Although it is too soon for an analysis of the rocks returned by *Apollo 15*, the material provided by earlier missions tells of a moon whose outer shell crystallized more than three billion years ago

by Brian Mason

The opportunity to examine rocks collected on the surface of the moon has been an intellectual challenge of the first magnitude. For geologists associated with the Apollo program, and many others besides, the sight on television of Neil A. Armstrong picking up the first lunar sample bordered on the miraculous. What had seemed a remote possibility a decade earlier had become a reality; rocks from the moon would soon be back on the earth and available for examination by all the techniques of the modern laboratory. One had reason to hope that information extracted from the lunar samples would not only illuminate the origin and evolution of the moon but also tell us much about the early history of the earth and the entire solar system.

Within the span of less than two years geologists, physicists and chemists have been able to study samples collected by three teams of lunar visitors—the astronauts of *Apollo 11*, *Apollo12* and *Apollo 14*—together with a smaller but nonetheless interesting sample of lunar soil collected automatically and returned to the earth by the U.S.S.R. spacecraft *Luna 16*. The samples collected two months ago by the astronauts of *Apollo 15* have not been analyzed as this article goes to press. Although the *Apollo 15* samples will undoubtedly yield new data and new insights, they will not alter the large body of information extracted from the earlier specimens.

On the basis of many careful and independent analyses of the first samples, weighing in aggregate more than 99 kilograms, we can begin to answer many of the questions that had been posed before man first set foot on the moon. How old are the lunar rocks? To which of the many minerals found on the earth do the lunar minerals correspond or most closely resemble? Does the moon contain entirely new kinds of minerals? Does the moon possess the same variety of elements found on the earth and in the same relative abundances? Was the moon ever molten? Did water play a role in lunar mineralogy?

We now know with reasonable confidence that the moon's composition is sufficiently different from the earth's to rule out the possibility that the two bodies were ever one. There had been other reasons, chiefly dynamical ones, for rejecting such a hypothesis, but the analysis of the lunar rocks removes virtually all doubt.

Classification

On July 21, 1969, *Eagle* lifted off from the moon with its 22-kilogram cargo of lunar rocks and soil. For those waiting to study *Apollo 11*'s treasure the following weeks passed with painful slowness. To guard against the possibility (however remote) of introducing pathogenic organisms from the moon, the lunar samples were placed in quarantine for seven weeks. During this period, however, the samples were remotely but intensively studied by a preliminary examination team. The samples were handled with gloves projecting into sealed cabinets that were either evacuated or filled with dry nitrogen gas.

Largely on the basis of visual inspection, the preliminary examination team divided the lunar material into four broad types. Type *A* consisted of dark gray rocks with mineral grains too fine to be seen with the unaided eye; they resembled the terrestrial volcanic rocks known as basalts. Type *B* rocks also resembled basalts, but they contained easily distinguishable grains, one millimeter or larger in size. Type *C* rocks were similar to terrestrial breccias, rocks composed of small rock fragments and minerals welded together in a matrix of finely pulverized material [*see illustrations on page 51*]. Type *D* material consisted of miscellaneous fines smaller than a centimeter in diameter, material sometimes called lunar soil.

When the samples collected by *Apollo 12* and *Apollo 14* were similarly classified, a number of significant differences appeared [*see top illustration on page 52*]. Whereas the *Apollo 11* site yielded approximately equal amounts of crystalline rocks and breccias, crystalline rocks far outweighed breccias in the *Apollo 12* sample and the rocks in the *Apollo 14* sample were almost entirely breccias. Although some of this variation may represent an accident of the collection procedure, there are good reasons to believe that the differences validly reflect differences among the sites themselves.

The breccias have been formed from preexisting rocks, which have been fragmented, mixed and finally welded

***APOLLO 12* PYROXENE CRYSTAL is shown on the opposite page in a photomicrograph made with polarized light. The specimen measures about two-thirds of a millimeter from top to bottom. The colors arise from zonal differences in composition and indicate that the specimen has undergone rapid nonequilibrium crystallization, a characteristic feature of many lunar minerals. The yellow core is the calcium-poor variety of pyroxene known as pigeonite; the pink and purple regions are calcium-rich augite. The green areas are hedenbergite, pyroxene that is rich in iron. The micrograph was made in the author's laboratory.**

by meteorite impact and possibly by volcanic activity. The high proportion of breccias in the *Apollo 11* collection and the still higher ratio in the *Apollo 14* collection imply that these sites had a more intensive history of impact and other processes leading to brecciation than the *Apollo 12* site did. The ages of the crystalline rocks are consistent with this interpretation. The *Apollo 12* rocks are the youngest, about 3.3 billion years, whereas the *Apollo 11* rocks have ages of about 3.7 billion years and the *Apollo 14* rocks appear to be somewhat older still. The radioactive-dating method tells us when a rock first crystallized. The oldest known terrestrial rocks are about 3.5 billion years old, so that some of the lunar rocks evidently crystallized before the earth had acquired a stable crust.

On the earth, weathering processes have created a large variety of secondary minerals from a comparatively few primary minerals found in igneous rocks. On the moon the absence of an atmosphere, and hence of weathering, has left the primary minerals virtually unchanged. Although we are still judging from samples collected in only four areas, it is reasonable to believe that the samples contain material ejected from other regions at a considerable distance as well as a small amount of material introduced by impacting meteorites. The limited variety of mineral types on the moon can also be ascribed in part to the limited range of chemical composition.

Mineralogy

Two minerals, plagioclase (a calcium sodium aluminosilicate) and pyroxene (a calcium magnesium iron silicate), constitute more than 10 percent of the crystalline material in the lunar samples collected so far [*see bottom illustration on page 52*]. Five other minerals make up between 1 and 10 percent of the samples: olivine, ilmenite (a titanium iron oxide), pyroxferroite and two forms of silica, cristobalite and tridymite. A number of other minerals, including metallic iron, are found in concentrations below 1 percent. Eight of these "accessory" minerals are the most important: four contain iron (troilite, chromite, ulvospinel and armalcolite), two are calcium phosphates (apatite and whitlockite), one is the potassium aluminum silicate, potash feldspar; the last is quartz, another form of silica.

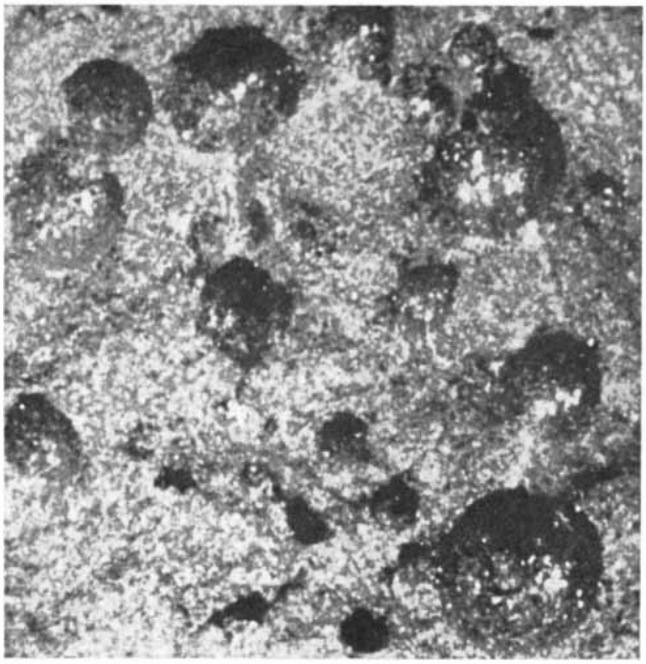
Two of these minerals are new to mineralogy. One, pyroxferroite, is closely related in composition and structure to the pyroxene family of basaltic minerals. The other is armalcolite, an iron magnesium titanate, found in rocks brought back by the *Apollo 11* astronauts, Armstrong, Edwin E. Aldrin, Jr., and Michael Collins, and named in their honor.

The mineralogy of the lunar rocks is similar to that of terrestrial basalts, but with important differences. The principal minerals in both are plagioclase and pyroxene. The plagioclase in the moon rocks, however, is almost pure anorthite ($CaAl_2Si_2O_8$), whereas the plagioclase in terrestrial basalts is usually an intermediate solid solution consisting of anorthite and albite ($NaAlSi_3O_8$). Also the *Apollo 11* rocks are some 10 times richer in ilmenite than terrestrial basalts are; the *Apollo 12* rocks are about three times richer.

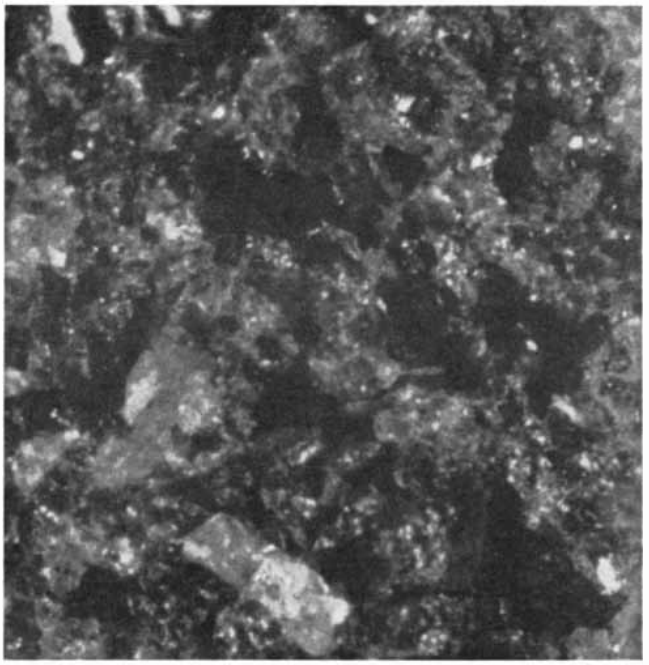
So far the moon has turned out to be a disappointing locale for the mineral collector interested in fine display specimens. In most of the rocks the individual mineral crystals are microscopic in size and rarely well formed. A few of the rocks contain small cavities lined with microscopic but attractive crystals. Many of the lunar minerals show clearly defined zones where the mineral composition changes sharply; this is evidence of rapid crystallization under nonequilibrium conditions. In one interesting example [*see illustration on page 48*] the crystal has a core of calcium-poor pyroxene (pigeonite), a mantle of calcium-rich pyroxene (augite) and a thin outer zone of iron-rich pyroxene (hedenbergite).

The rocks from the first three Apollo missions and the sample obtained in October, 1970, by *Luna 16* in Mare Fecunditatis are compared in average chemical composition with a typical terrestrial basalt in the table on page 56. The close similarity between the analyses of samples returned by *Apollo 12* and *Luna 16* are noteworthy, particularly when one considers that the sampling sites were separated by more than 2,000 kilometers (about one-third the

LANDING SITES of *Apollo*'s *11*, *12* and *Luna 16*, the robot sampler sent to the moon by the U.S.S.R., were all close to the lunar equator, in regions described as maria, or "seas." Actually such regions appear to have been excavated by the impact of large meteoroids and subsequently filled by lava, perhaps several times in thin layers. *Apollo 14* landed on a ridge of the Fra Mauro formation. The samples returned by *Apollo 15*, which landed this past summer at the base of the Apennine Mountains in the lunar highlands, have not yet been analyzed.



TYPE *A* LUNAR BASALT, a dark gray rock, has a fine, even grain size; it is frequently pitted by spherical vesicles with glassy linings. As reproduced here the sample is enlarged about six times.



TYPE *B* LUNAR BASALT has grains easily visible to the unaided eye. The whitish material is plagioclase; darker regions are pyroxene and ilmenite. The specimen is enlarged about 12 times.

TYPE *C* LUNAR BRECCIA consists of rock fragments of various sizes welded together in a fine-grained matrix. This rock is one of only four breccias in the *Apollo 12* collection; it is enlarged here about five times. *Apollo 14* samples are virtually nearly all breccias.

MINERAL TYPE	APOLLO 11		APOLLO 12		APOLLO 14	
	NUMBER	WEIGHT (KG.)	NUMBER	WEIGHT (KG.)	NUMBER	WEIGHT (KG.)
A (FINE-GRAINED)	8	3.37	26	16.34	9	3.83
B (MEDIUM-GRAINED)	8	1.49	16	10.31		
C (MICROBRECCIAS)	20	4.73	4	1.01	88	24.70
D (FINES)	—	11.90	—	7.44	—	13.56

CLASSIFICATION OF APOLLO SAMPLES shows the characteristics of 36 rocks collected at the *Apollo 11* site, 46 at the *Apollo 12* site and 97 at the *Apollo 14* site. In addition to these 179 rocks the three Apollo teams brought back 32.9 kilograms of lunar fines, or soil.

MAJOR MINERALS	
(MORE THAN 10 PERCENT BY WEIGHT)	
PLAGIOCLASE	$(Ca,Na)(Al,Si)_4O_8$
PYROXENE	$(Ca,Mg,Fe)_2Si_2O_6$
MINOR	
(1 to 10 PERCENT BY WEIGHT)	
OLIVINE	$(Mg,Fe)_2SiO_4$
ILMENITE	$FeTiO_3$
CRISTOBALITE	SiO_2
TRIDYMITE	SiO_2
PYROXFERROITE	$CaFe_6(SiO_3)_7$
ACCESSORY	
(LESS THAN 1 PERCENT BY WEIGHT)	
NICKEL-IRON	(Fe,Ni)
TROILITE	FeS
ARMALCOLITE	$(Fe,Mg)Ti_2O_5$
CHROMITE	$FeCr_2O_4$
ULVOSPINEL	Fe_2TiO_4
APATITE	$Ca_5(PO_4)_3(F,Cl)$
WHITLOCKITE	$Ca_9MgH(PO_4)_7$
POTASH FELDSPAR	$(K,Na)AlSi_3O_8$
QUARTZ	SiO_2

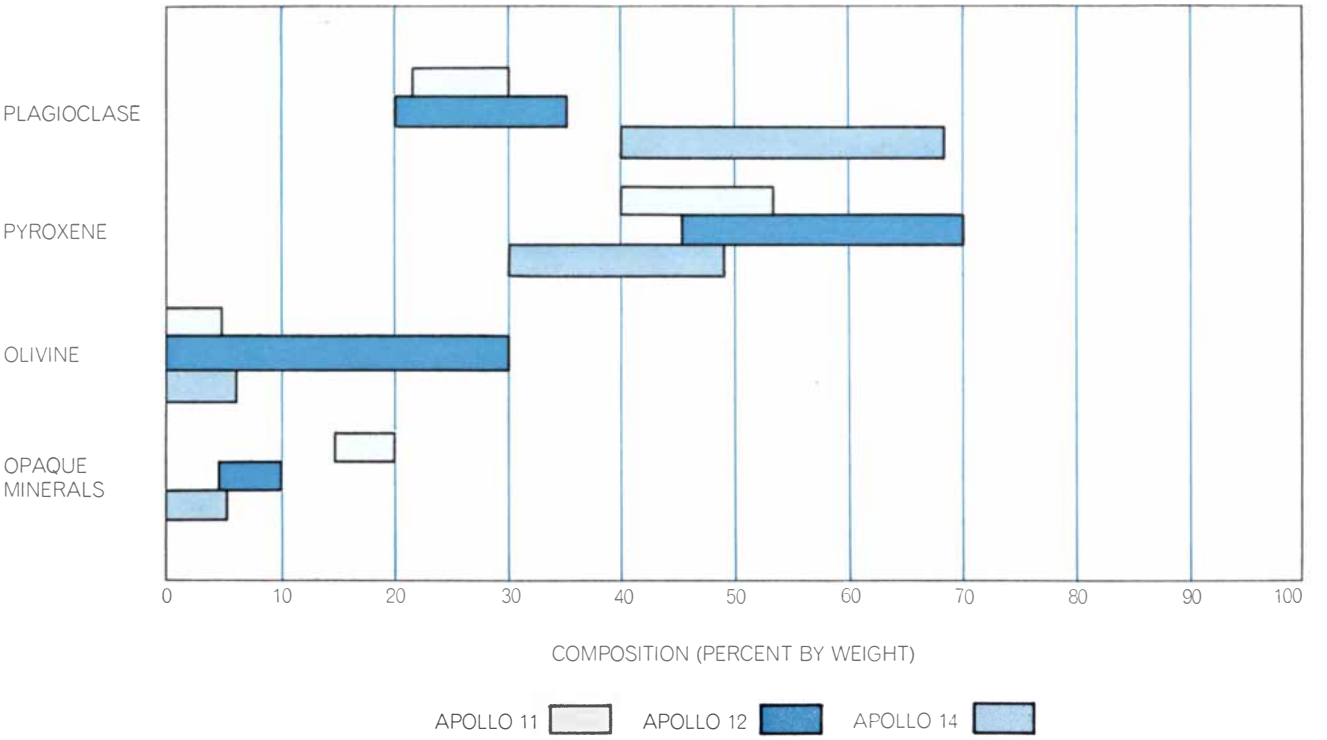
MINERALS IN LUNAR ROCKS consist predominantly of plagioclase and pyroxene, two minerals common in terrestrial volcanic rock. Compared with the great variety of minerals known on the earth, the variety seen in lunar samples is extremely limited. Two minerals, however, are new: armalcolite, named for the *Apollo 11* astronauts, and pyroxferroite.

moon's circumference). The *Apollo 11* material differs from these two samples mainly in having more titanium (measured as TiO_2) and less silica. *Apollo 11*, *Apollo 12* and *Luna 16* all landed in mares, the dark regions that resemble seas. *Apollo 14* landed on the Fra Mauro formation, believed to be a blanket of ejecta thrown out by the giant meteorite or planetesimal that excavated the basin of Mare Imbrium. The largest such structure on the moon, Mare Imbrium is about 1,300 kilometers in diameter. The great preponderance of breccias in the *Apollo 14* collection supports the hypothesis that the Fra Mauro formation consists largely of debris from a gigantic collision. The chemical composition of material collected by *Apollo 14* is also clearly different from the composition of rocks collected on earlier missions. The *Apollo 14* material is higher in alumina (Al_2O_3) and lower in iron oxide (FeO); it is still, however, broadly basaltic in composition.

The lunar rocks consistently contain more titanium and chromium and less sodium than terrestrial basalts. All except the *Apollo 14* breccias are also much richer in iron. To speak only of the average chemical composition of the lunar samples can be misleading, however. Although the range of composition of the *Apollo 11* rocks is rather limited, two chemically distinct groups can be distinguished. One group, essentially the Type *A* rocks, is relatively rich in potassium, rubidium, barium and rare-earth elements; Type *B* rocks are less rich in these elements. The *Apollo 12* rocks show a much wider range in chemical composition, particularly in major elements such as magnesium, calcium and titanium. The higher magnesium content shows up as a greater abundance of pyroxene and olivine [*see illustration on opposite page*]. The *Apollo 14* rocks are clearly distinguished from the *Apollo 11* and *Apollo 12* rocks by their greater content of plagioclase and lesser content of the other major minerals.

Texture

Much significant information can be derived from the texture of the lunar rocks. The sharpest division, of course, is between the crystalline rocks and the breccias. Within the crystalline rocks one can distinguish three major textures, broadly classifiable as porphyritic, ophitic and granular. Porphyritic rocks have large crystals (phenocrysts) of one mineral or more in a fine-grained matrix. Many of the *Apollo 12* rocks show phenocrysts of olivine in a ground mass



RANGE OF MAJOR MINERALS in the Apollo collections shows considerable overlap. The widest range is found in the *Apollo 12* rocks. The *Apollo 14* samples are notably enriched in plagioclase. "Opaque" minerals include ilmenite, which is rich in titanium.

that is glassy or microcrystalline [*see first of four micrographs on next two pages*]. Sometimes the phenocrysts are of pyroxene. The interpretation of this texture is that olivine was the first mineral to crystallize from the magma, or molten rock, and that the crystallization took place rather slowly, enabling large crystals to grow. At some point the magma was rapidly chilled, so that the remaining liquid solidified as a glass or as a microcrystalline matrix. Presumably the molten rock originated at some depth in the moon, cooled slowly with the crystallization of olivine and then was extruded as a lava flow on the surface, with consequent rapid chilling and solidification. This sequence of events has been duplicated in the laboratory with synthetic melts having the composition of the lunar basalts. In such experiments olivine begins to crystallize at between 1,200 and 1,300 degrees Celsius and continues to crystallize as the temperature drops, until at about 1,175 degrees C. pyroxene appears, followed shortly thereafter by plagioclase.

The ophitic texture is one in which lathlike crystals of plagioclase are enclosed by irregularly bounded grains of pyroxene, probably indicating that these two minerals crystallized simultaneously over a considerable range of temperature [*see second of four micrographs on next two pages*]. The texture described as granular is one in which the different minerals are essentially similar in grain size and in which there is no clear sequence of crystallization [*see third of four micrographs on next two pages*]. The granular texture probably indicates rapid crystallization when lava poured out on the lunar surface and quickly solidified. Synthetic melts of lunar composition can replicate the texture seen in the granular moon rocks; pyroxene, ilmenite and plagioclase crystallize together over a narrow temperature range: 1,150 to 1,100 degrees C.

The observation of textures of lunar rocks, together with laboratory melts of similar composition, thus show that lunar rocks crystallized from the molten state on cooling from about 1,300 degrees C. to 1,050 degrees. This temperature range is comparable to that for terrestrial basalts under low pressure in the absence of water. Judging from the experience with synthetic melts, the lunar lavas had a very low viscosity, being some 10 times more fluid than terrestrial basalt lavas. As a result the lunar lavas would have spread rapidly and cooled quickly, forming thin sheets rather than the cone-shaped mountains we associate with terrestrial volcanoes.

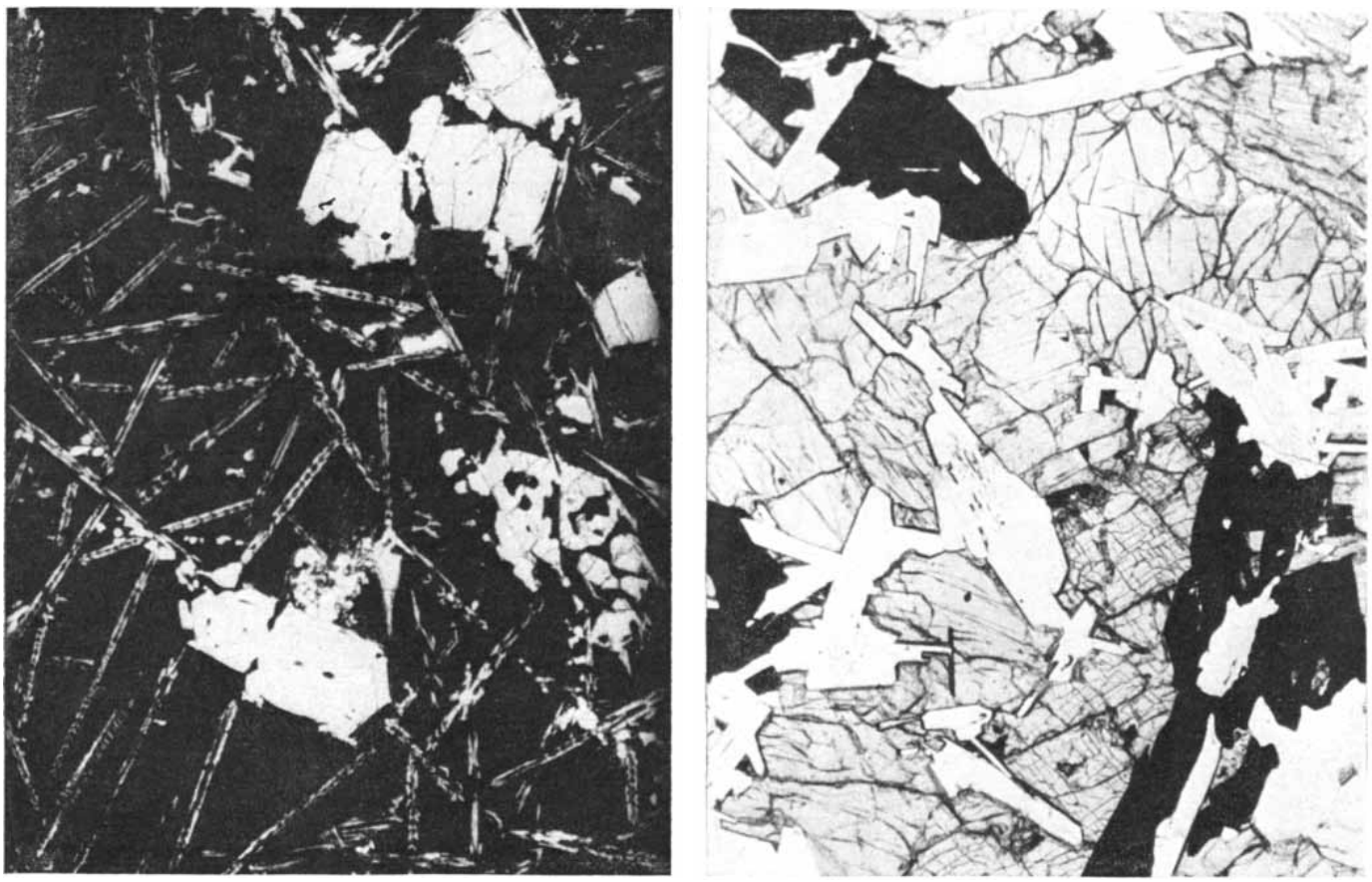
The preliminary examinations of the *Apollo 11* material indicated that the breccias and fines differed in composition from the crystalline rocks. Specifically, they are richer in calcium and aluminum, indicating a higher content of plagioclase than the crystalline rocks [see "The Lunar Soil," by John A. Wood; SCIENTIFIC AMERICAN, August, 1970]. It is now evident that the breccias and fines at the Apollo sites are not simply crushed local rocks but contain an admixture of foreign materials. A small fraction (1 or 2 percent) is an extralunar component of meteoritic or cometary origin, most readily identified by a relatively high content of nickel and platinum-group elements, which are found only in low concentrations in the crystalline rocks. The *Apollo 12* fines also show some enrichment in calcium and aluminum, but they are mainly distinguished by an additional component known by its acronym as KREEP, signifying material enriched in potassium (K), rare-earth elements (REE) and phosphate (P).

One of the few breccias collected on the *Apollo 12* mission (12013, that is, rock No. 13 of the *Apollo 12* collection) shows a remarkable enrichment in the KREEP component. An extremely complex rock, it has been intensively studied by several teams of investigators. The rock has three principal components: dark breccia, light breccia and white felsitic material [*see last of four micrographs on next two pages*]. The last component is particularly interest-

ing because its composition closely resembles that of terrestrial granitic rocks. It consists largely of potassium-rich feldspar and quartz. Small fragments of this composition have also been found in the *Apollo 12* fines by our group at the Smithsonian Institution, among others. Terrestrial rocks of granitic composition appear to be the product of lengthy and complex differentiation processes that concentrate silica, the alkalis and alumina; such rocks are largely confined to continental areas. Radioactive dating indicates that the 12013 breccia was formed four billion years ago, making it much older than the other *Apollo 12* basaltic rocks. The felsitic fraction is even older; it may date back 4.6 billion years, which would place it very early in the moon's history. The significance of these exotic fragments in the lunar breccias and fines is that extensive chemical differentiation appears to have taken place within the first few hundred million years of the moon's existence. The differentiation evidently resembled processes that took place in the early history of the earth. If so, the moon may have early developed a feldspathic crust, which is possibly preserved, in part at least, in the highland areas of the moon. The *Apollo 15* samples may tell us if this conjecture is correct.

Much has been made of the similarity between terrestrial basalts and the lunar crystalline rocks; as a result the latter are frequently called basalts. As I have pointed out above, however, significant differences do exist between the lunar rocks and their terrestrial counterparts. The differences are easily seen if one plots (on a logarithmic scale) the abundances of elements in the *Apollo 11* rocks against abundances in a terrestrial basalt [*see illustration on page 57*]. Elements falling on the diagonal line are equally abundant in the lunar and the terrestrial rocks. Elements falling above the line are more plentiful in the lunar rocks; elements falling below the line are less plentiful. The distance of a point from the diagonal line is a measure of the relative enrichment or depletion. Thus titanium and chromium are about 10 times more abundant in the *Apollo 11* rocks than in the terrestrial basalt. A similar enrichment is characteristic of zirconium, hafnium, yttrium, cerium and the other rare-earth elements. The major elements—iron, silicon, calcium, magnesium and aluminum—are found in about equal abundance in terrestrial basalt and in lunar rocks. Sodium, potassium and the other alkali elements (except lithium) are significantly lower in the lunar rocks, as is chlorine (but not fluorine). Nickel (along with gold and the platinum metals, which are not shown in the diagram because of their extremely low abundances) is notably depleted in comparison with terrestrial basalts. The inference is that although the lunar crystalline rocks and terrestrial basalts show close similarities in their mineralogy and probably had analogous histories, the initial compositions of the parent magmas were notably different. The lunar magmas appear to have been relatively enriched in refractory elements such as titanium, chromium, zirconium and the rare earths, and impoverished in volatile elements such as the alkali metals and chlorine, and in noble metals such as nickel, platinum and gold.

There has long been speculation that some fraction of the meteorites reaching



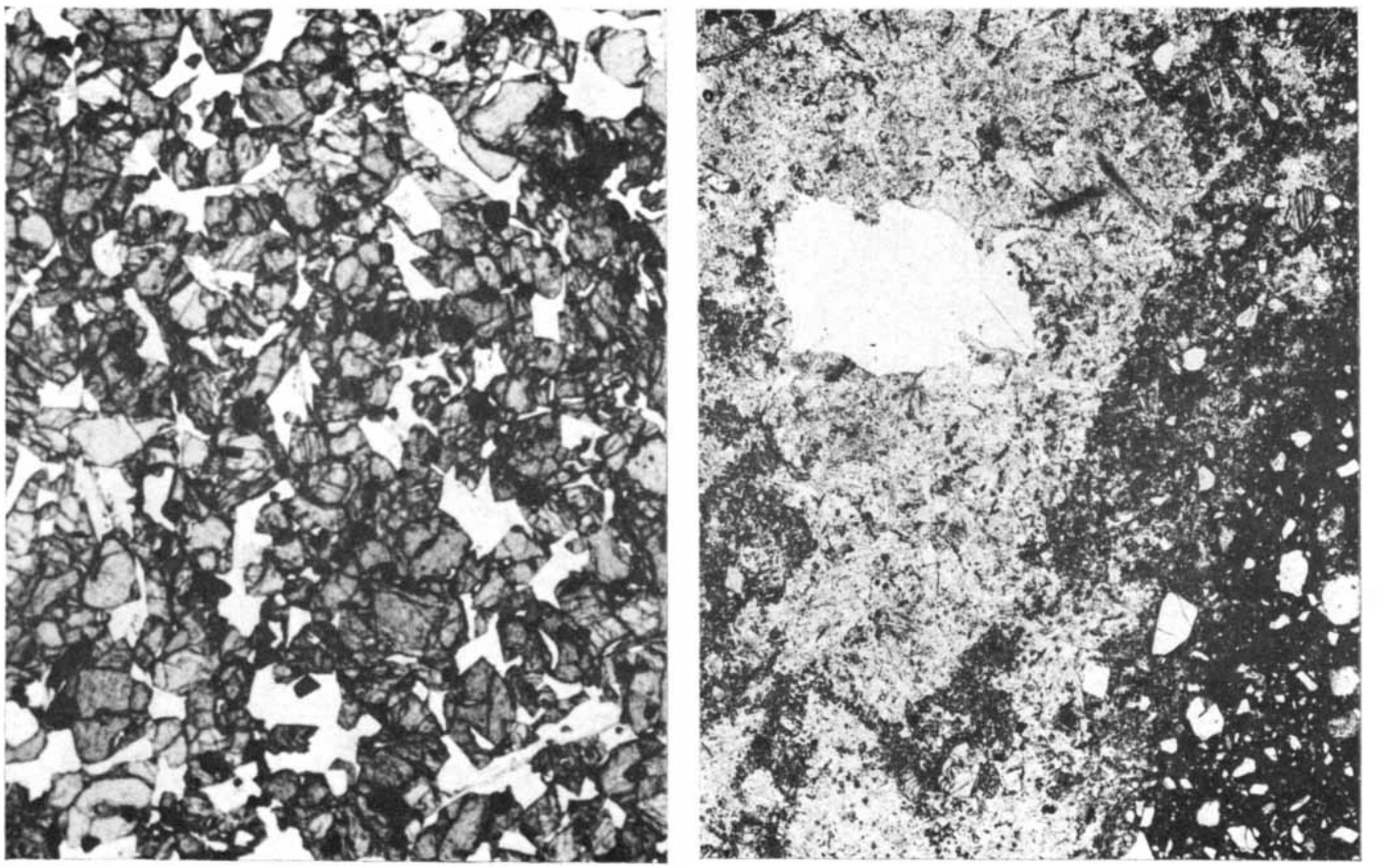
THREE LUNAR BASALTS AND ONE BRECCIA are represented in these four photomicrographs. The sample at the far left is a porphyritic basalt found at the *Apollo 12* site. The large white crystals are olivine, a magnesium iron silicate. Large crystals are evidence of slow, undisturbed growth. Subsequent rapid chilling produced the black glassy matrix; the needle-like crystals are skeletal pyroxene. The second specimen from the left, obtained at the *Apollo 11* site, contains lathlike crystals of plagioclase (*white*) enclosed

the earth may have originated on the moon. The mean density of the moon (3.34 grams per cubic centimeter) would seem to eliminate iron meteorites, but most stony meteorites are compatible with this density; moreover, stony meteorites are much commoner than iron meteorites among observed falls. As the curator of a large meteorite collection, I have been intrigued by the thought that among these specimens I unknowingly possessed lunar samples. However, even the limited data so far available on lunar compositions rule out an origin on the moon for the commonest types of stony meteorites, the chondrites. One small group (some 25 in all) of stony meteorites, the eucrites, does show chemical and mineralogical analogies with some of the lunar crystalline rocks. The analogies are not complete, however. The lunar rocks are still significantly higher in titanium and in many of the refractory minor and trace elements than their meteorite analogues. It seems probable that the eucrites were formed on an extraterrestrial body (probably an asteroid) that has had a history of melting and crystallization similar to that experienced by the moon.

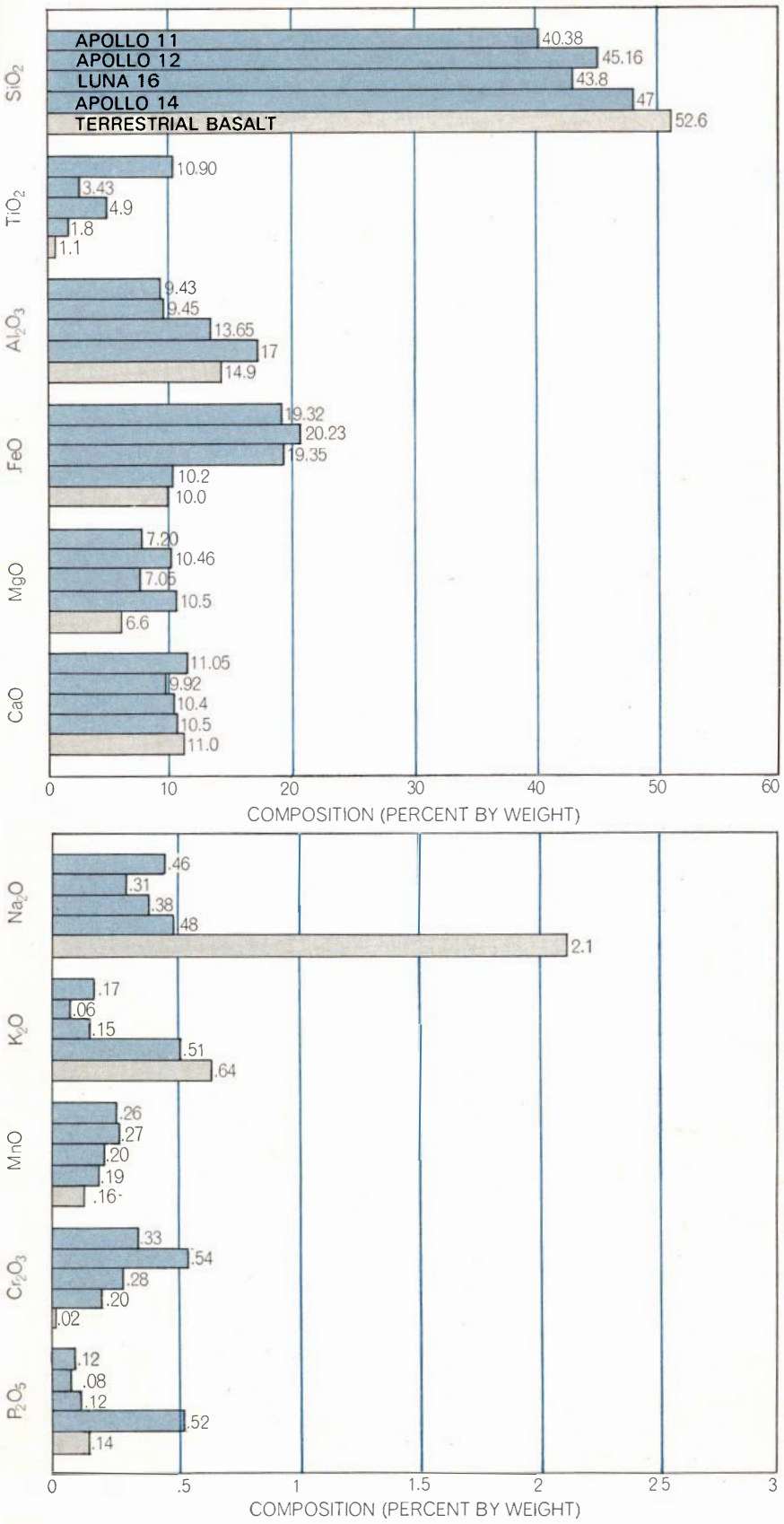
An enigmatic material for which a lunar origin has been ascribed is represented by the tektites. They are small glassy objects found in limited areas in a few regions of the earth's surface under conditions that preclude a volcanic origin. The largest tektite area is in Australia; these objects are found over the entire southern half of the continent and on the adjoining island of Tasmania. Well-preserved Australian tektites show clear evidence of aerodynamic shaping. Most of them have lenslike shapes, sometimes with an equatorial flange, that have evidently been produced by the heating and ablation of glass spheroids that traveled through the atmosphere at high velocity. Tektites consist of a glass with a composition of between 65 and 80 percent silica and are thus quite different in composition from meteorites. They superficially resemble obsidian from recent volcanoes but are distinct from terrestrial obsidian in composition and structure. Tektites have never been seen to fall, so that their identification as meteorites has always been ambiguous. In addition they do not show the effects of cosmic ray bombardment observed in meteorites. This implies that tektites could not have spent much time in extraterrestrial flight, which leaves a lunar or a terrestrial origin as the only possibility. Most of the lunar rocks, however, are far removed from the tektites in composition. Moreover, the ratios of various isotopes of oxygen, silicon and lead in the lunar rocks are unlike the ratios found in tektites. Therefore a lunar origin for tektites seems impossible.

Significance of the Findings

What is the significance of the information extracted from the lunar rocks so far? The mineralogical and chemical similarities between the rocks of the Apollo missions and *Luna 16* indicate a considerable degree of uniformity in composition and in geological development over large regions of the moon's crust. The three mare sites visited by *Apollo 11*, *Apollo 12* and *Luna 16* show a terrain made up essentially of lava flows that have been extensively fragmented by meteorite impacts over a long



in pyroxene (*gray*); ilmenite (*black*) is also present. The plagioclase and pyroxene evidently crystallized more or less simultaneously over a considerable temperature interval. The third specimen from the left, a basalt sample from the *Apollo 12* site, has three kinds of crystal all roughly the same size: plagioclase (*white*), pyroxene (*gray*) and some ilmenite (*black*). The texture suggests the quick cooling of a molten lava. The last specimen in the series is an *Apollo 12* breccia containing veins of potash feldspar and quartz.



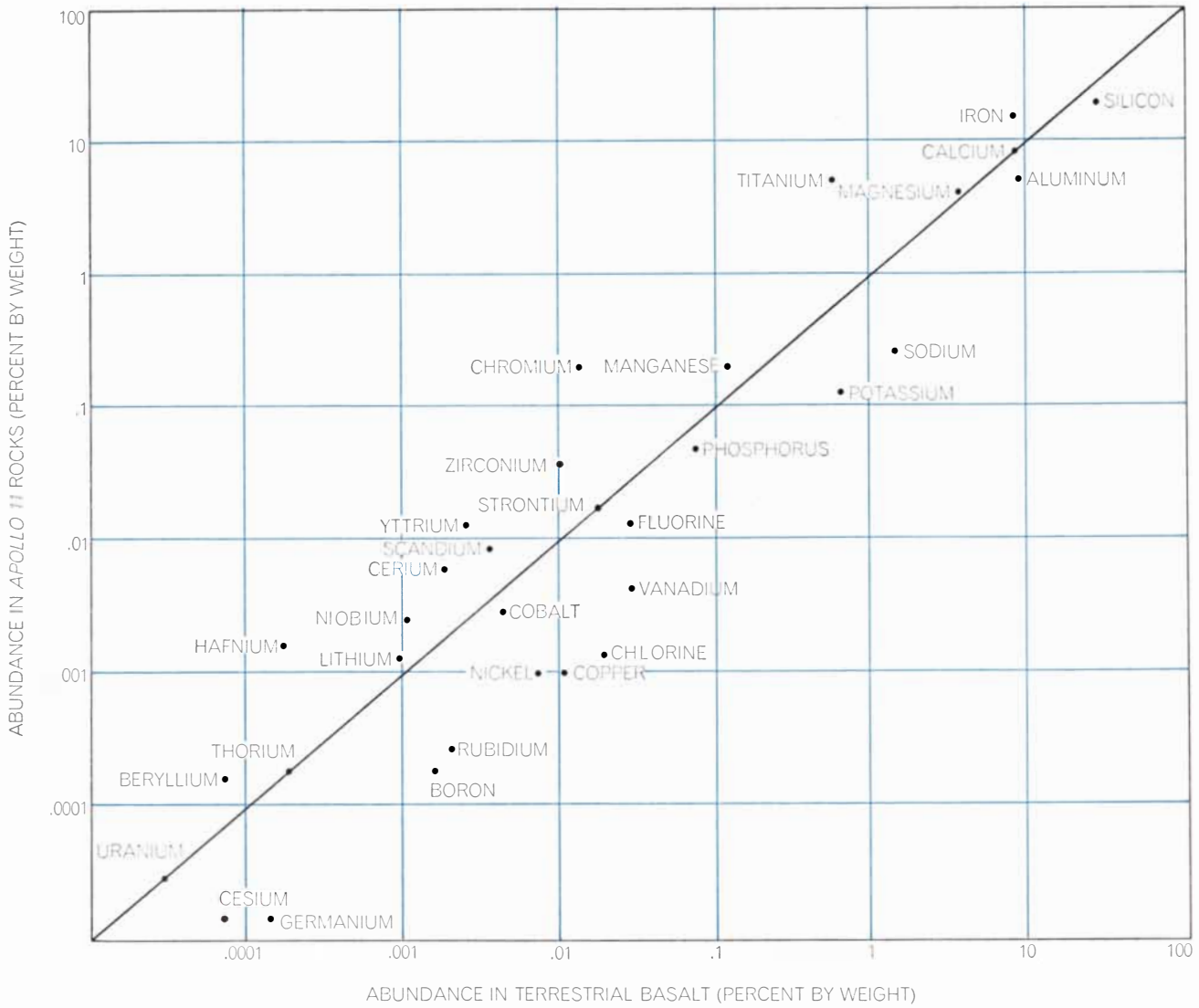
COMPARISON OF FOUR LUNAR SAMPLES shows considerable similarity, particularly the material returned by *Apollo 12* and *Luna 16*, collected at sites more than 2,000 kilometers apart. *Luna 16* landed in the Sea of Fertility in October, 1970. The composition of a typical terrestrial basalt is given in the last column. The *Apollo 11* sample is notable for its high content of titanium (shown as TiO_2) and relatively low content of silica (SiO_2). All the lunar samples contain less sodium and more chromium than terrestrial basalt does.

period of time. *Apollo 14* landed on a different terrain, believed to be part of the blanket of ejecta from the excavation of the basin of Mare Imbrium, and the nature of the rocks collected supports this interpretation. Although they are mineralogically similar to the rocks from the preceding missions, they are extremely brecciated and show a markedly higher proportion of plagioclase to pyroxene. Their composition suggests that they may represent the primary crust that once formed the surface of the Imbrium region and may have extended over a large part of the moon. The brecciation is the result of a catastrophic event, probably the impact of an asteroid-sized object, that blasted out the Imbrium basin.

The Imbrium basin and the other mare basins have evidently been filled by lavas of the basaltic type. Dating by radioactive isotopes shows that the rocks at the different sites have somewhat different ages, indicating that formation of mare basins and their subsequent filling by lavas may have extended over a considerable period of the moon's history. All the rocks, however, are very old. The youngest are those collected during the *Apollo 12* mission, which range in age from 3.1 to 3.3 billion years. This suggests that most of the moon's geological evolution was completed within the first 1.5 billion years of its existence, that volcanic activity may have ended about three billion years ago and that since then the moon has been a passive object modified only by external influences such as the solar wind and meteorite bombardment. This is in marked contrast to the earth, which first developed a stable crust about 3.5 billion years ago and has continued to be geologically active.

Volcanism on the Moon

What can one deduce about the interior of the moon from the nature of the surface rocks? One of the many interesting features of the *Apollo 11* and *Apollo 12* rocks is that their average density, which is about 3.3, is close to that of the mean density of the moon, which is 3.34. It would be quite wrong, however, to conclude that these rocks represent the bulk composition of the moon. Their composition, in particular their relatively high alumina content, ensures that if they were subjected to only moderate pressures, such as those that exist only a few hundred kilometers below the surface of the moon, they would be transformed from pyroxene-



DIFFERENTIAL PLOT allows a quick visual comparison of the difference in composition between *Apollo 11* rocks and terrestrial basalt. The abundances of the elements are plotted logarithmically; the diagonal line denotes equal abundances. Points above the line represent elements that are more abundant in lunar rocks; points below the line are elements more abundant in terrestrial rocks. The farther a point lies from the diagonal line, the greater the disparity is in the amount of that element in the two kinds of rock.

plagioclase rocks into pyroxene-garnet rocks. Garnet, which has the approximate composition $(Ca,Mg,Fe)_3Al_2Si_3O_{12}$, is a mineral of relatively high density. A pyroxene-garnet rock would have a density of 3.6 or 3.7, a value much too high to be compatible with the overall density of the moon.

One must therefore conclude that the surface rocks cannot possibly represent the bulk composition of the moon; they must be the products of complex chemical fractionations from the underlying material. This is not at all unexpected. Terrestrial volcanic rocks are known to be derived from an underlying mantle of quite different composition, by processes such as partial melting and fractional crystallization. Indeed, our knowledge of terrestrial magmatic processes has been directly applicable to the interpretation of the lunar rocks, even though the bulk composition of the moon differs from that of the earth in significant ways.

The Apollo missions have already resolved one of the major controversies that divided scholars for many years: the role of volcanism in lunar history. It is now clear that over a considerable part of the moon's lifetime volcanism played an important role, at least in the moon's outer parts. This leads to a wider question. How deep did this igneous activity extend? Was the moon once completely molten, or has the igneous activity been limited to an outer zone measured in a few tens or a few hundreds of kilometers? It may be difficult to conceive of a planetary body whose outer shell is hotter than its central regions, but several mechanisms for achieving such an apparent inversion of temperature are conceivable. For example, during the final stages of the moon's accretion from primordial material its steadily increasing mass would increase the impact velocity of infalling objects. If the bombardment were intense enough, the surface of the moon could have become very hot. One can also imagine that the outer region of the moon incorporated a higher concentration of heat-producing radioactive isotopes than the core region. Another possibility is that the outer part of the moon may have been intensely heated by heightened activity of the sun early in its history.

The rather uniform density of the

moon and the apparent absence of an earthlike core of an iron-nickel alloy strongly imply that the moon was never completely molten. If it had been, the heaviest material would have settled in the center, forming a dense core and leaving the lighter material as the mantle. On the other hand, the variety observed in the lunar crystalline rocks indicates extensive chemical fractionation, probably involving a large volume of lunar material. The evidence suggests that the moon was once molten to a depth of a few hundred kilometers. Subsequent cooling, fractional crystallization and gravitational separation of the resulting minerals could account for many of the features of lunar crystalline rocks. If the density of the melt were about 3, plagioclase (which has a density of about 2.75) would tend to float and the other common minerals (olivine, pyroxene and ilmenite) would tend to sink. This would produce a plagioclase-rich crust floating on a denser substratum. This primordial crust may still exist as the lunar highlands, which was an important reason for sending *Apollo 15* to the base of the Apennine Mountains. The original crust may be represented in the *Apollo 11* and *Apollo 12* collections as the small fragments of plagioclase-rich rocks in the fines and breccias. It may also be represented by plagioclase-rich rocks collected by the *Apollo 14* astronauts.

It is clearly premature to propound a comprehensive theory for the origin and evolution of the moon at this stage in space exploration. Nevertheless, the examination of the lunar materials so far collected has established a number of significant and fundamental facts. We now know that the rocks are igneous in origin, and that some of them have been strongly modified by meteorite impact, which has been the main agent in generating the breccias and fines. The lunar surface lacks water and organic matter. The maria are not, as some have thought, basins flooded by sediments of ancient seas, nor are they filled with dust eroded from the highlands. They are flooded with lavas similar to terrestrial basalts, probably in the form of a large number of thin flows. This seems to be confirmed by the direct observation of strata in certain areas near the *Apollo 15* landing site. Igneous differentiation (by melting, fractional crystallization, gravitational separation and possibly liquid immiscibility) has taken place. The rocks are all very old; many are older than any terrestrial rocks and some may be as old as any in the solar system.

When I say Chrysler gives every Imperial a road test, I don't mean they just drive it around the block.

They give it a road test.

I've seen the way Chrysler builds cars; they really care about their product. And when it comes to the Imperial, they don't stop with just building it. They run it through a road test that gives it over 100 different checks. From the windshield wipers to the transmission.

If it's not right, they don't want you to have it. That's nice to know when you spend that kind of money for a new car.

Look inside an Imperial. Examine some of the things they check during the road test. The way the seats work. The fit of the glove box door. The operation of the windows.

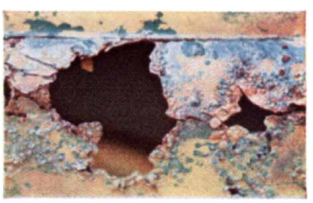
Then, feel the carpeting and the upholstery. Sit behind the wheel and look around you. I think the things you can see will tell you something about the way this car's put together.

If everybody would do as much as the automobile industry is doing to clean up our environment, we'd be well on the way to solving many of our problems.

Chrysler has already done a lot to cut down pollution.

And now they've developed a new electronic ignition system that does away with the points and condenser that can wear out. You can order it on every Chrysler.

It helps keep the engine tuned longer. And a tuned engine means a cleaner exhaust.



You're washing your car, you poke at a little spot and a chunk of rust falls off. Ever have that happen to you?

Well, the Chrysler people have been doing something to help keep that from happening. They dip their car bodies in special solutions to help prevent corrosion.

CHRYSLER
Plymouth

Coming through with the kind of car America wants.

That's their slogan this year. And I think that's the kind of car they're building. One that lasts longer and works better than anything they've ever built before.

I drive an Imperial. What else? It's big and beautiful and plush . . . and my snooty friends love to sit back in it.

But the important thing to me is the way Chrysler puts these cars together. They want this car to last. And I think that's the kind of car America wants.

The little oblong box and the emphysema crisis.

The little oblong box is called the Spirostat®. In full, "Spirostat photometric recording spirometer." And it represents a possible major breakthrough in solving one of medicine's most insidious problems.

Pulmonary disease is the fastest-growing killer of men. And as a disabler, it is already second only to heart disease.

Exact causes are still undetermined. Even definitions overlap.

But this much is known. The disease commonly called emphysema is irreversible. There is no cure.

However, there are warning indications before the irreversible stage is reached. And if they are discovered early enough, effective medical treatment is possible.

The best method of early detection is pulmonary function testing, measuring exhalation in both volume and time, with an instrument called a spirometer.

Unfortunately, until now most spirometers have been heavy, bulky, expensive and time-consuming to operate. And all present the danger of cross contamination.

As a result, they have been used far too infrequently. And often too late.

Fortunately, there is now hope for a dramatic change.

The Spirostat recorder is a new and revolutionary instrument for lung function testing. It was developed by Fibre-Optics Industries, Inc., whose medical advisors say:

"The Spirostat recorder gives an accurate tracing, in the form of a time-volume graph recorded on Polaroid Land film, in seconds.

"It weighs less than five pounds and is small enough to fit into a doctor's bag. So tests can be performed anywhere.

"The mouthpiece is a highly sensitive flowmeter. But it is completely disposable, thus eliminating the danger of cross contamination.

"It is so portable, so safe and easy to use, that it could well become a routine part of any thorough physical examination."

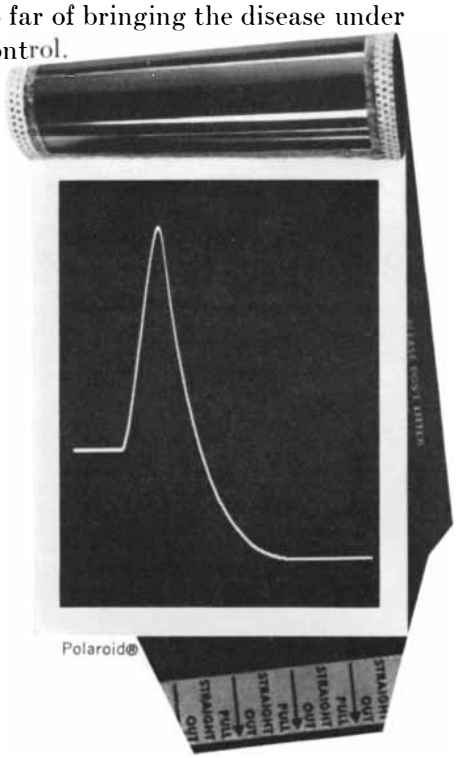
The Spirostat recorder's level of miniaturization and accuracy was achieved by a remarkable combination of electronics, computerization, light-transmitting fibre optics and instant photography.

To achieve the goal of making the information visual, permanent and immediately available, the originators made a Polaroid Land camera back an integral part of the design.

The Spirostat recorder offers no cures. Smoking and air pollution, which show a clear statistical relationship to emphysema, will still be ominous dangers.

But now there is the possibility that early detection will become routine.

And it presents the greatest hope so far of bringing the disease under control.

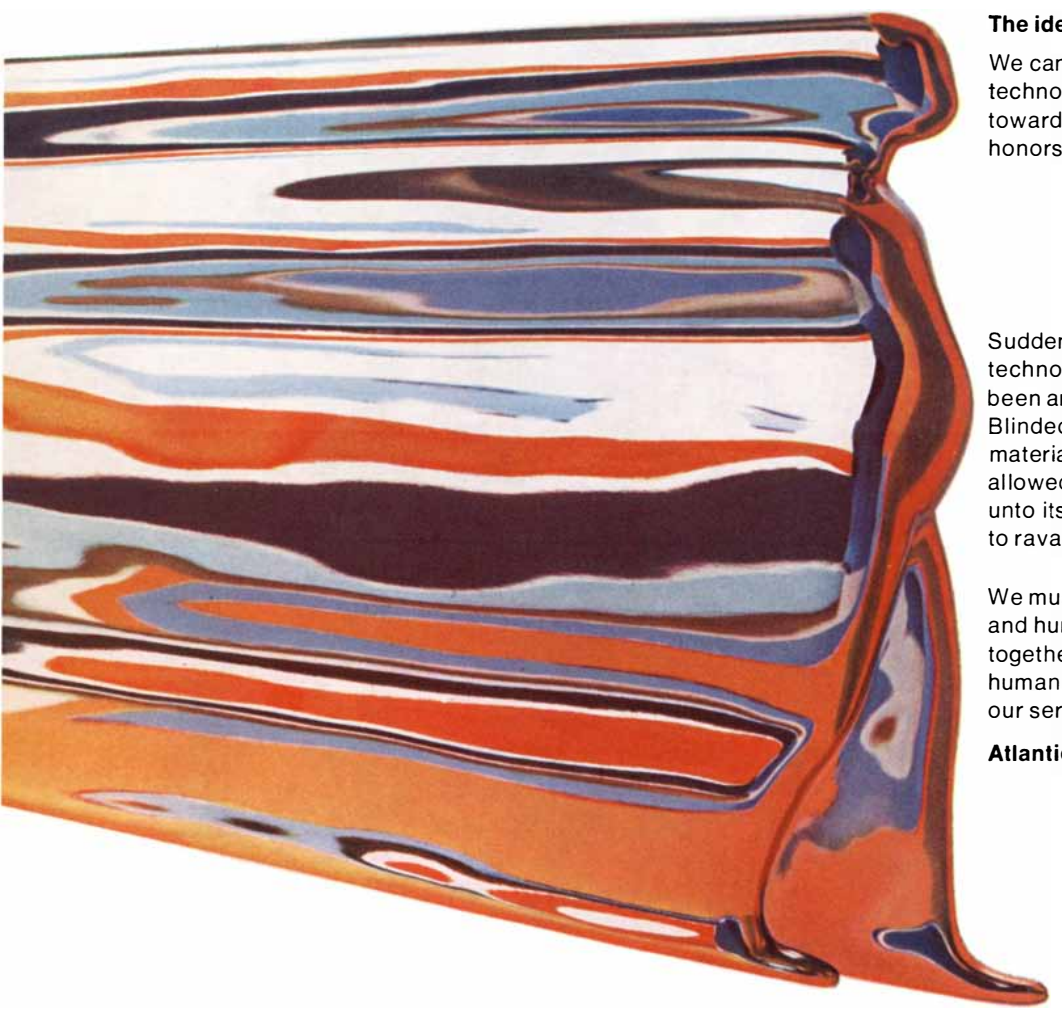


Polaroid Corporation
Cambridge, Mass.

artist: trova

The real

Man has created a technology that distorts his humanity.



The ideal

We can shape a new technology that moves us toward a future which honors the human dimension.

Suddenly, we know man's technological genius has not been an unmixed blessing. Blinded by its power to create material abundance, all of us allowed it to become an end unto itself and, in the process, to ravage the environment.

We must balance technological and human factors. Working together, we can build a humanized technology that is our servant, not our master.

AtlanticRichfieldCompany

Carbon 14 and the Prehistory of Europe

Tree-ring measurements have shown that early carbon-14 dates are off by as much as 700 years. As a result the view that cultural advances diffused into Europe from the east is no longer tenable

by Colin Renfrew

Our knowledge of European prehistory is currently being revolutionized. The immediate cause of the revolution is a recently discovered discrepancy between the actual ages of many archaeological sites and the ages that have been attributed to them on the basis of carbon-14 analysis. Some sites are as much as seven centuries older than they had been thought to be. This revelation has destroyed the intricate system of interlocking chronologies that provided the foundation for a major edifice of archaeological scholarship: the theory of cultural diffusion.

For more than a century a basic assumption of prehistorians has been that most of the major cultural advances in ancient Europe came about as the result of influences from the great early civilizations of Egypt and Mesopotamia. For example, megalithic tombs in western Europe feature single slabs that weigh several tons. The prevailing view of their origin was that the technical skills and religious motivation needed for their construction had come from the eastern Mediterranean, first reaching Spain and Portugal and then France, Britain and Scandinavia. To take another example, it was generally supposed that the knowledge of copper metallurgy had been transmitted by Mediterranean intermediaries to the Iberian peninsula and to the Balkans from its place of origin in the Near East. The revolution in chronology shows, however, that the megalithic tombs of western Europe and the copper metallurgy of the Balkans are actually older than their supposed Mediterranean prototypes.

When the scholars of a century ago wanted to date the monuments and objects of prehistoric Europe, they had little to help them. C. J. Thomsen, a Danish student of antiquities, had established a "three ages" frame of reference in 1836; structures and objects were roughly classified as Stone Age (at first there was no distinction between Paleolithic and Neolithic), Bronze Age or Iron Age. To assign such things an age in years was a matter of little more than guesswork.

Prehistoric finds are of course by their nature unaccompanied by written records. The only possible recourse was to work from the known to the unknown: to try to move outward toward the unlettered periphery from the historical civilizations of Egypt and Mesopotamia, where written records were available. For example, the historical chronology of Egypt, based on ancient written records, can be extended with considerable confidence back to 1900 B.C. because

MEGALITHIC MONUMENT near Essé in Brittany is typical of the massive stone structures that were raised in France as long ago as the fifth millennium B.C. Called "Fairies' Rock," it is made of 42 large slabs of schist, some weighing more than 40 tons. Because of the great effort that must have been required to raise such monuments, scholars traditionally refused to credit the barbarian cultures of prehistoric Europe with their construction and instead attributed them to influences from civilized eastern Mediterranean.

the records noted astronomical events. The Egyptian "king lists" can then be used, although with far less confidence, to build up a chronology that goes back another 11 centuries to 3000 B.C.

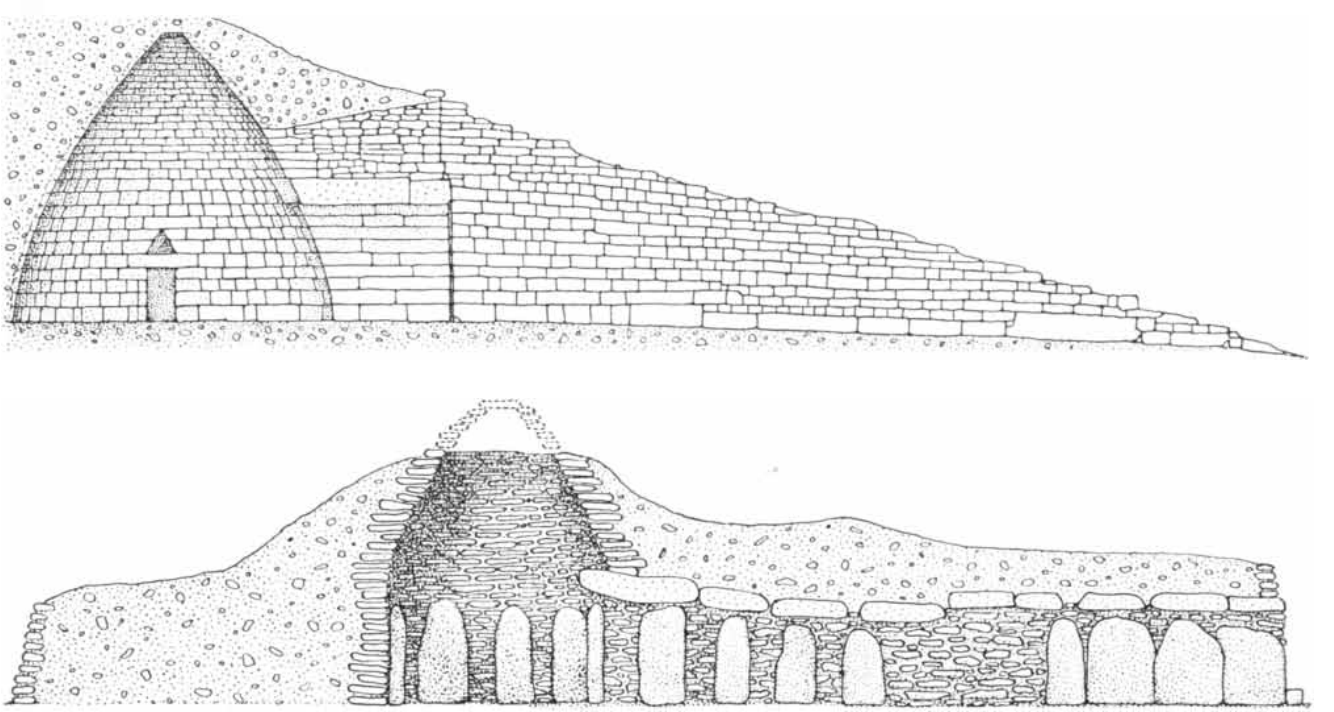
The need to establish a link with Egypt in order to date the prehistoric cultures of Europe went naturally with the widespread assumption that, among prehistoric sites in general, the more sophisticated ones were of Near Eastern origin anyway. In 1887, when the brothers Henri and Louis Siret published the results of their excavations in the cemeteries and settlements of "Copper Age" (late Neolithic) Spain, they reported finding stone tombs, some roofed with handsome corbeled stonework and others of massive megalithic construction. In the tombs there were sometimes human figurines carved in stone, and daggers and simple tools made of copper. That these structures and objects had evolved locally did not seem likely; an origin in the eastern Mediterranean—in Egypt or the Aegean—was claimed for all their more exotic features.

In the first years of this century this method of building up relationships and using contacts with the early civilized world to establish a relative chronology was put on a systematic basis by the Swedish archaeologist Oskar Montelius. In 1903 Montelius published an account of his "typological method," where the development of particular types of tools or weapons within a given area was reconstructed and the sequence was then compared with those of neighboring areas. Adjacent regions could thus be linked in a systematic manner, until a chain of links was built up stretching from the Atlantic across Europe to Egypt and Mesopotamia. It was still assumed that most of the innovations had come from the Near East, and that the farther from the "hearthlands" of civilization they were found, the longer it would have taken them to diffuse there.

Some diffusionist scholars went to extremes. In the 1920's Sir Grafton Smith argued the view that nearly all the innovations in the civilizations around the world could be traced back to Egypt. In this hyperdiffusionist theory the high cultures of the Far East and even the early civilizations of Central America and South America had supposedly stemmed from Egypt. Today very few continue to suppose that the essential ingredients of civilization were disseminated from Egypt to the rest of the world, perhaps in papyrus boats. There were, of course, scholars whose views lay at the other extreme, such as the German ultranationalist Gustaf Kossinna, whose chauvinist writings fell into a predictable pattern. For these men the truly great advances and fundamental discoveries always seem to have been made in the land of their birth. The *Herrenvolk* fantasies of Aryan supremacy in the Nazi era were rooted in Kossinna's theory of Nordic primacy.

Appalled by both of these extremes, the British prehistorian V. Gordon Childe tried to steer a middle course. In *The Dawn of European Civilisation,* published in 1925, Childe rejected Smith's fantasy that the ancient Egyptians were responsible for all the significant advances in prehistoric Europe. Working in the same framework as Montelius but with a detailed and sympathetic consideration of the prehistoric cultures of each region, he built up a picture in terms of what one colleague, Glyn E. Daniel, has termed "modified diffusionism."

Childe saw two main paths whereby a chronological link could be established between Europe and the Near East. First there were the Spanish "Copper Age" finds. Earlier writers had likened the megalithic tombs of Spain, particularly those with corbeled vaults, to the great tholos tombs of Mycenae, which were built around 1500 B.C. Childe saw that the Mycenaean tombs were too recent to have served as a model, and he suggested instead a link between the Spanish tombs and the round tombs of Bronze Age Crete, which had been built



TWO SIMILAR STRUCTURES with corbeled domes are the famous "Treasury of Atreus," a Mycenaean tomb built around 1500 B.C. (*top*), and a megalithic passage grave, Île Longue in Brittany, which is probably some 6,000 years old (*bottom*). Unaware of the true age of the French passage graves, the prehistorian V. Gordon Childe nonetheless dismissed the notion that they were inspired by a civilization as recent as Mycenae. He suggested that they were probably modeled on earlier Minoan tombs built around 2500 B.C.

about 2500 B.C. As subsequent work provided more detail, it was even suggested that colonists from the Aegean had set up settlements in Spain and Portugal. With them they would have brought their knowledge of architecture, their custom of collective burial, their belief in a "mother goddess" and their skill in metallurgy. The fortifications at one or two of these early Iberian sites resemble those at the settlement of Chalandriani on the Aegean island of Syros [*see bottom illustration at right*].

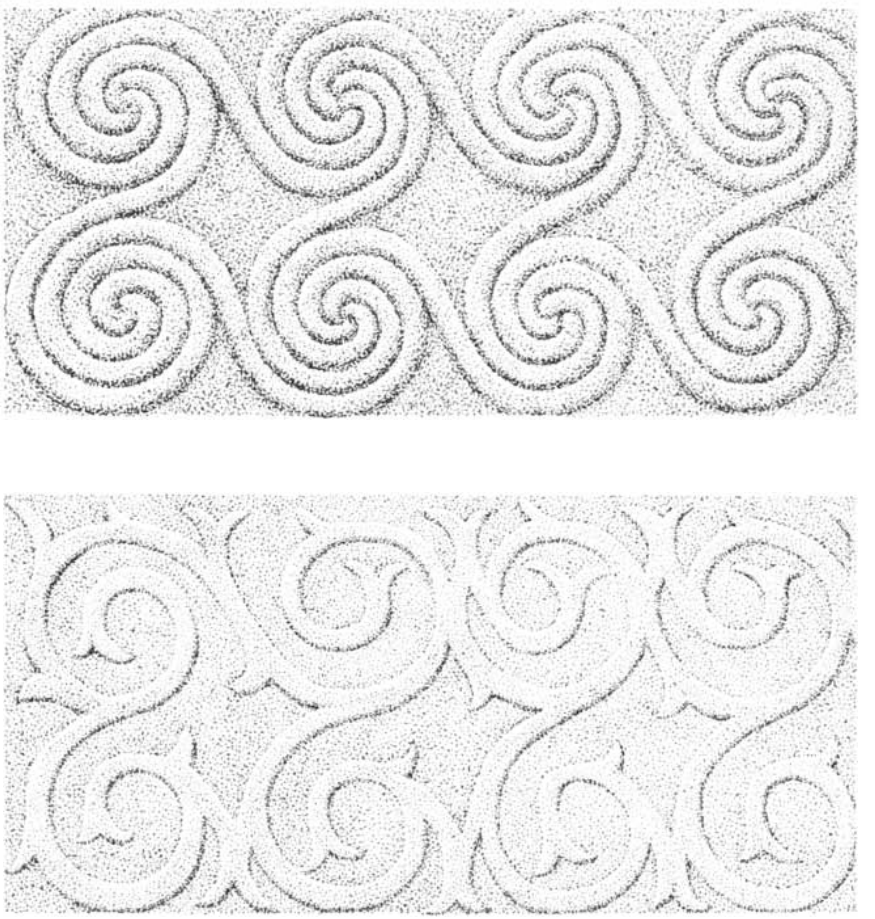
It was on this basis that the earliest megalithic tombs of the Iberian peninsula were assigned an age of around 2500 B.C. The similar French and British tombs, some of which also have stone vaults, were assigned to times a little later in the third millennium.

Similar logic was used in assigning dates to the striking stone temples of Malta. Sculptured slabs in some of the island's temples are handsomely decorated with spirals. These spirals resemble decorations from Crete and Greece of the period from 1800 to 1600 B.C. The Maltese temples were therefore assumed to date from that time or a little later.

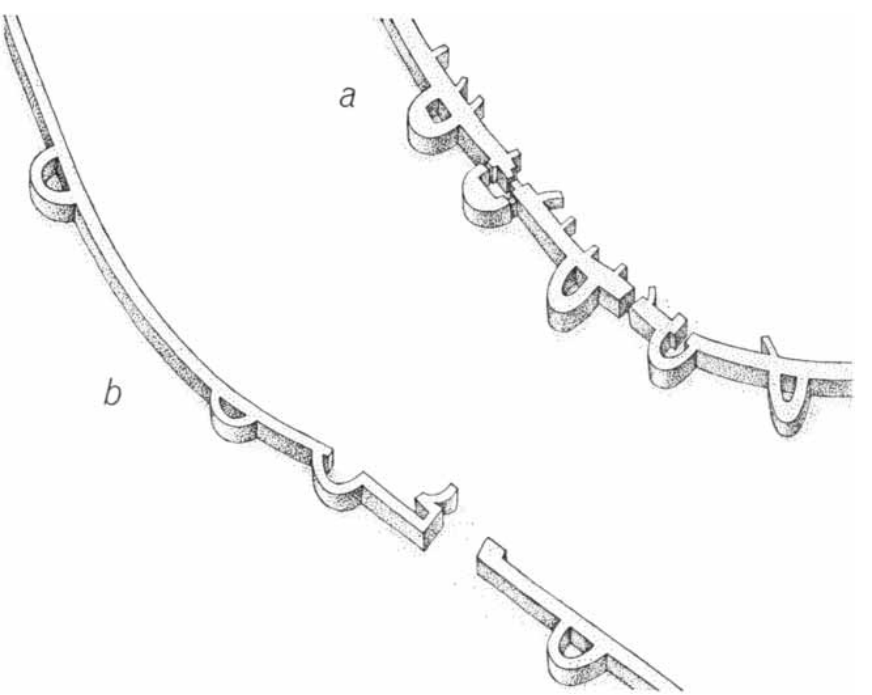
Childe's second path for chronological links between western Europe and the Near East was the Danube. Artifacts of the late Neolithic period found at Vinča in Yugoslavia were compared by him to material from the early Bronze Age "cities" at Troy. The Trojan finds can be dated to within a few centuries of 2700 B.C. It was concluded that metallurgy had arisen in the Balkans as a result of contacts with Troy. This view was strengthened by certain similarities between the clay sculptures found at Vinča and various artistic products of the early Bronze Age Aegean.

These twin foundations for the prehistoric chronology of Europe have been accepted by most archaeologists since Childe's day. The appearance of metallurgy and of other striking cultural and artistic abilities in the Balkans, and of monumental architecture on the Iberian peninsula, were explained as the result of contacts with the Aegean. Such skills make their appearance in the Aegean around 2500 B.C., a point in time that is established by finds of datable Egyptian imports in Crete and of somewhat later Cretan exports in datable contexts in Egypt. The chronology of Crete and the southern Aegean is soundly based on the chronology of Egypt and has not been affected by the current revolution.

It should be noted that, as Childe himself pointed out, these conclusions rested on two basic assumptions. First, it



TWO SIMILAR SPIRALS are the decorations on a stele from a Mycenaean shaft grave (*top*) and decorations at temple of Tarxien in Malta (*bottom*). Mycenaean spirals were carved about 1650 B.C. Maltese ones were held on grounds of resemblance to be same age.



TWO SIMILAR FORTIFICATIONS are the bastioned walls at Chalandriani (*a*), a site on the Aegean island of Syros, and the walls of Los Millares (*b*), a "Copper Age" site near Málaga in Spain. The likeness was once attributed to the work of Aegean colonists in Spain.

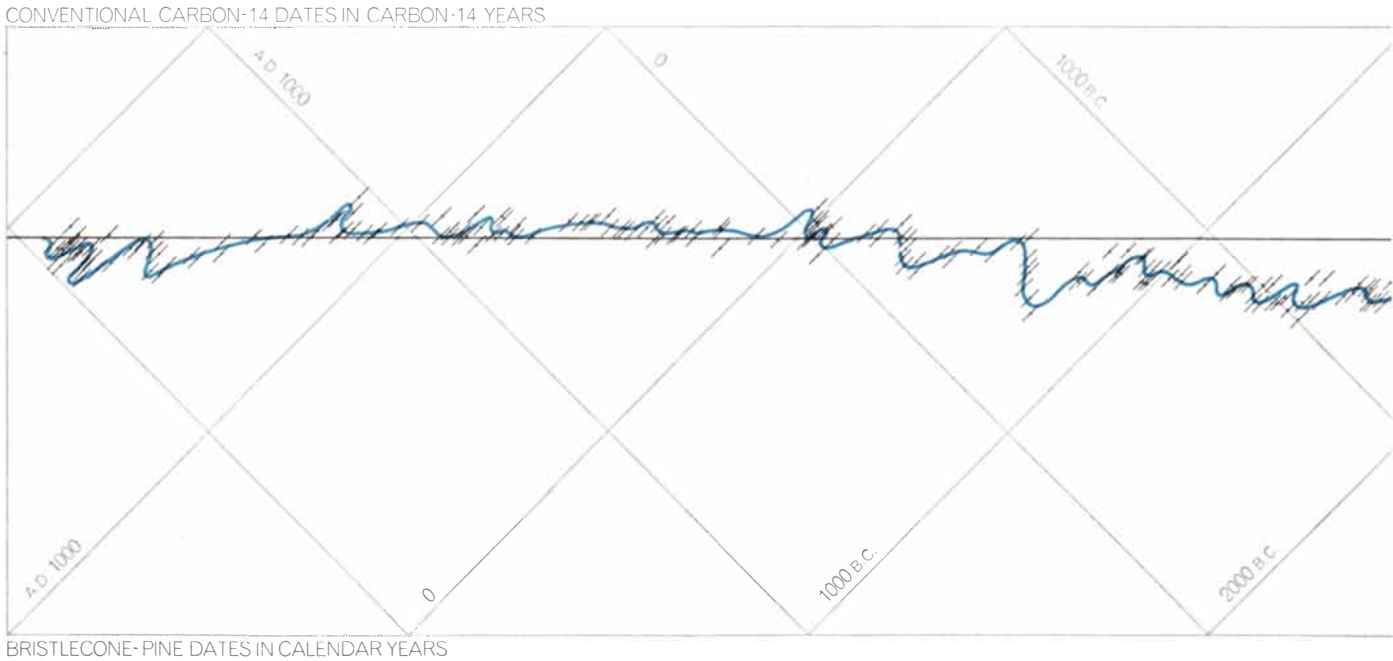
was assumed that "parallel" developments in different regions—the appearance of metallurgy or the beginning of monumental tomb architecture—were not entirely independent innovations. Second, it was assumed that if the developments had indeed diffused from one region to another, the ancient civilizations of the Near East were the innovators and the barbarians of Europe were the beneficiaries. Childe realized that these assumptions could be questioned, but in the absence of any independent dating method the only way prehistoric Europe could be dated at all was to relate it to the dated civilizations of the Near East. In practice this meant full acceptance of the assumptions. As Childe remarked of his work, "the sole unifying theme was the irradiation of European barbarism by Oriental civilization."

The discovery of carbon-14 dating in 1949 offered, in principle at least, the possibility of establishing a sound absolute chronology without the need for the assumptions that Childe had had to make. Even without carbon-14 dating, however, some of the arguments of the modified diffusionist school were susceptible to criticism. For example, there are no megalithic tombs in the Aegean, so that some special pleading is needed to argue a Near Eastern origin for those of western Europe. Again, detailed studies in the Aegean area show that the resemblances between the pottery and figurines of the Iberian peninsula and those of Greece, the supposed homeland of the "colonists," are not as close as had been supposed. Nor are the Balkan Neolithic finds really very closely related to the Aegean ones from which they were supposedly derived. There was certainly room for doubt about some of the details in the attractive and coherent picture that diffusionist theory had built up.

Although the introduction of carbon-14 dating did not disrupt the diffusionist picture or the chronology based on it, the dates did produce a few anomalies. A decade ago there were already hints that something was wrong. The carbon-14 method, originated by Willard F. Libby, ingeniously exploits the production of atoms of this heavy isotope of carbon in the upper atmosphere. The carbon-14 atoms are produced by the absorption of neutrons by atoms of nitrogen 14. The neutrons in turn are produced by the impact of cosmic ray particles on various atoms in the atmosphere. Carbon 14 is radioactive, and like all radioactive elements it decays in a regular way. Its half-life was originally estimated by Libby to be some 5,568 years.

The manufacture of the radioactive isotope by cosmic radiation and its diminution through decay sets up a balance so that the proportion of carbon 14 to carbon 12, the much more abundant nonradioactive isotope, is approximately constant. The atoms of the radioactive isotope in the atmosphere, like the atoms of normal carbon, combine with oxygen to form carbon dioxide. This substance is taken up by plants through photosynthesis and by animals feeding on the plants, and in that way all living things come to have the two kinds of carbon in the same proportion in their tissues while they are alive. At death, however, the cycle is broken: the organisms no longer take up any fresh carbon and the proportion of the two isotopes steadily changes as the radioactive isotope decays. Assuming that the proportion of the two isotopes in the atmosphere has always been constant, one can measure how much carbon 14 is left in plant or animal remains (in charcoal, say, or bone) and, knowing the half-life of the radioactive isotope, can calculate how long the decay process has been going on and therefore how old the sample is.

This, put rather simply, is the principle of the dating method. In practice it is complicated by the very small number of carbon-14 atoms in the atmosphere and in living things compared with the number of carbon-12 atoms: approximately one per million million. The proportion is of course further reduced in dead organic material as the rare isotope decays, making accurate measurement a delicate task. Nonetheless, samples from archaeological sites began to yield coherent and consistent dates soon after 1949. In general the carbon-14 dates in Europe tallied fairly well with those built up by the "typological method"



BRISTLECONE-PINE CALIBRATION worked out by Hans E. Suess of the University of California at San Diego makes it possible to correct carbon-14 dates. The dates running across the top and the lines on which they rest refer to carbon-14 dates in carbon-14 years; the dates running across the bottom and the lines on which they rest refer to bristlecone-pine dates in calendar years. The col-

back to about 2500 B.C. The great surprise was how early the Neolithic period, defined by the appearance of farming villages, began everywhere. Instead of yielding the expected dates of around 4000 or 4500 B.C., the earliest villages in the Near East proved to date back to as early as 8000 B.C.

These dates for the early Neolithic period were most important. Indeed, their impact on prehistoric archaeology can be regarded as the first carbon-14 revolution. The sharp increases in age did not, however, actually disrupt the diffusionist picture. Farming developments in the Near East remained in general earlier than those in Europe. The pattern did not change nor did the Near East lose its primacy; it was just that all the dates were earlier than had been expected. Everyone had always been aware that, for the period before 3000 B.C., which is when the Egyptian chronology begins, all dates were guesswork. What the first carbon-14 dates demonstrated was that the guesses had not been bold enough.

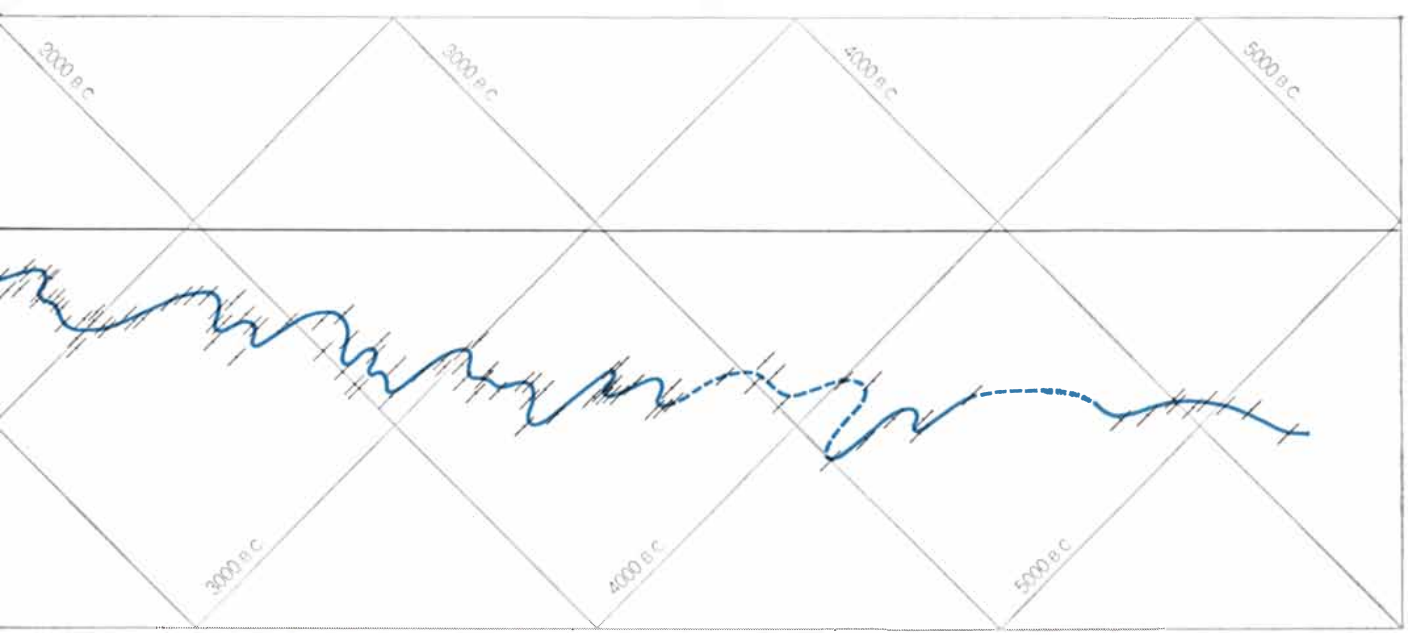
Thus the first carbon-14 revolution did not seriously challenge the relationships that had previously been established in terms of relative chronology between the different areas of Europe and the Near East. Even with respect to the crucial period after 3000 B.C., for which the Egyptian historical chronology provided a framework of absolute rather than relative dating, the new dates seemed to harmonize fairly well with the traditional ones. Just three troublesome problems hinted that all was not yet well. First, whereas many of the early carbon-14 dates for the megalithic tombs in western Europe fell around 2500 B.C., which fitted in with Childe's traditional chronology, the dates in France were somewhat earlier. In Brittany, for example, the dates of several corbeled tombs were earlier than 3000 B.C. This did not agree with the established picture of megalithic tombs diffusing from Spain to France sometime after 2500 B.C. Most scholars simply assumed that the French laboratories producing these dates were no better than they ought to be, and that the anomaly would probably disappear when more dates were available.

Second, the dates for the Balkan Neolithic were far too early. Sites related to the Vinča culture gave carbon-14 readings as early as 4000 B.C. This implied that not only copper metallurgy but also the attractive little sculptures of the Balkans were more than a millennium older than their supposed Aegean prototypes. Clearly something was wrong. Some archaeologists, led by Vladimir Milojčić, argued that the entire carbon-14 method was in error. Others felt that some special factor was making the Balkan dates too early, since the dates in other regions, with the exception of Brittany, seemed to be in harmony with the historical dates for the third millennium B.C.

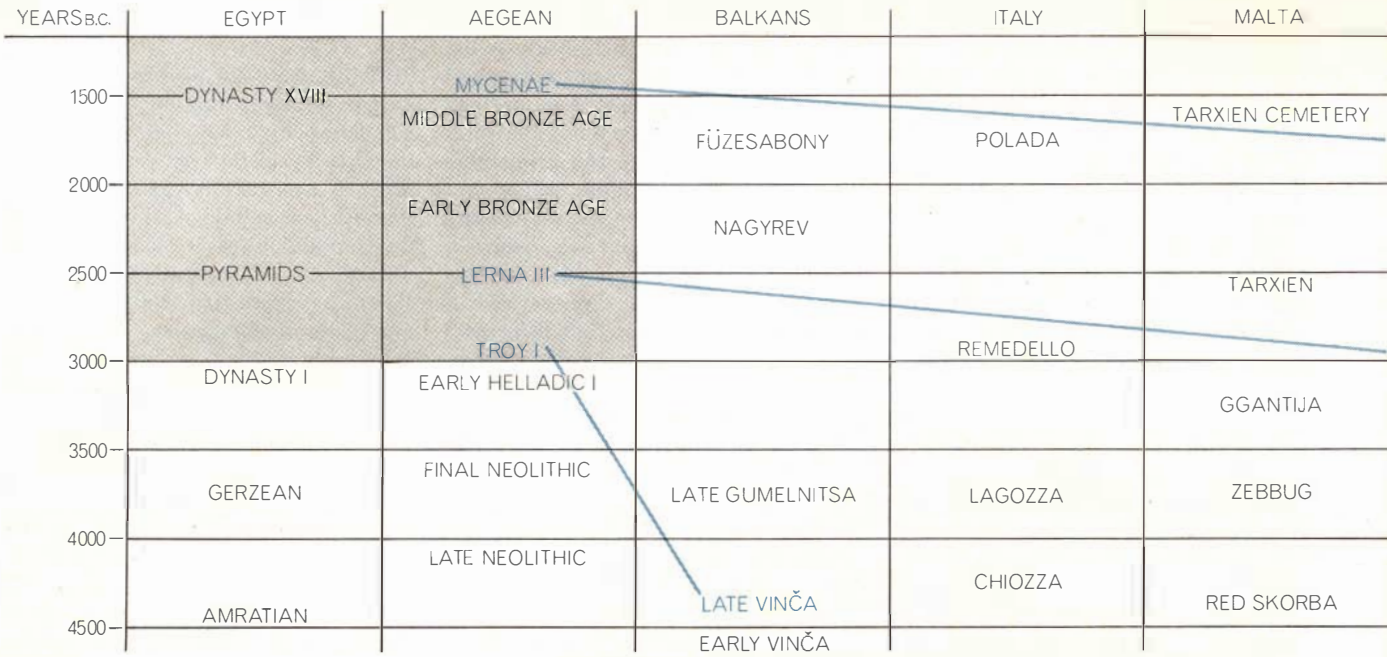
Third, the dates for Egypt were too late. In retrospect this now seems highly significant. Egyptian objects historically dated to the period between 3000 and 2000 B.C. consistently yielded carbon-14 dates that placed them several centuries later. With the early inaccuracies and uncertainties of the carbon-14 method these divergences could at first be dismissed as random errors, but as more dates accumulated such an excuse was no longer possible. The archaeologists kept on using their historical dates and did not bother too much about the problems raised by the new method.

The physicists were more concerned, but they supposed, to use Libby's words, "that the Egyptian historical dates beyond 4000 years ago may be somewhat too old, perhaps five centuries too old at 5000 years ago, with decrease in error to [zero] at 4000 years ago.... It is noteworthy that the earliest astronomical fix is at 4000 years ago, that all older dates have errors and that these errors are more or less cumulative with time before 4000 years ago." For once, however, the archaeologists were right. The discrepancy was to be set at the door of the physicist rather than the Egyptologist. The consequences were dramatic.

Remote as it may seem from European archaeology, it was the venerable pine trees in the White Mountains of



ored curve, which follows many individual measurements, shows how the carbon-14 dates go off with time. To calibrate a carbon-14 date, say 2000 B.C., one follows the line for that date until it meets the colored curve. At that point a diagonal is drawn parallel to the bristlecone-pine lines and the date is read off on the bristlecone-pine scale. The corrected date would be about 2500 B.C.



REVISED CHRONOLOGY, taking the Suess calibration into account, destroys the basis for the diffusionist theory of European prehistory. Colored area at left marks the portion of Egyptian and Aegean chronology that is related to historical records. Colored

California that brought about the revolution in Old World prehistory. These trees have provided a reliable check of the carbon-14 method and have produced significant modifications. By 1960 one major assumption of the method was already coming into question. This was that the rate of production of carbon 14 in the atmosphere, and hence its proportion in all living things, had been constant over the past 40,000 years. The assumption was first really checked when Eric H. Willis, Henrik Tauber and Karl Otto Münnich analyzed samples of wood from the stump of a giant sequoia that could be dated exactly by counting its annual growth rings. Although the carbon-14 dates and the tree-ring dates agreed to within 100 years all the way back to A.D. 650, some minor but real fluctuations were observed. This suggested that there had been definite small changes in the rate of carbon-14 production in the past.

It was obviously desirable to check back to even earlier periods. Fortunately the fantastically long life of the California bristlecone pine (*Pinus aristata*) was known to the late Edmund Schulman of the Laboratory of Tree-Ring Research at the University of Arizona. Bristlecone pines as old as 4,600 years had been authenticated. Since Schulman's death the study of the trees has been energetically pursued by Charles Wesley Ferguson of the same laboratory. With ring sequences from many bristlecones, Ferguson has succeeded in building up a continuous absolute chronology reaching back nearly 8,200 years. The compilation of such a chronology, with due provision for multiple growth rings and missing rings, is a formidable task. Ferguson and his colleagues have developed computer programs for the comparison and matching of the ring sequence of different trees. This admirably systematic work has been the indispensable foundation of the second carbon-14 revolution.

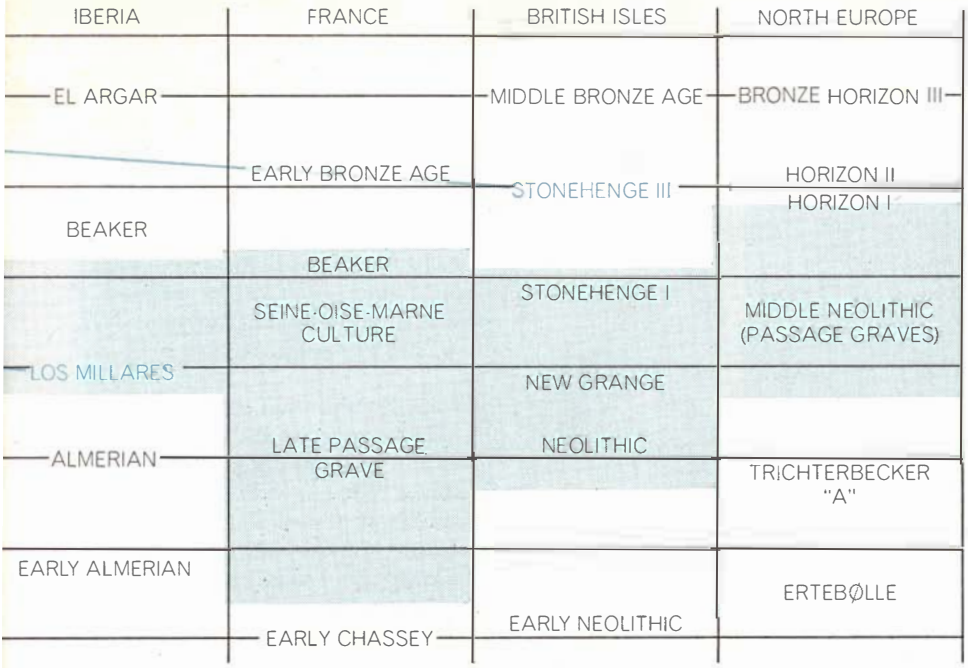
Ferguson supplied wood samples whose absolute age had been determined by ring-counting to three independent carbon-14 laboratories: one at the University of Arizona, one at the University of Pennsylvania and one at the University of California at San Diego. The carbon-14 determinations, which in general agree fairly well with one another, reveal major discrepancies between previously accepted carbon-14 dates and actual dates. At San Diego, Hans E. Suess has analyzed more than 300 such samples and has built up an impressively clear and coherent picture of these discrepancies.

The divergence between the carbon-14 and tree-ring dates is not serious after 1500 B.C. Before that time the difference becomes progressively larger and amounts to as much as 700 years by 2500 B.C. The carbon-14 dates are all too young, but Suess's analysis can be used to correct them [*see illustration on preceding two pages*].

One problem that has emerged is that, in addition to a large first-order divergence, Suess's calibration curve shows smaller second-order fluctuations or "kinks." Sometimes the rate of carbon-14 production has fluctuated so rapidly that samples of different ages show an identical concentration of carbon 14 in spite of the fact that the older sample allowed more time for radioactive decay. This means that a given carbon-14 date can very well correspond to several different calendar dates.

The reasons for the fluctuations are not yet known with certainty, but the Czechoslovakian geophysicist V. Bucha has shown that there is a striking correlation between the divergence in dates and past changes in the strength of the earth's magnetic field. The first-order variation is probably due to the fact that as the strength of the earth's field changed it deflected more or fewer cosmic rays before they could enter the atmosphere. There are strong indications that the second-order fluctuations are correlated with the level of solar activity. Both the low-energy particles of the "solar wind" and the high-energy particles that are the solar component of the cosmic radiation may affect the cosmic ray flux in the vicinity of the earth. Climatic changes may also have influenced the concentration of carbon 14 in the atmosphere.

To the archaeologist, however, the reliability of the tree-ring calibration is more important than its physical basis. Libby's principle of simultaneity, which states that the atmospheric level of carbon 14 at a given time is uniform all



area at right indicates periods when megalithic monuments were built in the European areas named. Lines and names in color show "connections" now proved to be impossible.

over the world, has been in large measure substantiated. Tests of nuclear weapons have shown that atmospheric mixing is rapid and that irregularities in composition are smoothed out after a few years. The California calibration should therefore hold for Europe. There is no need to assume that tree growth or tree rings are similar on the two continents, only that the atmospheric level of carbon 14 is the same at a given time.

There remains the question of whether some special factor in the bristlecone pine itself might be causing the discrepancies. For example, the diffusion of recent sap across the old tree rings and its retention in them might affect the reading if the sap were not removed by laboratory cleaning procedures. Studies are now in progress to determine if this is a significant factor; present indications are that it is not. Even if it is, it would be difficult to see why the discrepancy between carbon-14 dates and calendar dates should be large only before 1500 B.C.

The general opinion, as reflected in the discussions at the Twelfth Nobel Symposium at Uppsala in 1969, is that the discrepancy is real. Suess's calibration curve is the best now available, although corrections and modifications can be expected. It is particularly satisfying that when the carbon-14 dates for Egypt are calibrated, they agree far better with the Egyptian historical calendar. Further work is now in progress at the University of California at Los Angeles and at the British Museum on Egyptian samples specially collected for the project, so that a further check of the extent to which the calibrated carbon-14 dates and the historical chronology are in harmony will soon be available.

The revision of carbon-14 dates for prehistoric Europe has a disastrous effect on the traditional diffusionist chronology. The significant point is not so much that the European dates in the third millennium are all several centuries earlier than was supposed but that the dates for Egypt do not change. Prehistorians have always used the historical dates for Egypt because they seemed more accurate than the carbon-14 dates. They have been proved correct; the calibrated carbon-14 dates for Egypt agree far better with the historical chronology than the uncalibrated ones did. Hence the Egyptian historical calendar, and with it the conventional Egyptian chronology, remains unchanged. The same is true for the Near East in general and for Crete and the southern Aegean. The carbon-14 dates for the Aegean formerly seemed too young; they too agree better after calibration.

For the rest of Europe this is not true. Over the past decade prehistorians in Europe have increasingly been using carbon-14 dates to build up a chronology of the third millennium B.C. Except in Brittany and the Balkans, this chronology had seemed to work fairly well. The dates had still allowed the megalithic tombs of Spain to have been built around 2500 B.C. There was no direct contradiction between the diffusionist picture and the uncalibrated carbon-14 chronology.

All that is now changed. A carbon-14 date of about 2350 B.C. for the walls and tombs at Los Millares in Spain must now be set around 2900 B.C. This makes the structures older than their supposed prototypes in the Aegean. Whereas the carbon-14 inconsistency in western Europe was formerly limited to Brittany, it now applies to the entire area. In almost every region where megalithic tombs are found the calibrated carbon-14 dates substantially predate 2500 B.C. The view of megalithic culture as an import from the Near East no longer works.

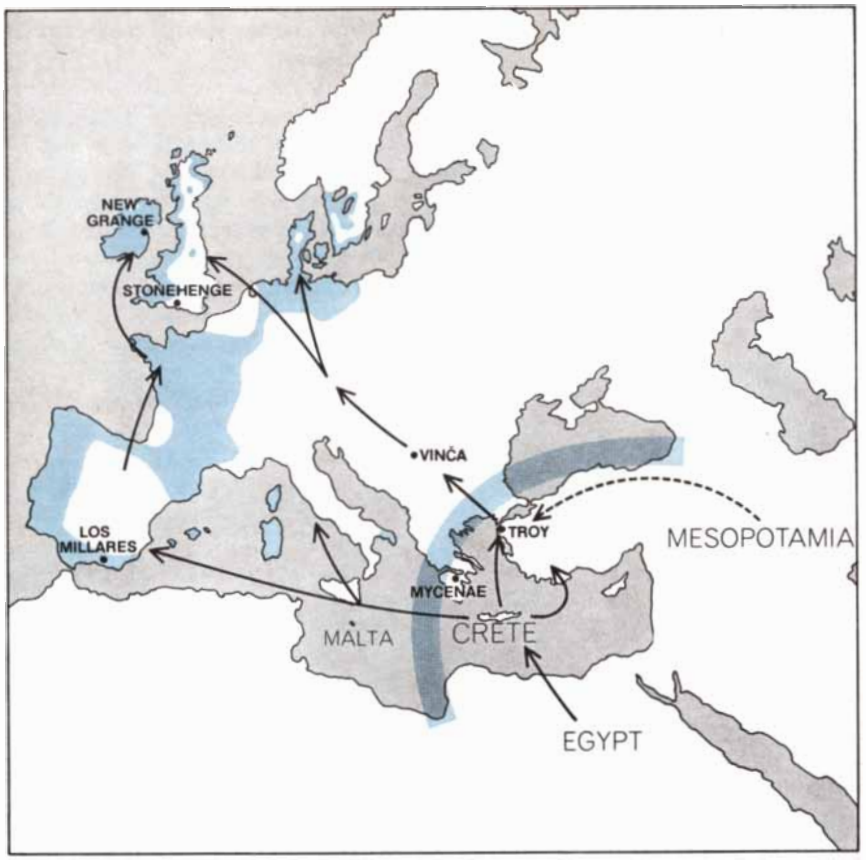
The same thing seems to be happening in Malta, although there are still too few carbon-14 dates to be certain. A date of 1930 B.C. for the period *after* the temples now becomes about 2200 B.C. Clearly the spirals in the temples cannot be the result of Aegean influence around 1800 B.C.

The Balkans are affected too. The figurines of the Vinča culture now have dates earlier than 4500 B.C.; to associate them with the Aegean of the third millennium becomes ludicrous. The revision of dates also shows that in the Balkans there was a flourishing tradition of copper metallurgy, including such useful artifacts as tools with shaft holes, before metal production was well under way in the Aegean.

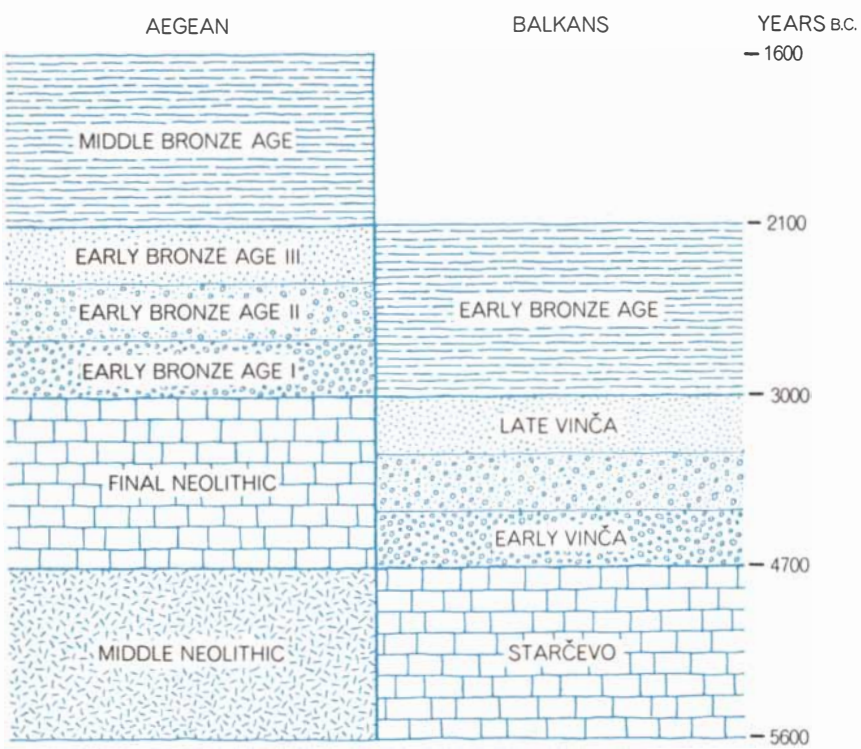
Similar changes are seen all over Europe. Stonehenge was until recently considered by many to be the work of skilled craftsmen or architects who had come to Britain from Mycenaean Greece around 1500 B.C. The monument is now seen to be several centuries older, and Mycenaean influence is clearly out of the question.

All is not confusion, however. As we have seen, the chronology of Egypt, the Near East, Crete and the Aegean is not materially changed in the third millennium B.C. Although the actual dates are altered in the rest of Europe, when we compare areas dated solely by carbon 14 the relationships between them are not changed. The great hiatus comes when we compare areas that have calibrated carbon-14 dates with areas that are dated by historical means. The hiatus may be likened to a geological fault; the chronological "fault line" extends across the Mediterranean and southern Europe.

On each side of the fault line the relationships and the successions of cultures remain unaltered. The two sides have shifted, however, *en bloc* in relation to each other, as the geological stra-



CHRONOLOGICAL "FAULT LINE" (*curved bar*) divides all Europe except the Aegean from the Near East. Arrows above the fault line are supposed chronological links now discredited. Areas of Europe that contain megalithic chamber tombs are in color at left.



FAULT-LINE SLIPPAGE is shown schematically as it affects the chronological connection between the barbarian Balkans and the civilized Aegean. Strata with the same markings were once thought to be contemporary. Estimated Balkan dates, however, were too recent.

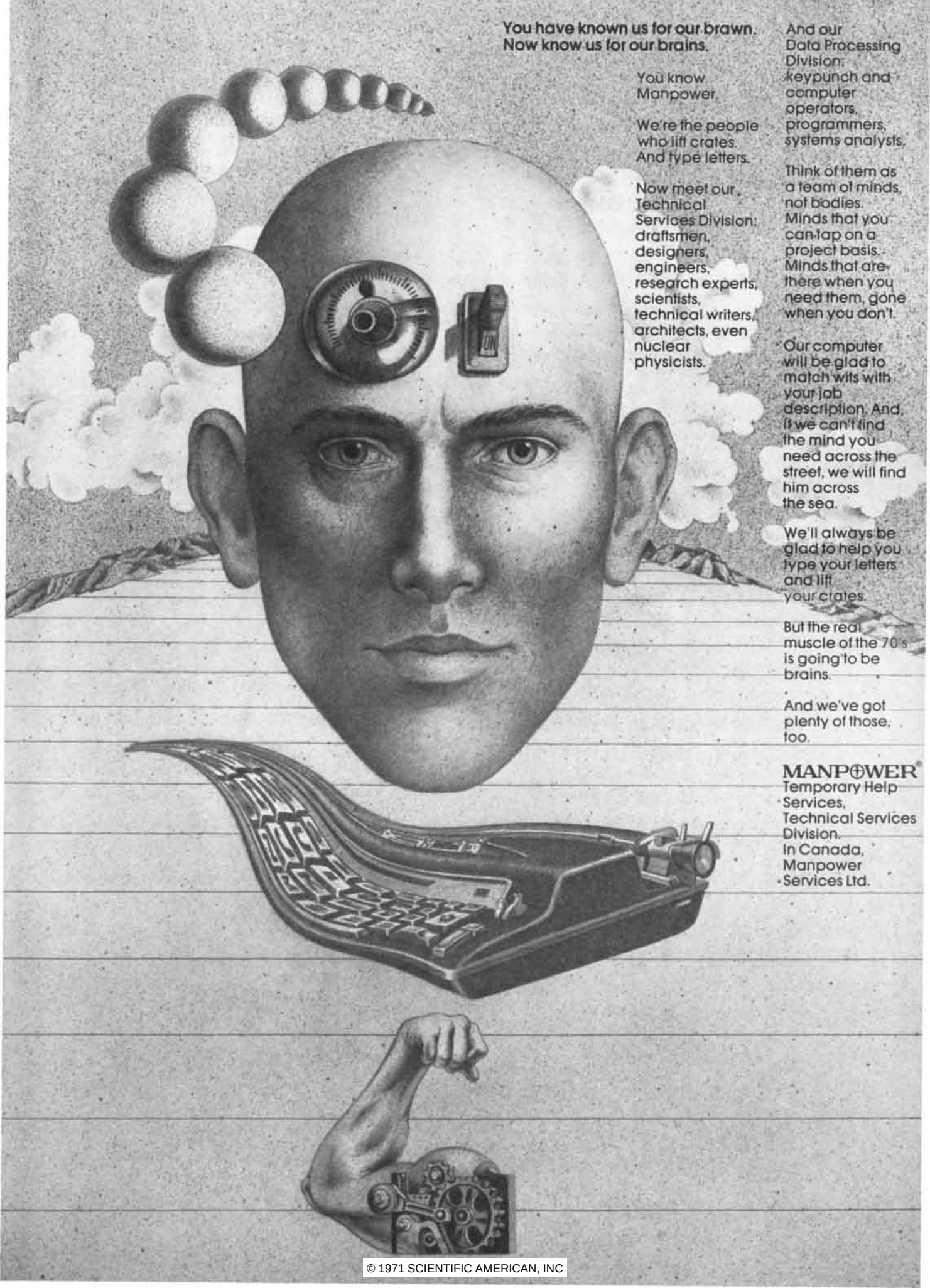
ta on two sides of a fault might. As a result much of what Montelius and Childe wrote about relationships and relative chronologies within continental Europe still stands. It is only the absolute chronology in calendar years and certain key links—between Spain and the Aegean and between the Balkans and the Aegean—that are ruptured. The dates for Europe as a whole have moved back in time, and the old diffusionist view of links connecting Europe and the Near East is no longer tenable.

The really important effect of tree-ring calibration is not that it changes the dates for prehistoric Europe by a few centuries. What matters is that it transforms our picture of what happened in prehistoric Europe and of how Europe developed. No longer can the essential theme of European prehistory be Childe's "irradiation of European barbarism by Oriental civilization." Indeed, the very early dates for some of the achievements of the prehistoric inhabitants of Europe make the term barbarism quite inappropriate.

Now it is clear that megalithic chamber tombs were being built in Brittany earlier than 4000 B.C., a millennium before monumental funerary architecture first appears in the eastern Mediterranean and 1,500 years before the raising of the pyramids. The origins of these European burial customs and monuments have to be sought not in the Near East but in Europe itself. The temples of Malta must likewise be viewed as remarkable, indeed unique, local creations: the oldest freestanding stone monuments in the world.

Even metallurgy may have been independently invented in the Balkans, and possibly in Spain as well. Certainly it was flourishing in the Balkans earlier than it was in Greece. The possibility remains, however, that the art of metalworking was learned from the Near East, where it was known even earlier than in the Balkans.

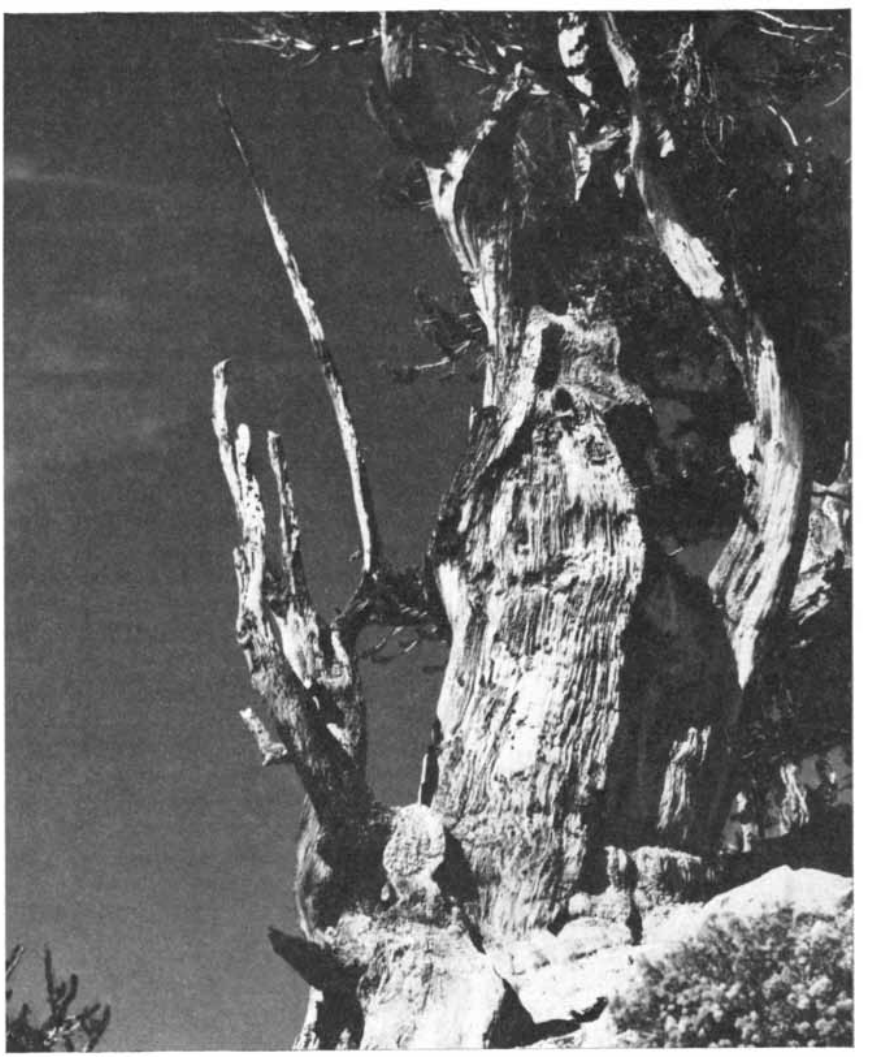
The central moral is inescapable. In the past we have completely undervalued the originality and the creativity of the inhabitants of prehistoric Europe. It was a mistake, as we now can see, always to seek in the Near East an explanation for the changes taking place in Europe. Diffusion has been overplayed. Of course, contact between prehistoric cultures often allowed ideas and innovations to pass between them. Furthermore, evidence might easily emerge for occasional contacts between western or southern Europe and the Near East in very early times. This, however, is not



an adequate model for the explanation of culture change. Nor is there any case for turning the tables on the old diffusionists by suggesting that the early monuments and innovations in Europe inspired the pyramids of Egypt or other achievements in the Near East. That would merely be to reverse the arrows on the diffusionist map, and to miss the real lesson of the new dating.

The initial impact of the carbon-14 revolution will be to lead archaeologists to revise their dates for prehistoric Europe. This is the basic factual contribution that the tree-ring calibration has to make, although inevitably it will be some years before we can develop a definitive and reliable calibrated chronology for the entire area. The more profound impact, however, will be on the kind of explanation that prehistorians will accept in elucidating cultural change. A greater reluctance to swallow "influences" or "contacts" as sufficient explanations in themselves, without a much more detailed analysis of the actual mechanisms involved, is to be expected. This is in keeping with much current archaeological thinking. Today social and economic processes are increasingly seen as more important subjects for study than the similarities among artifacts.

When the textbooks are rewritten, as they will have to be, it is not only the European dates that will be altered. A shift in the basic nature of archaeological reasoning is necessary. Indeed, it is already taking place in Europe and in other parts of the world. This is the key change that tree-ring calibration, however uncertain some of its details remain, has helped to bring about.



ANCIENT PINE, its trunk scarred and its branches twisted, is one of the many trees of the bristlecone species (*Pinus aristata*) that grow in the White Mountains of California. An analysis of this tree's growth rings proves it to be more than 4,500 years old. Using this and other specimens, Charles Wesley Ferguson and his co-workers at the University of Arizona have built up a continuous tree-ring chronology with a span of more than 8,000 years.

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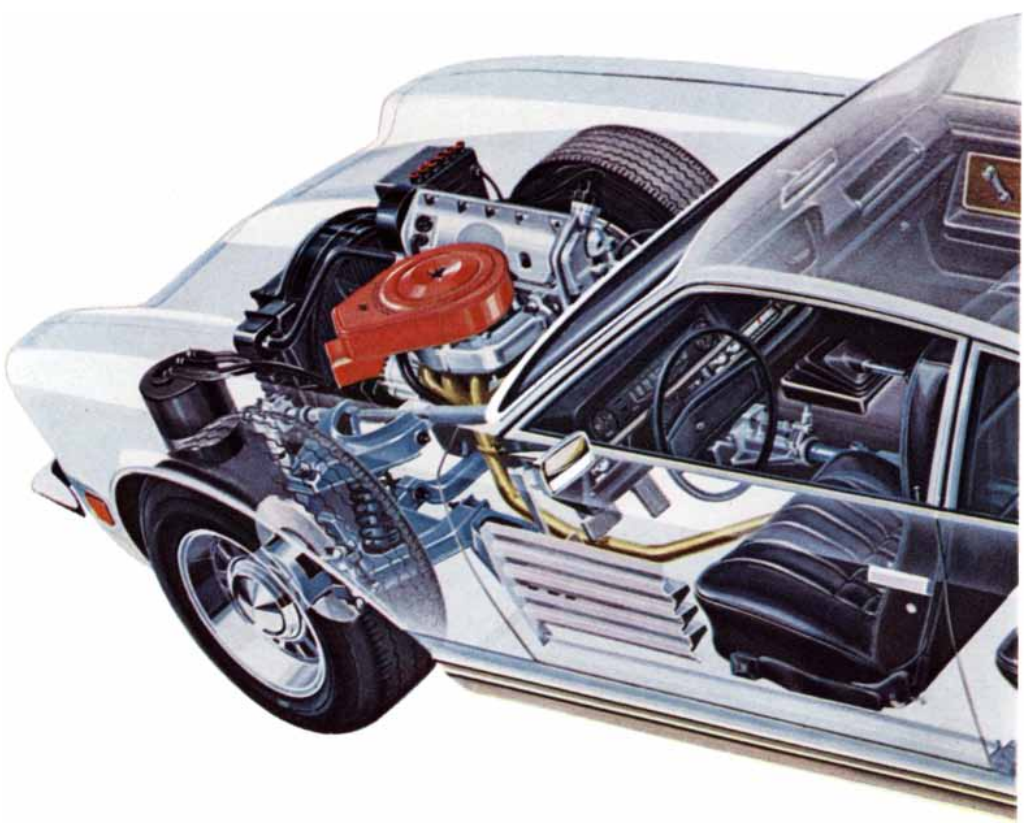

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But you can feel them.

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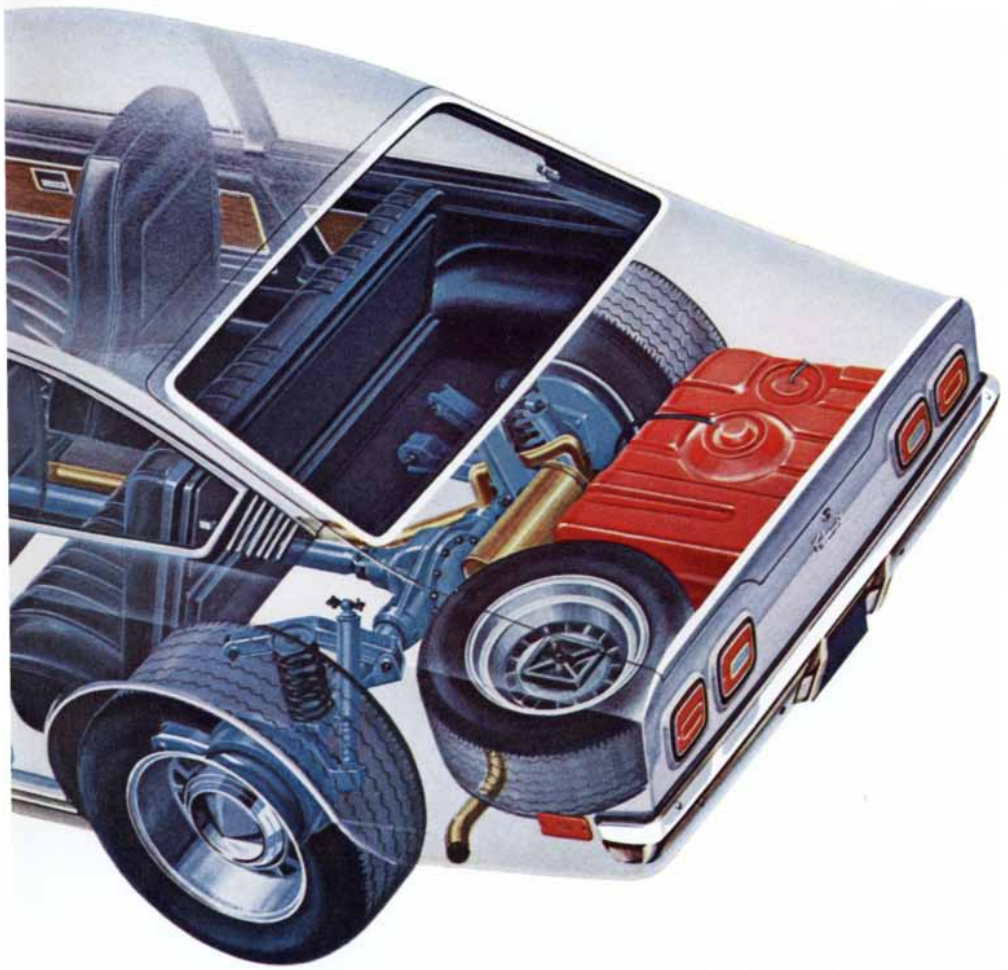

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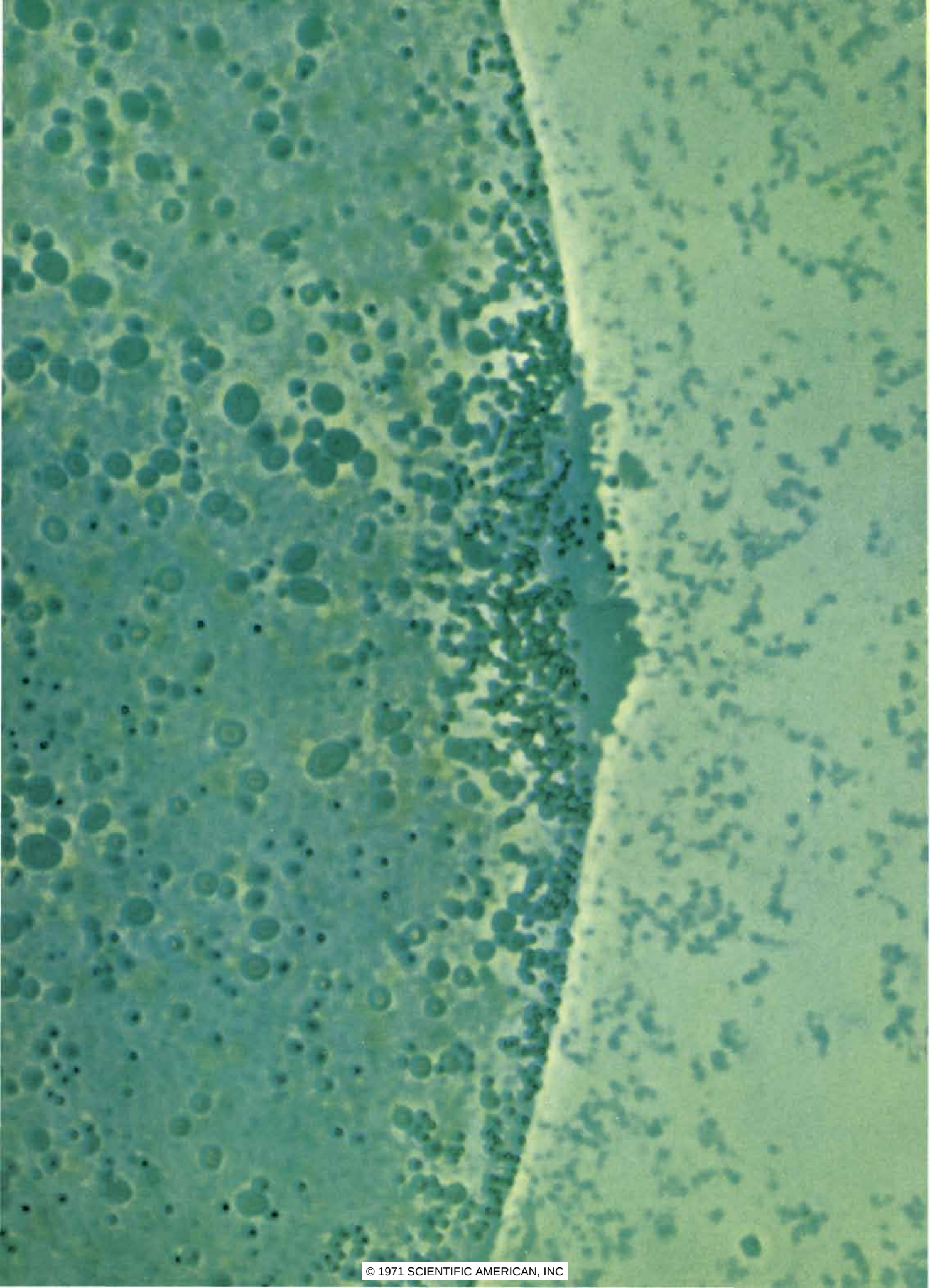


HOW LIVING CELLS CHANGE SHAPE

All embryonic cells and many mature ones bend, bulge, stretch out and even travel from place to place. In doing so the cells use two distinct kinds of filament that seem to act as skeleton and muscle

by Norman K. Wessells

Single-celled animals such as the amoeba are not the only cells that are capable of self-propelled movement. Even in highly organized multicelled animals, including man, many cells can creep about and engage in movements that change their shape. Clearly the individual cells must have built-in machinery that enables them to do this. The nature of the machinery is not obvious, as these cells do not possess cilia or other appendages that might account for their locomotion or shape-altering movements. With the help of the electron microscope and certain drugs, however, the mechanisms responsible for the performance and control of these movements are now being investigated in detail. The subject is of much practical interest, since cell movement plays a crucial role in the normal development of animal embryos, and abnormal movements of cells may be a critical factor in certain disease conditions.

When a single cell of certain tissues is isolated and placed in a culture medium, the cell can be seen to wander about over the bottom of the culture dish. Studying such movement, Michael Abercrombie and his colleagues at University College London found that the moving cell thrusts the forward edge of its membrane ahead; as the thrust occurs, the edge appears to flutter up and down. The undulating, advancing part of the membrane attaches itself to the substratum and apparently contracts to draw the cell forward. The cell can readily change the direction of its travel by activating a different part of its perimeter; the side that had been moving forward becomes quiescent and the newly activated side begins to flutter and extend itself, drawing the cell off in the new direction. A migrating cell often changes direction in this way when it encounters other cells or asymmetries in its path.

A related kind of movement is involved in the alteration of the shape of the cells that make up certain tissues. Usually a cell in a tissue remains in a fixed position in relation to its neighbors; nevertheless, it can change in shape by elongation or by a widening or narrowing of some part of the cell body, apparently through a process of contraction. When such a narrowing or elongation of cells takes place, the tissue itself assumes a new configuration; a flat sheet, for example, may be converted into a ball-like, hollow structure. This is the process that forms organs such as the lungs and the pancreas during the development of an embryo.

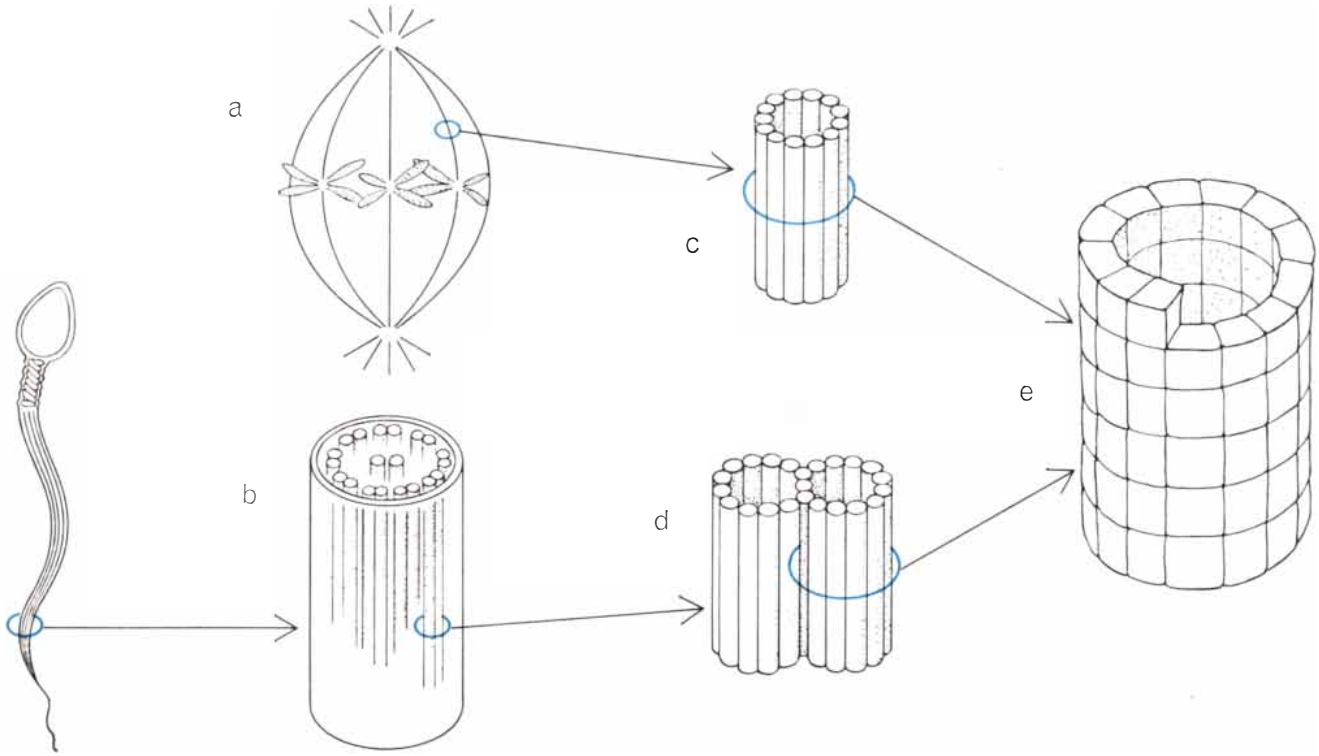
What kind of system could account for a cell's ability to engage in the movements we have described? Thinking about the situation in strictly biological terms, one can start from the basic features of the machinery for movement of an animal as a whole. Broadly speaking, this system has two principal components: the skeleton, which gives shape, rigidity and support to the body or its appendages, and the muscles, which provide the power that moves the skeleton and thus the organism itself. Can we find structures in the individual cell that are analogous to these two components? Investigation has now shown that the cell does indeed possess such structures. It turns out that this cellular machinery apparently accounts for the two very different types of movement discussed above—locomotion and change of shape—and also for a third kind of movement within the cell. An example is the action of the mitotic spindle in pulling the chromosomes apart when a cell divides.

The two basic components of the machinery for movement discovered in the cell are microtubules, which correspond to a skeleton, and microfilaments, which correspond to muscles. Let us consider the microtubules first.

The microtubules are very fine tubes averaging 250 angstroms in diameter. They are found in cilia, in the tail of sperm cells, in the mitotic spindle of a dividing cell and in the cytoplasm of many types of cell (where they have been studied by Keith R. Porter, Lewis G. Tilney and J. Richard McIntosh of Harvard University). A clue to a possible method of examining their function was provided by the response of the tubules in the mitotic spindle to the drug colchicine. This substance, an alkaloid extracted from plants of the lily family, has been used for many years as an inhibitor of cell division in plants and animals; division stops because the spindle microtubules are disrupted and therefore prevented from pulling the chromosomes apart. In order to analyze the roles of microtubules in cells we applied colchicine to cells growing in cultures in our laboratory at Stanford University. Following the lead of Henry Wisniewski of the Albert Einstein College of Medicine in New York, who had worked with nerves in whole organisms, we started with nerve cells.

The axon, or principal fiber, of a nerve

CONTRACTING CORTEX of the fertilized egg of a frog is magnified 2,000 times in the photomicrograph on the opposite page. The contraction was induced by injecting calcium ions through the surface membrane of the embryo. The presence of a distinctive band of dense material, consisting largely of microfilaments, in the cytoplasm at the site of the injection suggests that injection of calcium caused network of filaments in egg to contract.

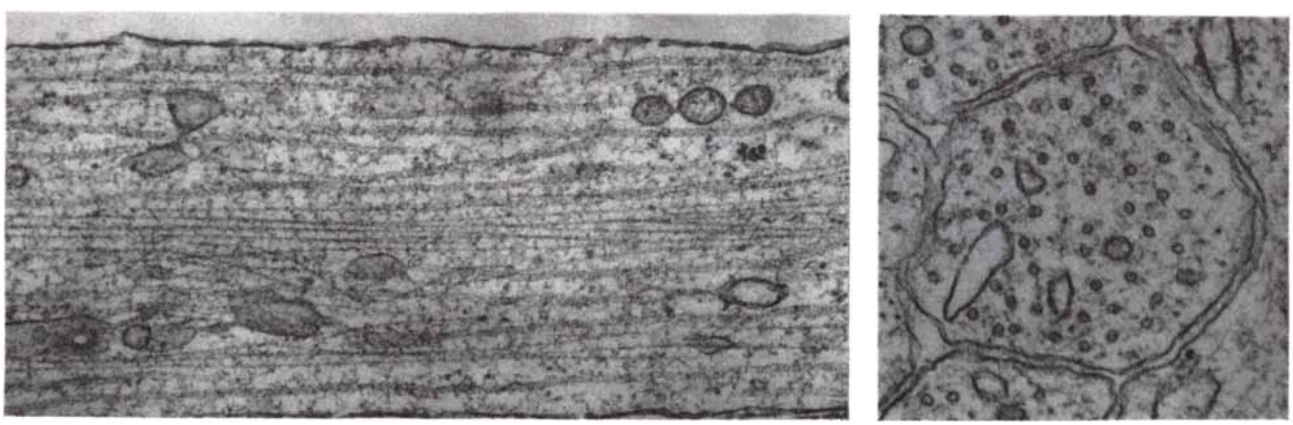


MICROTUBULES are found in such dissimilar cellular structures as the mitotic spindle (*a*) that controls the separation of the chromosomes during cell division and the flagellum (*b*) that propels the sperm cell. The spindle tubules (*c*) form a circular array totaling 13. The flagellum tubules form a double circle (*d*) and number 23. The tubules (*e*) consist of a series of linked protein subunits.

cell is a long, rather rigid cylinder containing many microtubules and tipped at its end with a mobile "growth cone." In the culture of a single nerve cell on a plate the growth tip of the axon advances over the surface of the plate. We found that when colchicine was added to the culture medium, the cell went on growing in this way for about 30 minutes; then the walls of the axon began to look crinkled and the axon shrank back toward the cell body. Eventually the axon pulled its tip free of the plate and collapsed completely into the cell body.

The microtubules had disappeared; instead the cytoplasm of the cell body contained masses of a filament, averaging only about 100 angstroms in diameter, that apparently was a different form of the protein that had composed the microtubules. The results of the experiment indicated that the microtubules when intact had acted as a "skeleton" supporting the axon, much as the long bones support a human arm or leg. The axon had apparently collapsed when these microtubules were broken down through the action of colchicine. The microtubules themselves were evidently not the direct agents for the movement of the growth cone, but in the absence of the axon's stabilizing "skeleton" the tip could not grow and advance.

Colchicine experiments with other types of cell added significant further information. These were migratory cells from the embryonic heart and the

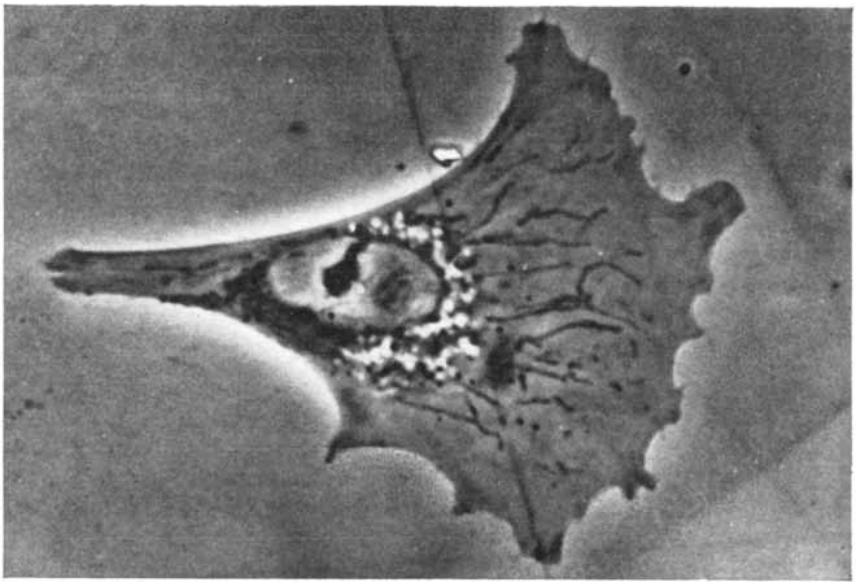


NERVE-CELL AXON is seen in longitudinal section (*left*) and transverse section (*right*). The long parallel structures near the top and bottom of the longitudinal section are microtubules. Near the center of the axon are thinner structures; they are called neurofilaments, and their function is unknown. In the transverse section the microtubules have the appearance of the cut ends of straws.

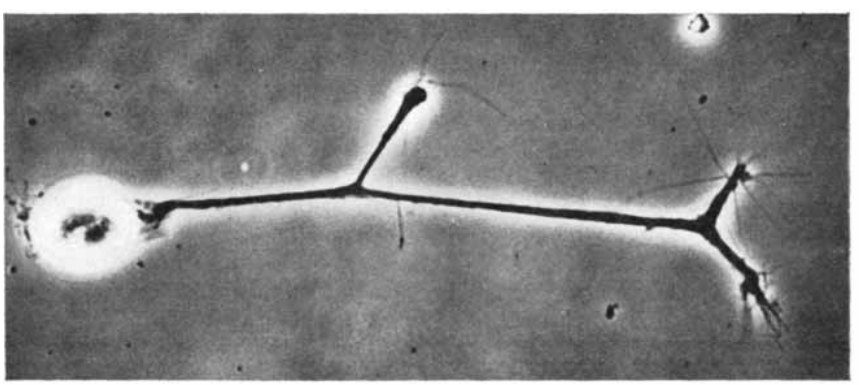
nervous system. Such cells often have a trailing "tail," drawn out into a long, stiff process, that contains microtubules. When the cell is treated with colchicine, the disruption of the microtubules causes the "tail" to be retracted into the cell body, and thereafter any part of the membrane perimeter may act as an undulating leading edge, so that the cell moves to and fro in various directions—forward, backward or sideways with equal impartiality. My colleague Brian Spooner observed that the cell behaves as if it had lost its "steering wheel" while the engine (the undulating membrane system) continues to operate. Experiments conducted by the Russian biologist J. M. Vasiliev support this conclusion, particularly with respect to the treated cells' inability to change the direction of travel in response to "roadbed" asymmetries. It seems likely that in these cells the microtubules normally serve as a skeleton that stabilizes the sides of the cell but not the front. Therefore the front of the membrane normally is free to act as an undulating leading edge, causing the cell to move in a directed manner rather than at random.

What is the nature of the "engine" that powers cell movement? Here again the use of a drug, applied to cell cultures, helped to identify the mechanism. It was known that many cells contain bundles or networks of microfilaments. The filaments are only 40 to 60 angstroms in diameter—considerably smaller than the microtubules that serve as cellular skeleton. During the division of a cell there is a ring of such filaments just below the contracting "furrow" at the area of cleavage. At the Woods Hole Marine Biological Laboratory, Thomas Schroeder examined this system by means of a drug called cytochalasin, a compound secreted by certain fungi. He found that the drug caused the microfilaments to disappear, and the furrow ceased to contract. When the drug was removed from the culture, the filaments reappeared and the cells resumed their division! Apparently the microfilaments were the contractile agents, or "muscles," that drove the cleavage process.

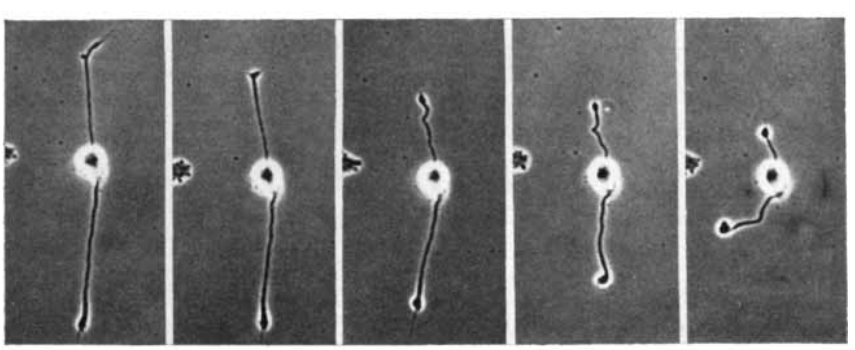
My associate Kenneth Yamada has used cytochalasin to study the movement of nerve cells and migratory cells. Both of these cell types are rich in microfilaments at the scene of action. At the growing tip of a nerve axon there is a network of microfilaments within the growth cone and in the long, thin processes, called microspikes, that extend ahead of the cone like a set of antennas and wave back and forth as if they were probing the area in front.



LIVING CELL travels from left to right across the bottom of a culture dish. The central oval is the nucleus of the cell; the wormlike dark structures are mitochondria. The "tail" of the cell (*left*) is supported by a "skeleton" of microtubules. The membrane that is advancing (*right*) will contract after attachment to the surface of the dish, thus pulling the cell forward. The movement may be powered by microfilaments, the "muscles" of the cell.



GROWING NERVE CELL in a culture dish consists of a cell body (*left*), containing the nucleus, and a long axon that has one upward branch and two more branches at the tip. The thin spikelets at the end of the branches arise from the "growth cone" regions of the cell. When the microtubules that form the "skeleton" of the axon are exposed to the alkaloid colchicine, microtubules are broken down and the axon soon withdraws into cell body.



EFFECT OF COLCHICINE on the axons of a nerve cell is dramatic. Growth continues for perhaps half an hour; the first micrograph shows the cell 17 minutes after the alkaloid was added to the culture dish. The axons begin to collapse after 25 minutes (*second micrograph*), shrink further after 32 and 38 minutes (*third and fourth*) and are mostly withdrawn into the cell body after 45 minutes (*fifth*). Thin filaments are found in cell but no tubules.

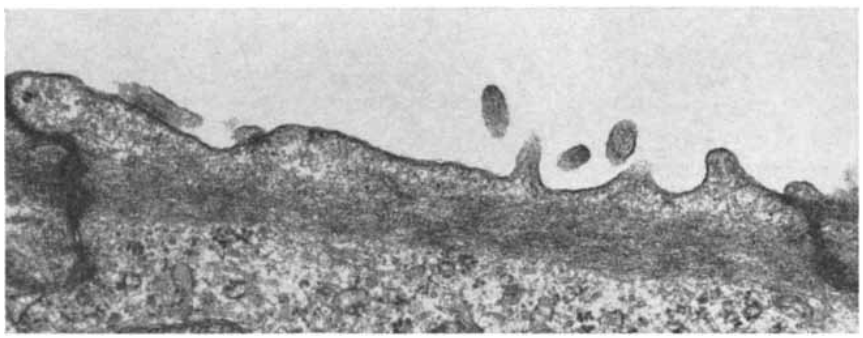
Similarly, in a migrating cell the undulating membrane that pulls the cell forward is filled with a network of microfilaments.

In the case of the nerve cell, when Yamada added cytochalasin to the culture medium, the axon stopped elongating within a few minutes. The microspikes wilted and retracted into the growth cone, and the tip as a whole rounded up and ceased to move over the substratum. Examination with the electron microscope showed that the filamentous network had become a mass of short, densely packed filaments. Treatment of migrating cells with cytochalasin altered the network of microfilaments in the undulating membrane in a similar way, stopping the cell's movement and causing the surface membrane to sink back toward the cell nucleus.

The most extraordinary feature of these experiments is the reversibility of the drug's effect. Even after hours of immobilization under cytochalasin's influence the cells recover their mobility when the drug is removed from the medium. The filamentous network is restored, the nerve cell's growth tip and the migratory cell's undulating membrane regain their normal structure and movement is resumed.

The accumulating evidence, although indirect and circumstantial, leaves little doubt that the microfilaments are indeed the "muscles" that actuate the cell movements, particularly since there are no other visible structures in the cells that could plausibly play that role. What is the chemical mechanism that gives the microfilaments the power to contract? This is still an unanswered question. Studies of primitive organisms suggest a possible answer. Certain biochemical investigations of slime molds and protozoans indicate that the microfilaments may be composed of a substance like actin, the contractile protein that is an important component of muscle in the higher animals.

When we turn to investigation of what is involved in the change of shape in cells and cell populations, it becomes apparent that here too the active agents are the microfilaments. Their role has been demonstrated in events such as the shaping of a bird's oviduct and of a mammal's salivary gland during development of the embryo.



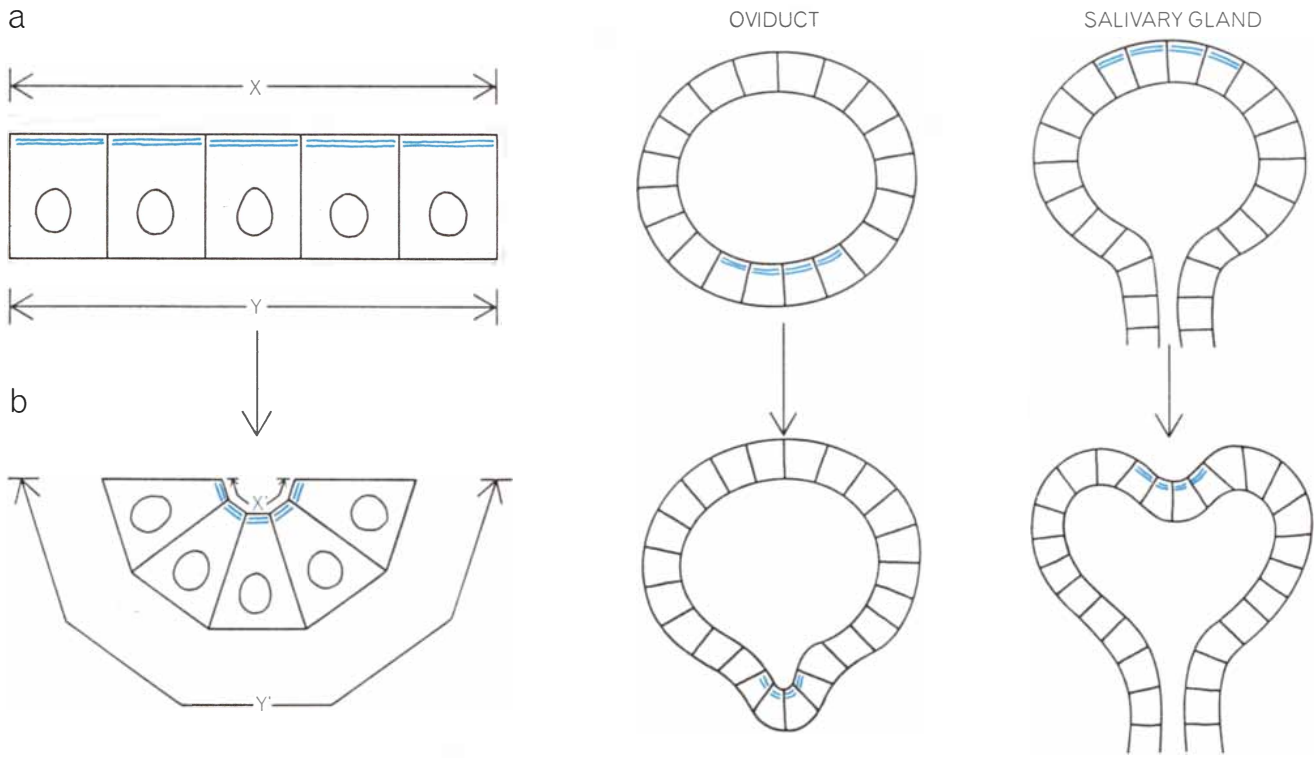
CELL "MUSCLE," which can produce changes in the shape of cells, is made up of microfilaments arrayed in bundles. Seen in the micrograph is such a bundle, lying parallel to the surface of an epithelial cell in the oviduct of a bird. The drug cytochalasin, the secretion of a fungus, has the property of disrupting microfilament "muscles" (*see illustration below*).

FILAMENT BUNDLES have disappeared in the surface region of an oviduct cell similar to the one at top. Cytochalasin was added to medium in the culture dish. The filaments will reorganize themselves into bundles once cytochalasin is removed even though the cell can no longer make protein, suggesting that the filaments were dispersed, not destroyed.

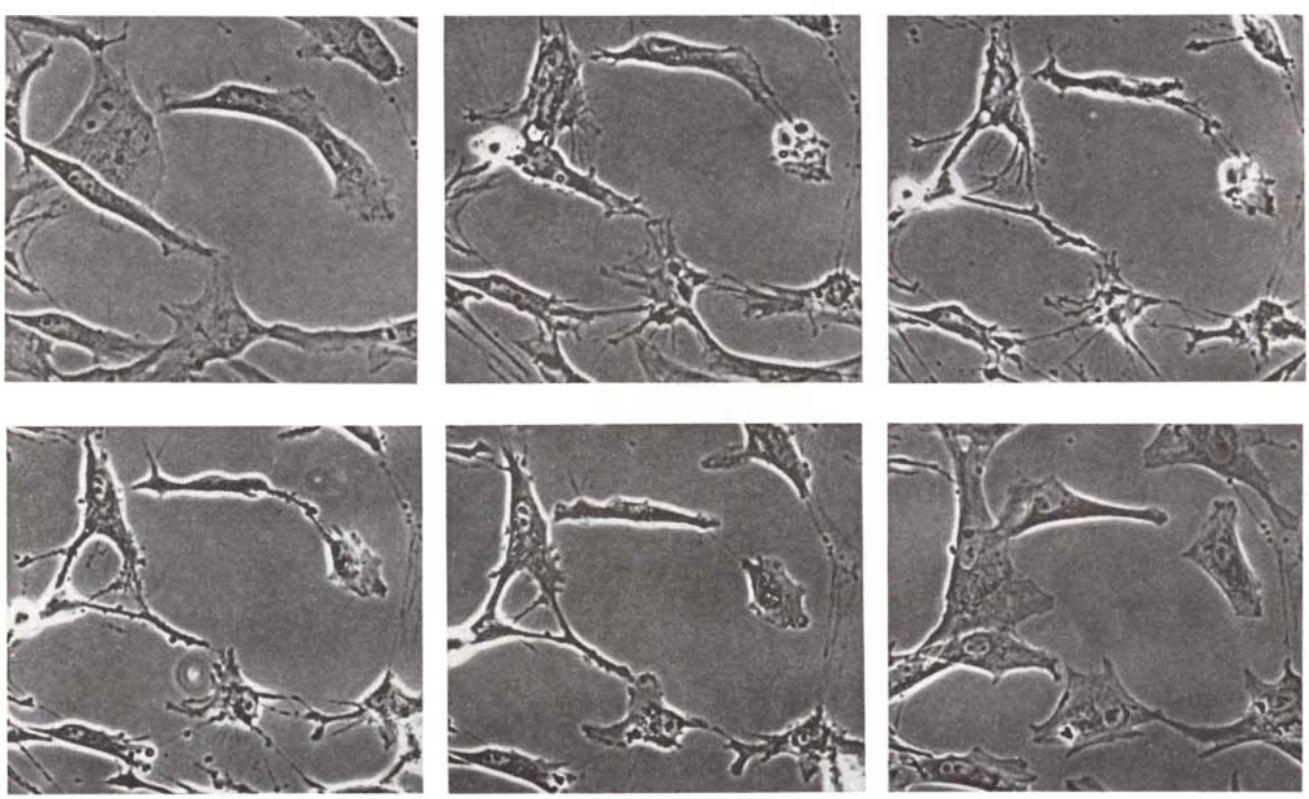
Consider the form of the oviduct in a mature bird that has reached the egg-producing stage. The wall of the organ bulges outward in many places in finger-like structures known as tubular glands. The glands form originally as small knoblike bulges in the oviduct wall. Microscopic inspection shows that on the inner side of such a bulge some of the cells are narrowed at one end. The narrowness accounts for the curvature and rounded shape of the bulges. If the cells are examined at the time of narrowing, bands of microfilaments are seen running across the cell. In all likelihood it is the contraction of these filaments that causes the narrowing. The filaments are the only observable structures in the cell that are oriented in a manner that could produce such a result.

My associate Joan Wrenn investigated development of the oviduct, speeded up by artificial means, in very young chicks. An injection of the female hormone estrogen can stimulate the oviduct to develop prematurely. Mrs. Wrenn found that after estrogen was administered to a five-day-old chick, within 24 hours bands of microfilaments formed across the inner ends of the cells in the embryonic oviduct, and tubular glands soon began to bulge from the tissue. It turned out that the drug cytochalasin could halt this process just as it did the movement of a migrating cell or a cell's mitotic division. The drug disrupted the bands of microfilaments in the cells and caused the glands to sink back into the oviduct structure so that it reverted to a knobless cylinder.

The formation of a mammal's salivary glands is physically opposite to that of a bird's oviduct; instead of there being bulges, a number of folds and clefts develop in the corpus of the salivary gland, with the result that it becomes a branching, treelike structure. This process is due to narrowing of the outer ends of cells at the point of the cleft; as in the bird oviduct bands of microfilaments are found at the narrowed cell ends. Cytochalasin will reverse this development too: it disrupts the microfilament bands, smooths out the clefts and folds in the salivary gland and causes the entire organ to flatten into a thin, cookie-like sheet. When the drug is removed from the culture medium, the gland recovers in a spectacular fashion. Within 18 hours it re-forms deep clefts, with thick bands of microfilaments reappearing at the bases of the clefts. Interestingly, the recovery takes place even if the cells are treated with drugs that inhibit the synthesis of new protein. The re-formation of microfilament networks also occurs in



CHANGES IN CELL SHAPE produce movement in a sheetlike array of adjacent cells. In an ideal sheet of cells (*a*) distances at top and bottom of the array (*x*, *y*) are equal as long as the line of microfilaments (*color*) does not contract. Following contraction (*b*), however, the distance at top is reduced (*x'*) and the distance at bottom (*y'*) is the same or greater. Similar contractions make cells push out into the tissue surrounding a maturing oviduct or intrude into the central cavity of the salivary gland (*right*).



REVERSIBILITY of cytochalasin disruption is demonstrated in these micrographs of cells from embryo heart tissue. The top three micrographs show cells in untreated medium (*left*) and cells after six minutes' exposure (*center*) and 11 minutes' exposure (*right*) to cytochalasin. The bottom three micrographs record the recovery of the cells. The first (*left*) shows the cells two minutes after the cytochalasin was removed from the culture dish, the next (*center*) shows them after five minutes and the last (*right*) an hour later.

other situations in which protein is not being produced. It seems likely, therefore, that cytochalasin does not destroy the microfilaments themselves but only disrupts their cooperative aggregation and activity.

We arrive at the apparently inescapable conclusion that the normal shaping of organs, as well as the migration and other movements of cells, depends on the integrity and action of microfilament systems. In the case of the developing oviduct we know what elicits the formation of the microfilament bundle; the inciting agent is the hormone estrogen. We are still in the dark, however, as to the mechanism that triggers microfilament systems to contract. Obviously it is important to understand this process, because it determines when organs are formed and what their shape will be as well as when cells may migrate or nerve axons may elongate.

What might the control mechanism be? We know that the contraction of muscles is activated by nerve impulses. A single migrating cell is not connected to nerves, however, nor does a cell population that is being shaped into an organ usually have any contact with nerves. A hint as to the identity of a possible activating agent in cells was furnished by experiments performed by the British investigator David Gingell. He found that an injection of calcium ions into an amphibian's egg caused the surface of the egg at the injection site to contract. Short lengths of filamentous material showed up near the site.

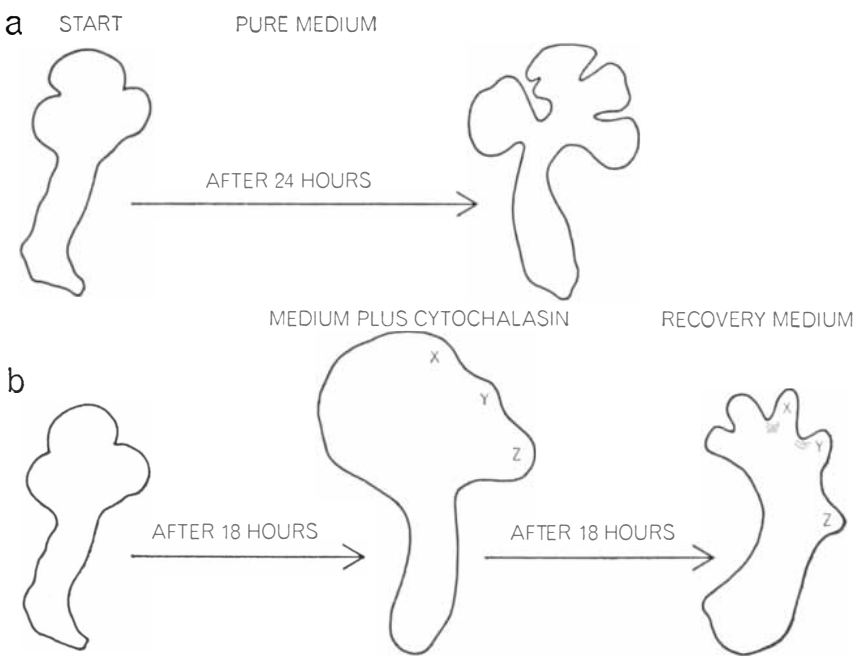
Now, it is well known that calcium ions are involved in the contraction of muscle. Might they also perform a similar function at the cell level? My colleague J. F. Ash proceeded to experiment with the calcium treatment, using early embryos of the African clawed toad (*Xenopus laevis*). He inserted the tip of a very fine hollow electrode into cells just through the surface membrane. When a current was applied, calcium ions flowed from within the electrode into the cells. The egg cortex rapidly contracted, and within minutes the electrode was surrounded by a dense black halo composed of pigment granules. Examination of the individual cells with the light microscope and the electron microscope revealed a distinctive band of dense material, largely composed of microfilaments, running through the cytoplasm across the site where the ions had entered the cell. A distinct network of microfilaments could not be discerned, but this may be attributable to the fact that amphibian cells are notoriously difficult to preserve intact for examination with the electron microscope. The observed presence of microfilaments, however, was consistent with the hypothesis that a network of filaments had been formed in the area where calcium had instigated contractions.

An intriguing question immediately presented itself: Would treatment with cytochalasin counteract the effect of calcium? The answer was clear. Within 10 minutes after the drug was applied the cells of this amphibian embryo lost all capacity to respond to calcium ions. The injection of calcium produced no contraction of the cell cortex, nor did it cause a dark halo to form at the site of injection. Here, then, was a link to the behavior and possible contraction mechanism of other cells that exhibit movement: the migratory cells and those that change shape. Since they are sensitive to cytochalasin, it seems likely that in those cells, as in the cells of the *Xenopus* embryo, calcium is the agent that controls contraction.

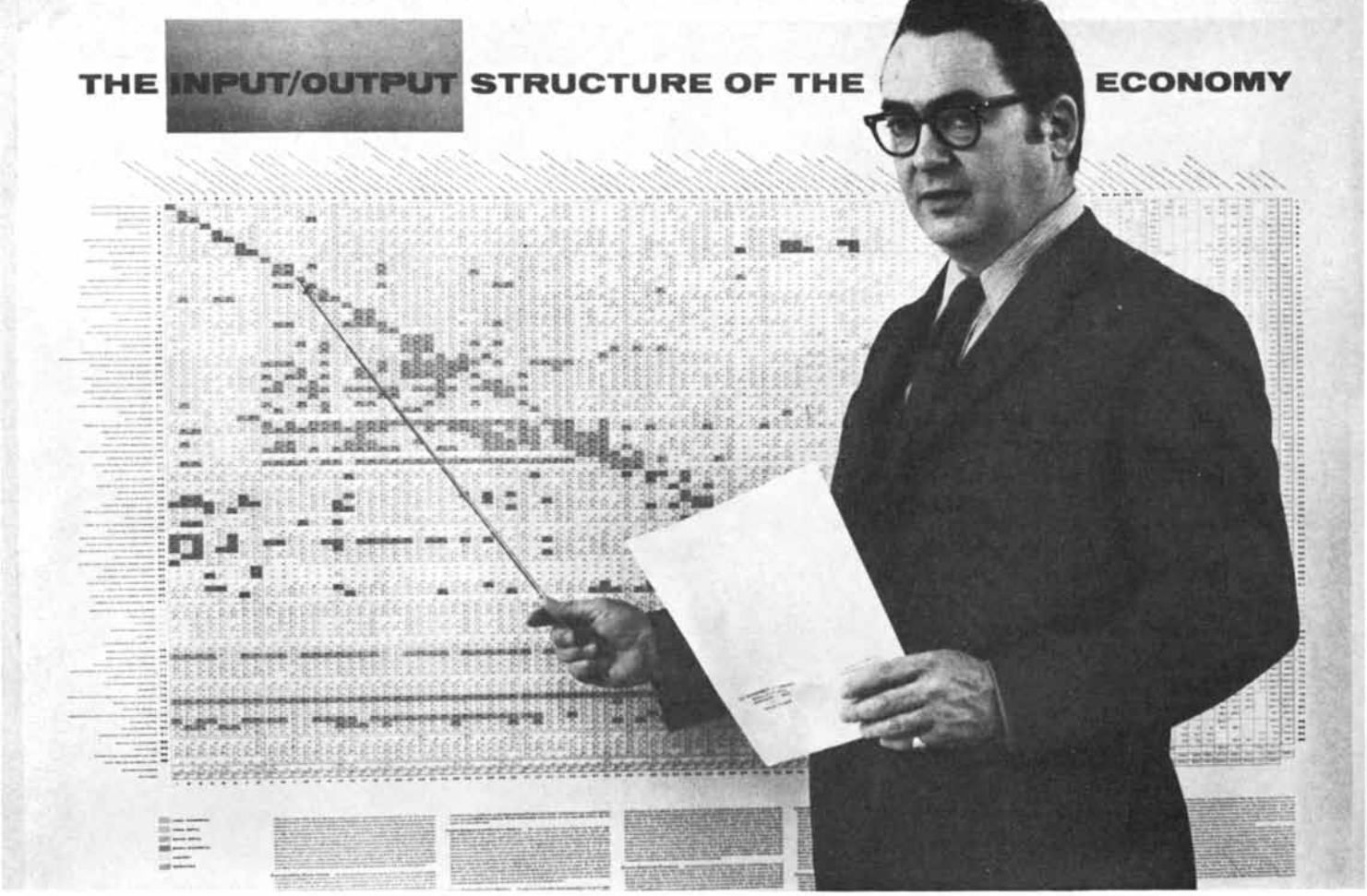
Further experiments with the *Xenopus* embryo brought forth another interesting finding. The cells of this embryo, like those of most other early embryos, have the capacity to heal a wound in the cell surface. When a small rip is made in the surface membrane with a needle, the edges of the wound first spread apart and then within minutes are drawn together by contraction to close the opening. This contraction and healing takes place only if calcium is present in the bathing medium. On the other hand, treatment with cytochalasin prevents the healing response. The wound gradually enlarges, even in the presence of calcium, and eventually the cell bursts.

A uniform and consistent picture is beginning to emerge. It appears that the various forms of cell movement—the healing of wounds in normal embryonic cells, the migration of individual cells, the division of cells at mitosis, the shaping of cell populations into organs—are all produced by a common mechanism: systems of contractile microfilaments. It also appears that calcium may play a key role in instigating contraction of this cellular system, just as it does in producing the contraction of skeletal muscles.

If this hypothesis is correct, a crucial question remains to be answered. How is the calcium control called into play? Is this activating substance stored away somewhere in the cell when the cell has no need for movement or operation of the microfilaments? If so, how is it released on demand to spark the important cell movements on which normal development and life depend? And what happens if, through some aberration, the calcium activator is released needlessly, initiating cell movements that can serve no good purpose?



NORMAL AND ABNORMAL BEHAVIOR of an epithelium from a salivary gland was traced in the presence and absence of cytochalasin. The control tissue (*a*) grew in a medium lacking the drug; 24 hours later its clefts had grown deeper and its ramifications were more numerous. After 18 hours in medium that included the drug the test tissue (*b*) showed greatly reduced clefts. With drug removed clefts soon reappeared, as did filaments (*color*).



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

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

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

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

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

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

Input/Output Economics
by Wassily W. Leontief

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

The Structure of Development
by Wassily W. Leontief

The Structure of the U.S. Economy
by Wassily W. Leontief

The Economics of Technological Change
by Anne P. Carter

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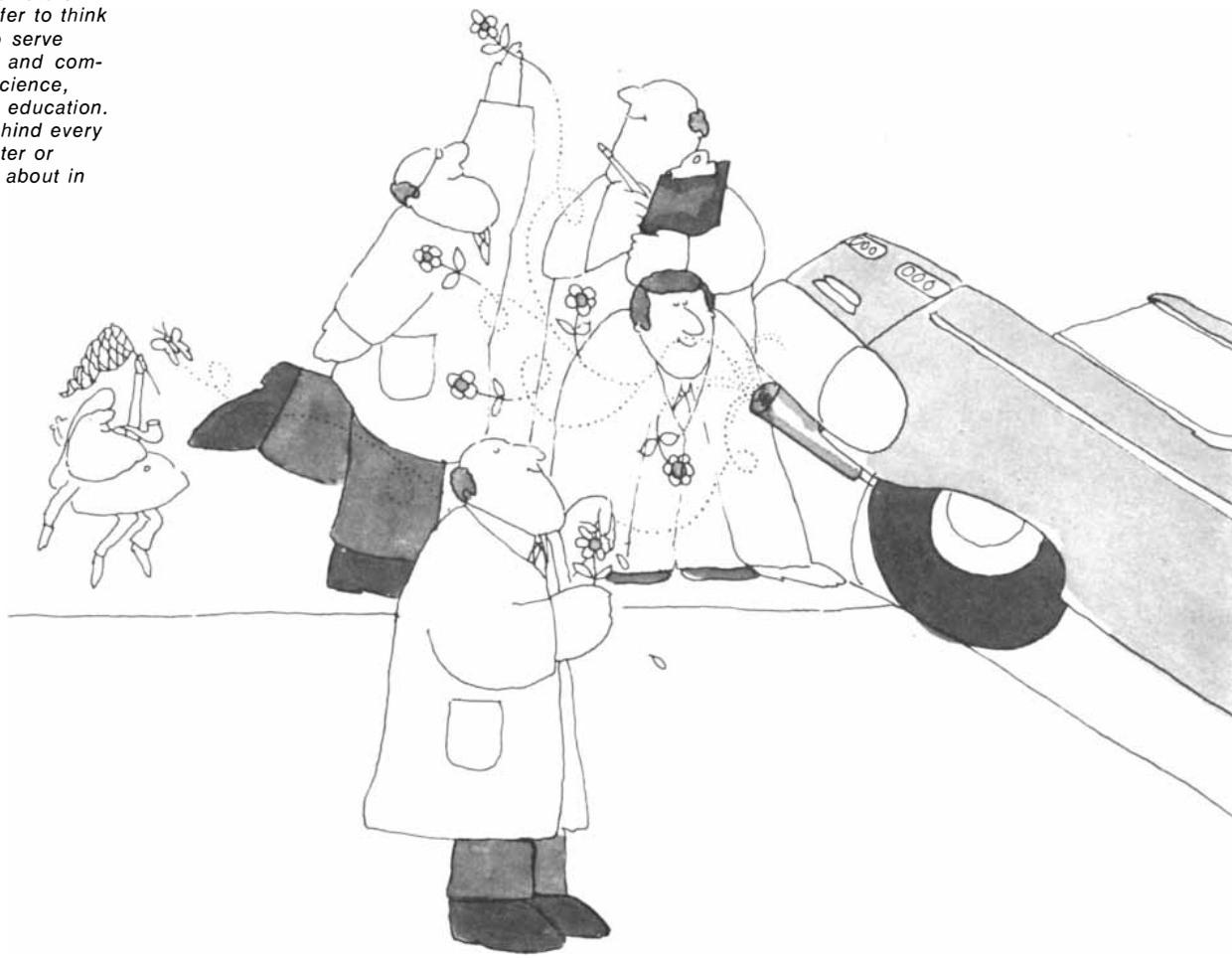

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MÖSSBAUER SPECTROSCOPY

A physicist's discovery is providing chemists with sensitive measurements of the energy states of atomic nuclei, thereby supplying new clues to the architecture of complex molecules

by R. H. Herber

One of the most useful new tools available to the chemist for the study of molecular structure and molecular bonding is a form of spectroscopy based on the Mössbauer effect, for which Rudolf L. Mössbauer was awarded the Nobel prize in physics for 1961. Three years earlier Mössbauer had found that gamma rays of extremely precise wavelength can be obtained from suitable radioactive sources if the emitting atoms are incorporated in a crystal structure capable of uniformly absorbing the recoil energy of the gamma rays. Unless the atoms are so incorporated the gamma rays emerge with a spectrum of energies depending on how the total energy is divided between the emitted photon (gamma ray) and the recoiling source. If the source is free to recoil randomly, it can be compared to a rifle that is fired while it is suspended in midair; when the source is securely held in a crystal, it is like a rifle rigidly anchored on a test stand.

A typical gamma ray emitter that shows the effect discovered by Mössbauer is iron 57, which is produced by the decay of radioactive cobalt 57. (The numbers refer to the total number of protons and neutrons in the nucleus.) When iron 57 is first produced, it is in an excited energy state; in dropping to the ground state, or lowest energy state, it emits a gamma ray. If the emitted gamma ray strikes a target containing iron 57 in the ground state, the gamma ray will ordinarily be absorbed, raising the target nucleus from the ground state to the first excited state. If for any reason the ground-state energy of the target has a value slightly lower or higher than the "normal" value (which must be defined), the incident gamma ray will continue on undisturbed. By placing a gamma ray detector in line with the emitter and target one can readily tell whether or not absorption has taken place.

With Mössbauer's method for obtaining gamma rays of precise wavelength, the difference between absorption and nonabsorption could be made so critical that one could detect extremely slight changes in the ground-state energy of the target nucleus. For example, physicists were able to confirm Einstein's prediction that the wavelength of radiation emitted by a source in a gravitational field is dependent on the strength of the field. This was tested simply by placing the source several meters higher than the absorber in the earth's gravitational field; under these conditions the wavelength of the emitted gamma rays no longer coincided exactly with the wavelength needed to excite the target nuclei from the ground state. Such applications of the Mössbauer effect are obviously far removed from the study of the chemical nature of matter. In the early days (1958–1959) about the only visible connection between the Mössbauer effect and chemistry was to be found in one physicist's advice: "For the preparation of a good recoilless emission source find yourself a good chemist."

Although the Mössbauer effect continues to be useful to physicists, it has emerged as a very general and powerful tool in the hands of the physical chemist. Mössbauer-effect spectroscopy is now used extensively for studying chemical bonds, the architecture of molecules and the distribution of electronic charge around atoms. It has joined other tools (such as visible-light spectroscopy, infrared spectroscopy, nuclear magnetic resonance and X-ray diffraction) in providing fundamental information about the way atoms are put together to form molecular structures. Like nuclear-magnetic-resonance spectroscopy, Mössbauer-effect spectroscopy extracts molecular information by reporting on conditions inside atomic nuclei. Thus it operates at a deeper level than infrared spectroscopy and X-ray diffraction, whose results are supplied primarily by electrons.

What the Mössbauer effect provides is a probe for examining how the energy state of an atomic nucleus is altered, however slightly, by the other atoms in a molecular configuration. Ordinarily atomic nuclei are in the ground state. The precise level of this state, however, is minutely perturbed by the molecular environment in which the nucleus finds itself. The chemical origin of these perturbations was identified in 1960 by O. C. Kistner and A. W. Sunyar of the Brookhaven National Laboratory. They recognized that according to the principles of quantum mechanics the electrons that ordinarily surround the nucleus have a finite probability of being found inside it. Electrons can therefore interact with nuclear matter (particular protons) and modify nuclear energy states. The degree of modification is changed slightly when the nucleus is incorporated in different kinds of molecules, each of which modifies the electronic environment in a distinctive way. In many cases the radius of the nucleus also varies according to the energy state, so that a given nucleus will interact differently with a given electronic environment, depending on whether it is in a ground state of given radius or in a higher energy state of different radius.

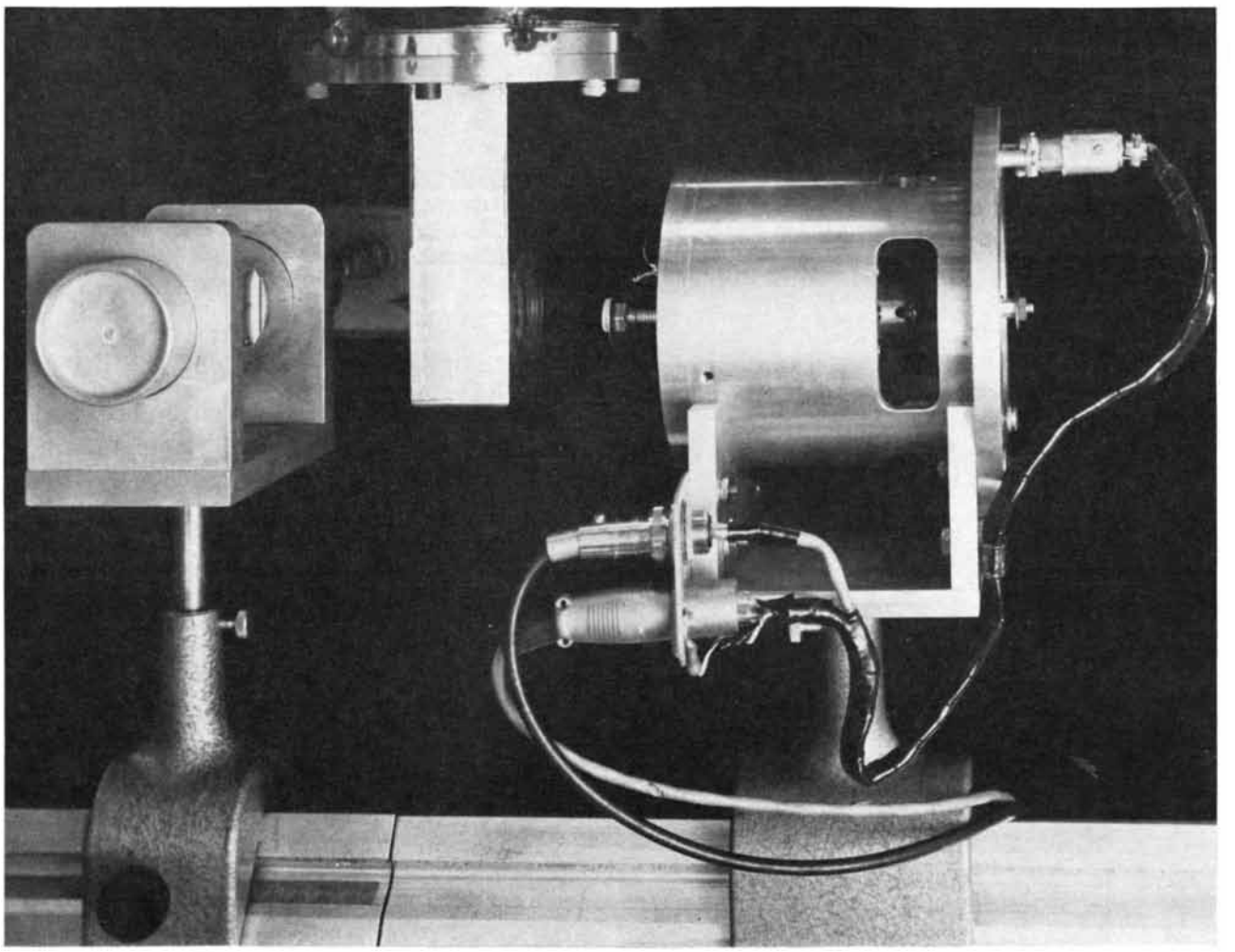
In order to probe the energy states of a particular atomic nucleus by the Mössbauer effect one must have a source consisting of the same element in an excited state. To obtain a nucleus in an excited

state one must usually find a radioactive nuclide (nuclear species) that yields the desired nuclide in an excited state when it decays. At the present time suitable sources have been found for about 40 of the known elements [*see top illustration on page 90*]. Because of their particular properties, however, the three nuclides that have been found most useful for Mössbauer-effect spectroscopy are cobalt 57, which decays to iron 57, tin 119 (produced by the decay of a long-lived isomeric state of the same isotope) and iodine 129 (produced by the decay of tellurium 129). With these nuclides as gamma ray sources chemists have been able to study a wide range of compounds of iron, tin and iodine.

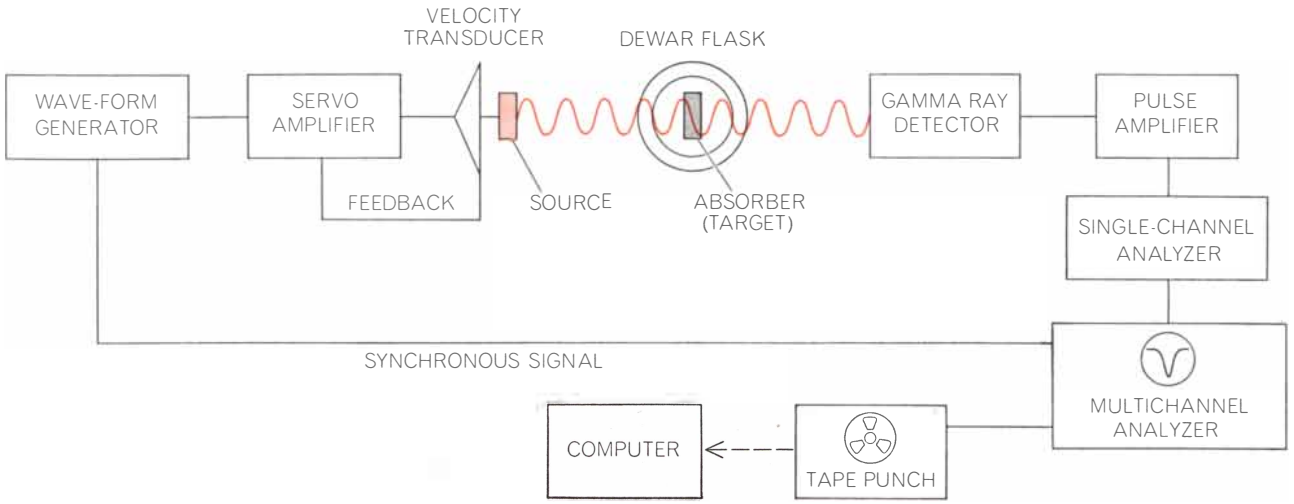
Since the energy state of a nucleus is altered by its chemical environment, how does one obtain a gamma ray of exactly the right frequency to be absorbed? The answer is that one changes the frequency of the gamma rays directed at the target by moving the source and the absorber with respect to each other. If the source is moving toward the absorber, the gamma rays have a slightly higher frequency (shorter wavelength) than they do if the source and the absorber are kept stationary. Conversely, if the source and the absorber are made to travel in opposite directions, the gamma rays reach the absorber at a slightly lower frequency. Such changes in frequency produced by relative motions of source and target are familiarly known as Doppler shifts. When the energy of the gamma radiation just matches the energy of the lowest-lying state of nuclei in the absorber, the radiation is absorbed. To be precise, the gamma rays are absorbed and almost instantly (within about 10^{-9} second) reemitted in all directions, a phenomenon called resonance fluorescence. At this point the absorber acts as a uniform scatterer, so that a significant fraction of the gamma radiation incident on the absorber is no longer transmitted through the sample and hence does not reach the radiation detector located behind it.

A Mössbauer-effect spectroscope consists of a means for moving the source and the absorber with respect to each other and for plotting the intensity of the gamma rays transmitted by the sample at each instant as the relative velocity varies [*see illustration below*]. If the transmission is plotted as a function of relative velocity, it will be seen to go through a minimum when the frequency of the incident gamma rays exactly coincides with the frequency needed to excite the nuclei in the absorber.

A typical Mössbauer-effect spectrum is characterized by a magnitude, a line position and a line width [*see bottom*



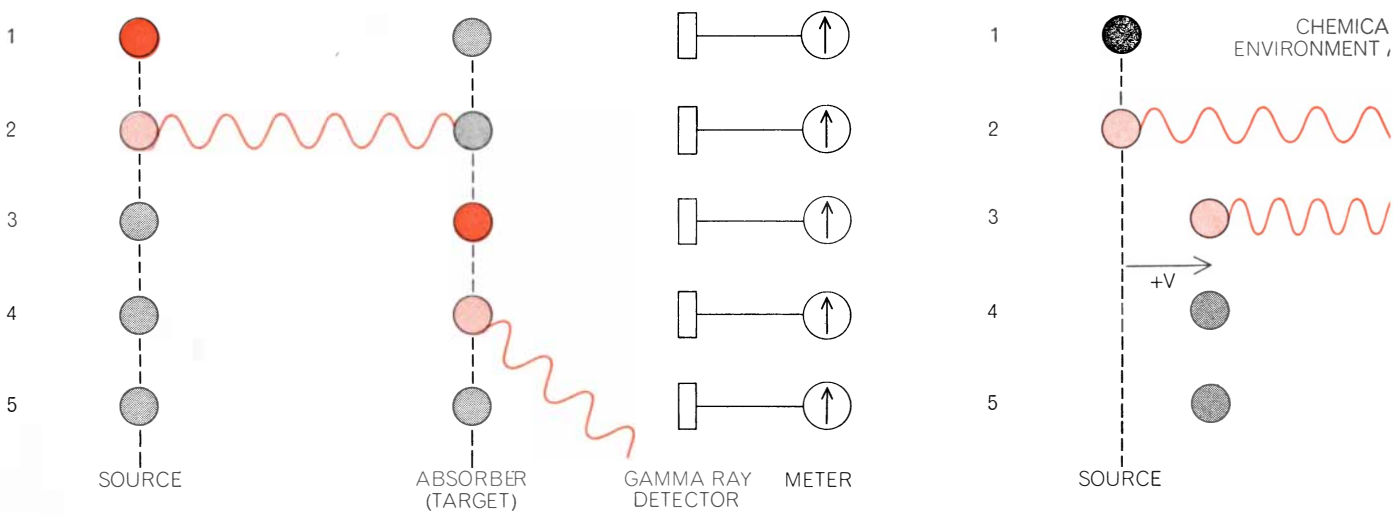
MÖSSBAUER-EFFECT SPECTROSCOPE is shown in the author's laboratory at Rutgers University. A gamma ray source is mounted on a thin rod attached to an electromechanical velocity transducer (*cylindrical object at right*). The radiation passes through the experimental sample held in a liquid-nitrogen Dewar flask (*center*) and impinges on a lead-shielded gamma ray detector (*device at left*). The velocity transducer and detector are mounted on optical rails to allow changes in geometry as may be required by the experiment.



EXPERIMENTAL ARRANGEMENT for performing Mössbauer-effect spectroscopy utilizes the components shown here in schematic form. The wave-form generator imparts a precise periodic motion to a velocity transducer that carries the source toward and away from a sample substance, the absorber, held at cryogenic temperatures in the Dewar flask. The purpose of the transducer is to induce precise changes in the frequency of the gamma rays (*color*) produced by the excited atomic nuclei in the source. When the frequency of the gamma rays exactly matches the frequency needed to excite the nuclei in the sample, some of the gamma radiation is absorbed. This change is sensed by the gamma ray detector and is depicted on the screen of the multichannel analyzer.

illustration on page 90]. The shorter the lifetime of the nuclear excited state, the larger the observed line width. One of the impressive features of Mössbauer-effect spectroscopy is the small amount of modulation energy needed to shift the energy of the source with respect to the absorber by a single line width. For iron 57 the "natural" line width (calculated from the lifetime of the excited state) is only 4.67×10^{-9} electron volt. Since an experiment using the Mössbauer effect involves both a source and an absorber, the minimum line width that can be observed is twice the natural line width; in the case of iron 57 it is 9.34×10^{-9} electron volt. Since the energy of the gamma ray emitted by a nucleus of iron 57 in going from the first excited state to the ground state is 1.44×10^{4} electron volts, it is seen that the minimum modulation energy is only 6.5×10^{-13}, or about six parts in 10 trillion, of the nuclear excitation energy.

It must not be concluded, however, that a Mössbauer experiment provides knowledge of the energy of a nuclear transition to six parts in 10 trillion. In fact, the energy is usually known only to about one part in 10,000 or 100,000. What one can determine with extraordinary precision is whether two excitation energies (that of the source and that



MÖSSBAUER EFFECT can measure with great precision the degree to which the ground-state energy levels of atomic nuclei are shifted by the chemical environment in which the nuclei find themselves. In the sequence at the left the source and the target are nuclei of the same element in the same chemical environment, hence both have the same ground-state energy. The source, however, is in the first excited state, indicated by the dark color (*1*). When it drops to the ground state, it emits a gamma ray whose frequency is exactly right for absorption by the target nucleus (*2*), which raises it to the first excited state (*3*). After an instant, typically 10^{-9} second, the target nucleus emits a gamma ray (*4*) and drops to the ground state (*5*). Since the gamma ray is emitted randomly in any direction it is unlikely to strike the gamma ray detector. In the middle sequence the target nucleus is incorporated in a molecule (*chemical environment A*) that slightly depresses the ground state of the nucleus (*1*). The gamma ray normally emitted by the source now lacks sufficient energy to raise the target nucleus to the first excited state and therefore travels harmlessly by and

of the absorber) match to within a small fraction of a line width. This is somewhat analogous to the experience of a man who drives his car from New York to San Francisco and at the end of the trip drives into his garage. If he drives six inches too far he can hear (and feel) the mismatch in distance, and he will have a damaged bumper (and garage) as proof. This does not mean, however, that he now knows the distance from New York to San Francisco to within six inches. In a Mössbauer experiment one can similarly tell quite readily if two energies match (or nearly match) without knowing exactly the absolute value of the energies.

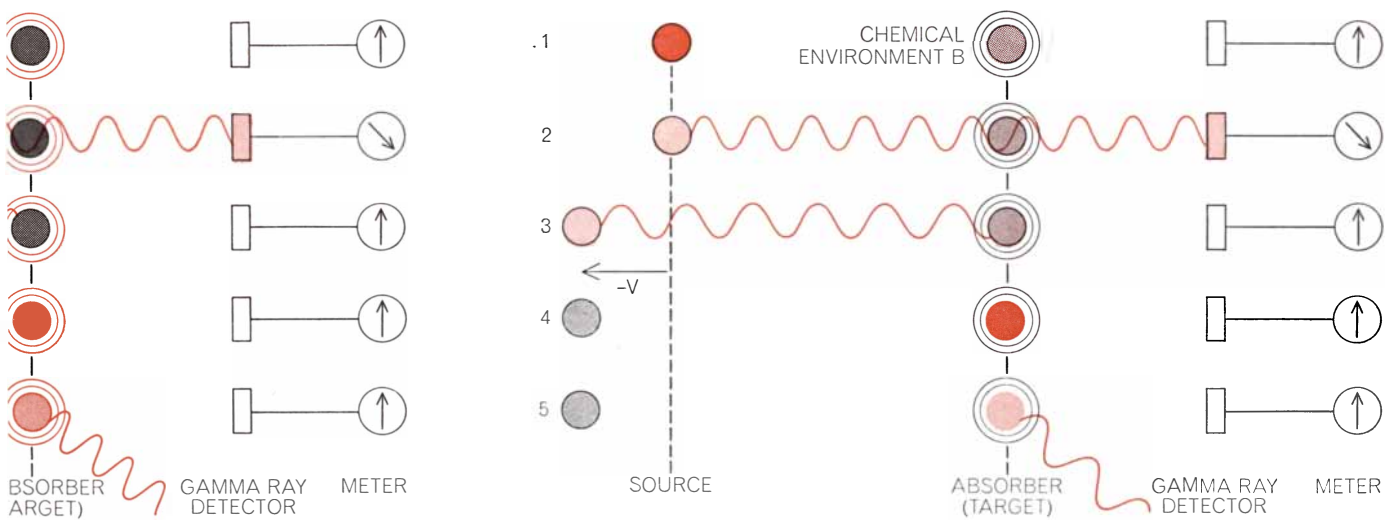
Let us consider briefly the situation that arises in a Mössbauer experiment in which the source atom is in a chemical state *A* and the absorber atom is in a chemical state *B*. Because of the difference in chemical environments the energy that separates the ground state from the excited state is not identical in the source nucleus and the absorber nucleus. If the energy gap in the absorber is larger than the energy gap in the source, the gamma ray emitted must be given an energy increment to compensate for the larger energy required to pump the absorber nucleus from the ground state to the excited state. Conversely, if the energy gap in the absorber is smaller than it is in the source, energy must somehow be abstracted from the incident gamma ray for pumping to occur [*see bottom illustration on these two pages*].

The changes in the energy gap brought about by changes in the chemical environment are typically on the order of 5×10^{-8} electron volt for iron 57 and tin 119. This difference is so small it can readily be supplied by a modest relative motion between the source and the absorber, referred to as the Doppler velocity. The required Doppler velocity is the shift in the energy gap (say 5×10^{-8} electron volt) divided by the total transition energy (1.44×10^{4} electron volts) multiplied by the velocity of light (3×10^{10} centimeters per second), or roughly one millimeter per second. Velocities of this magnitude can be obtained in many ways, but the simplest scheme is to employ an electromechanical transducer. A "woofer" speaker of the type used in high-fidelity sound systems does very nicely. The gamma ray source is usually attached to a rod that is rigidly mounted on the cone of the speaker. The cone is caused to oscillate very precisely (in terms of its amplitude and frequency) at about five cycles per second by means of an electrical signal produced by a sine-wave or triangular-wave generator.

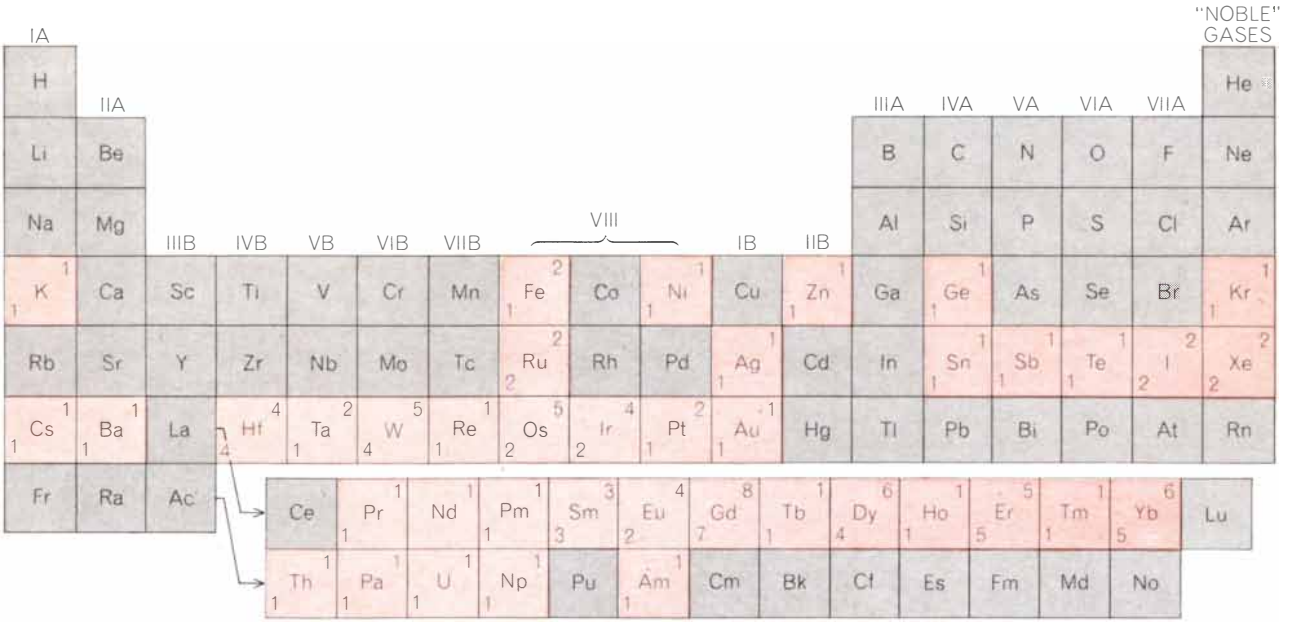
The relative velocity that is required between the source and the absorber to just compensate for the difference in energy caused by the difference in the chemical environment around the source and the absorber is called the isomer shift (or sometimes the chemical shift). It is commonly expressed in units of millimeters per second or centimeters per second. When tin 119 is used in Mössbauer spectroscopy, one finds that stannous compounds, in which the tin atom has given up two electrons (written Sn^{2+}), and stannic compounds (Sn^{4+}), in which the atom has lost four electrons, exhibit distinctly different isomer shifts [*see bottom illustration on page 92*]. As a result the charge state of the metal atom can be directly determined from the spectrum.

It should be noted that Mössbauer spectroscopy involves the matching of two transition energies: the energy in the source with the energy in the absorber. As a result the isomer shift always reflects the difference in energy between two chemical states; therefore absolute values of the isomer shift have little significance. For this reason isomer shifts are frequently expressed as shifts of the resonance line from some selected standard. When spectroscopy is done with iron 57, the standard is commonly metallic iron or the nitroprusside compound $Na_2[Fe(CN)_5NO] \cdot 2H_2O$. For tin 119 the reference lines are usually provided by SnO_2, $BaSnO_3$ or metallic tin in the alpha-crystalline state.

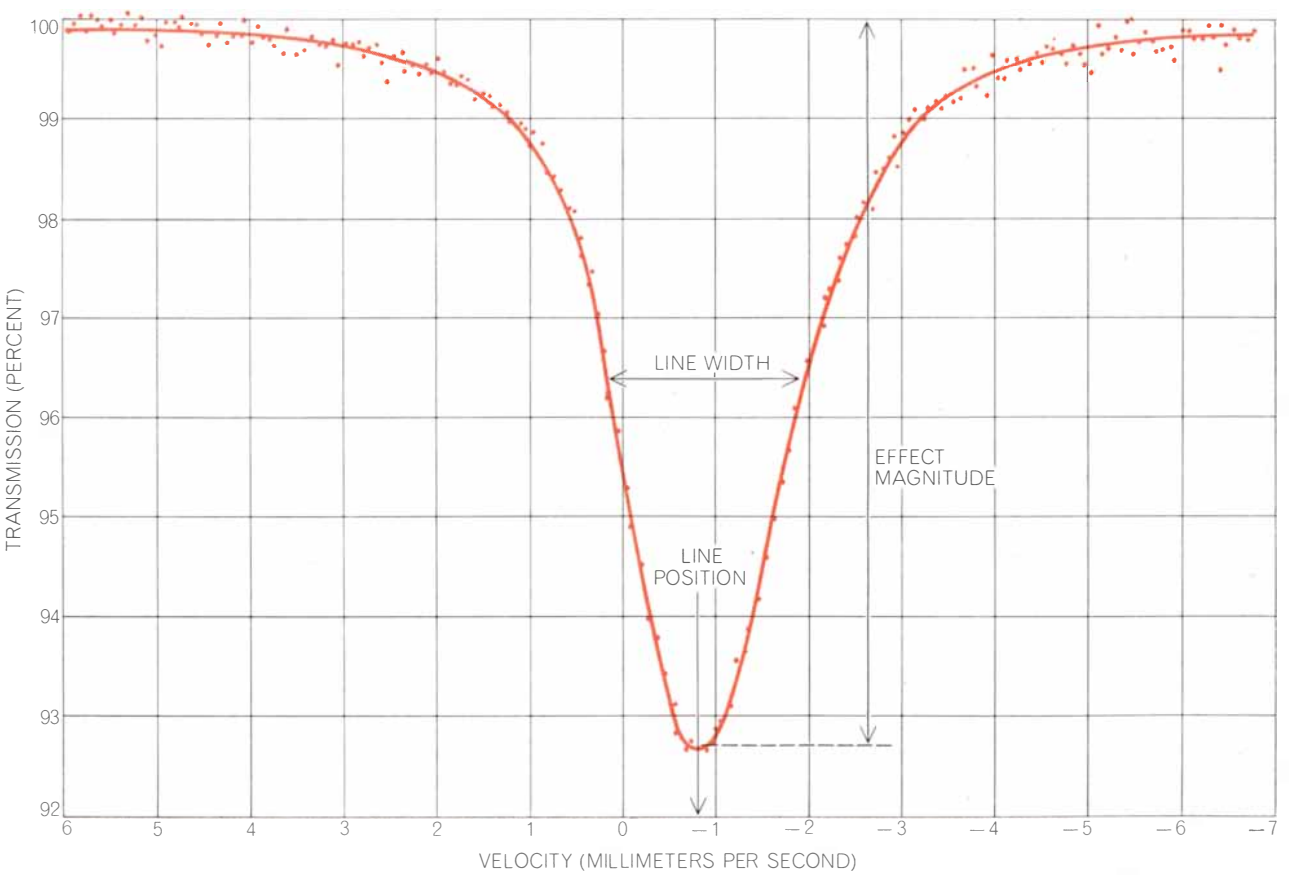
One of the most fruitful applications of isomer-shift measurements has been



strikes the detector (2). To provide the extra energy needed the source is given a velocity ($+V$) toward the target; the emitted gamma ray is now absorbed (3), raising the target nucleus to the first excited state (4). When it drops to the ground state, the gamma ray it emits has the same energy as the one it absorbed; the emitted radiation, as before, has a low probability of reaching the detector (5). In the sequence at right the target nucleus is held inside a molecule (*chemical environment B*) that slightly raises its ground-state energy (1). The gamma ray normally emitted by the source is therefore too energetic to be absorbed and thus continues unimpeded to register in the detector (2). A gamma ray of diminished energy is produced by giving the source a negative velocity ($-V$); the gamma ray of lowered frequency is absorbed (3). The target nucleus is raised to the first excited state (4) and almost immediately emits a gamma ray similar to the one it had absorbed (5). By correlating the velocity changes needed to create gamma rays of the right energy for absorption by the target one can establish how the ground states of nuclei are altered by their chemical environment.



MÖSSBAUER-EFFECT ELEMENTS, elements whose nuclei exhibit energy transitions in which the Mössbauer effect can be studied, now include 40 (*color*) of the 103 elements in the periodic table. The number at the lower left corner of a colored box indicates the number of nuclides of the element in which the Mössbauer effect has been observed. The number in the upper right corner shows the number of observed energy transitions; it can be greater than the number of nuclides if a nuclide exhibits more than one transition. The great majority of chemical studies have involved three nuclides: iron 57, tin 119 and iodine 129 (symbols Fe, Sn, I).



SIMPLE MÖSSBAUER SPECTRUM consists of a single resonance maximum, which appears as a sharp reduction in the flux of gamma rays reaching the detector. The extent of the reduction is termed the effect magnitude. The line position is read on the horizontal scale, which shows the velocity, plus or minus, imparted to the source. The line width is read at one-half the effect magnitude.

in clarifying the concept of electronegativity. The term refers rather loosely to the ability of an atom to attract electrons to itself. For the chemist it provides a qualitative understanding of the relative bonding properties of different atoms or groups of atoms that can form a bond with the same atom.

It turns out that the isomer shift for tin 119 is a sensitive function of the electronegativity of atoms bonded to the tin. The isomer shift for tin chloride ($SnCl_4$), tin bromide ($SnBr_4$) and tin iodide (SnI_4) varies in a systematic way with the electronegativity of chlorine, bromine and iodine, three elements that belong to the same chemical family: the halides. A similar observation has been made in my laboratory at Rutgers University for the octahedral complexes of tin with fluorine, chlorine, bromine and iodine (general formula SnX_6^{2-}) and for the mixed complexes of these elements such as $SnCl_2I_4^{2-}$. Since it is also possible to synthesize tin compounds containing six such groups as cyanate (NCO^-) and azide (N_3^-) in a structure closely related to that of the hexahalogen complexes, one can also estimate their electronegativity from measurements of the isomer shift. Since the electronegativities of such groups cannot be calculated in the same way as the electronegativities of single atoms, there had been much speculation in the literature as to their appropriate values. One can appreciate that the information supplied by Mössbauer spectroscopy has been very helpful to chemical theoreticians in their effort to gain a clearer understanding of bonding interactions in complex molecules.

So far I have described only how Mössbauer studies elucidate an atom's chemical environment by indicating changes in the electron density at the atom's nucleus. One can also employ Mössbauer spectroscopy to extract information about the shape of the distribution of electronic charge around the nucleus and thereby learn something about a molecule's symmetry and architecture. The states of nuclei are characterized not only by their energy but also by a spin quantum number. For nuclei with an even number of nucleons (protons and neutrons) the spin quantum number is either zero or some integral number (±1, ±2, $\pm3\ldots$); for nuclei with an odd number of nucleons the spin quantum number is an integral multiple of 1/2 ($\pm1/2$, $\pm3/2\ldots$).

It is observed that nuclei with spin states having half-integral quantum numbers larger than 1/2 are often "degenerate" (that is, several states have precisely the same energy) when they are placed in a uniform electrostatic field. The degeneracy can be removed when the shape of the electrostatic field is suitably altered. This simply means that in a nonuniform field such nuclei will exhibit energy levels that are split into a number of sublevels corresponding to the number of allowed orientations of the nucleus considered as a body with "north" and "south" magnetic poles. The same kind of line-splitting can be observed in whole atoms when the electron configuration imparts a dipole character to the atom. (It is then called the Stark effect.)

For nuclei such as iron 57 and tin 119 the splitting observed in a nonuniform electrostatic field takes a particularly simple form. The nuclear ground state, with a spin of 1/2, remains unaffected. The first excited state, which has a spin of 3/2, is split into two sublevels (identified as $\pm1/2$ and $\pm3/2$) that are separated by an energy gap known as the quadrupole splitting energy. The Mössbauer spectrum of such nuclei will therefore show two resonance lines rather than one. Two transitions can now be observed: one between the ground state and the lower level (spin $\pm1/2$) of the first excited state and another between the ground level and the higher level (spin $\pm3/2$) of the first excited state [*see top illustration on page 93*].

To illustrate the structural information that can be derived from a knowledge of transitions due to quadrupole splitting, I shall describe the difference in the Mössbauer spectra of two related ferrous complexes: the hexacyanide ion, $Fe(CN)_6^{4-}$, and the nitroprusside ion, $Fe(CN)_5NO^{2-}$. The first ion consists of an iron atom symmetrically bound to six cyanide groups; the second ion is not quite symmetrical because one of the cyanide groups has been replaced by a nitrosyl (NO^+) group. The Mössbauer spectrum of the first ion consists of a single sharp line; the spectrum of the second ion consists of two lines, indicating that the first excited state is split by the breaking of symmetry [*see bottom illustration on page 93*]. In $Na_2[Fe(CN)_5NO] \cdot 2H_2O$ the quadrupole splitting between the two levels of the excited state is 1.705 millimeters per second (equivalent to 8.2×10^{-8} electron volt). This information, together with other relevant spectroscopic and structural data, has led to a reasonably complete molecular-orbital description of the electrons that bind the cyanide and nitrosyl groups to iron in the nitroprusside ion.

One further interesting Mössbauer experiment has been carried out on this ion, following a suggestion made in 1964 by Stanley L. Ruby of the Westinghouse Electric Corporation and Paul A. Flinn of the Carnegie Institute of Technology. They theorized that if one placed the nitroprusside ion in a magnetic field while its Mössbauer spectrum was being run, one should observe a splitting of lines (the nuclear equivalent of the Zeeman effect) from which the shape of the electrostatic field could be deduced. When the experiment was performed, it was found that the magnetic-field gradient around the iron atom was consistent with only one of several molecular-orbital models that had been proposed.

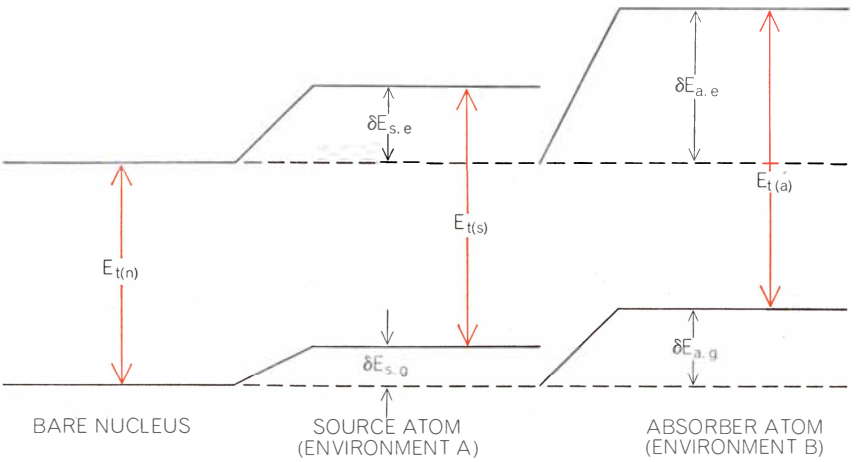
In another instance Mössbauer spectroscopy furnished evidence that of three proposed structures for a particular substance, iron dodecacarbonyl, all were incorrect. The molecule has the formula $Fe_3(CO)_{12}$. On the basis of early infrared data two linear structures were proposed: in one scheme the 12 carbonyl groups were visualized in a 4–2–2–4 arrangement; in the other the arrangement was 3–3–3–3 [*see illustration on page 94*]. In the first model the three iron atoms were bridged by two sets of carbonyl groups; in the second model the bridging was accomplished by three sets of carbonyls. On the basis of X-ray diffraction studies still a third model was proposed in which the three iron atoms were all assumed to be equivalent and located at the corners of a triangle instead of being linked together in an open chain.

In collaboration with G. K. Wertheim of the Bell Telephone Laboratories my colleague W. R. Kingston obtained a Mössbauer spectrum of $Fe_3(CO)_{12}$ and found that it consisted of three distinct resonance lines [*see top illustration on page 95*]. Similar results were reported by a group working at the University of Heidelberg. Of the several possible ways of interpreting the three-line Mössbauer pattern only one appears to be consistent with the present theory of isomer shifts and quadrupole splitting.

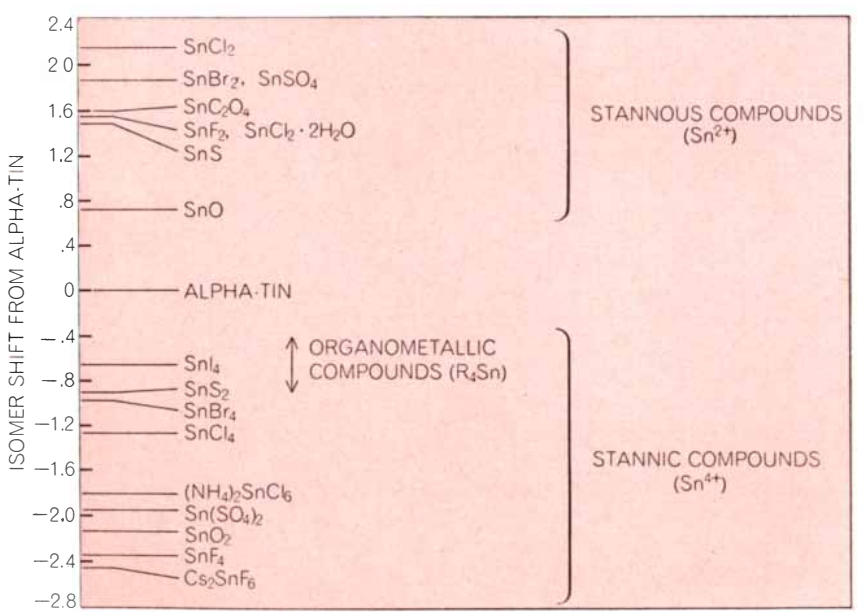
In this interpretation $Fe_3(CO)_{12}$ contains two kinds of iron atom, which are present in the ratio of two to one. One of these kinds of iron atom gives rise to a quadrupole-split resonance pattern; the other, to a single line. Moreover, the electrostatic field surrounding the second kind of iron atom must have cubic (or nearly cubic) symmetry, since the Mössbauer resonance ascribed to this

atom is unsplit by the field. It was clear from the Mössbauer spectrum that the three iron atoms in this molecule could not all be equivalent. These results prompted Lawrence F. Dahl and his students at the University of Wisconsin to undertake a reexamination of the X-ray diffraction data for $Fe_3(CO)_{12}$. The final structure they deduced is a triangular one with nonequivalent iron atoms, in consonance with the Mössbauer results [*see bottom illustration on page 95*].

One of the most remarkable achievements of Mössbauer-effect spectroscopy has been the elucidation of the structure of a compound that has not yet been synthesized in the laboratory by ordinary chemical means. This feat was accomplished by the husband-and-wife team of G. J. Perlow and M. R. Perlow working at the Argonne National Laboratory. The compounds they studied were two chlorides of xenon, $XeCl_2$ and $XeCl_4$, which they produced indirectly by synthesizing analogous compounds where radioactive iodine 129 took the place of xenon. When a nucleus of iodine 129 decays, it emits an electron and becomes an excited nucleus of xenon 129, with an energy of 39.6×10^3 electron volts above the ground state. Earlier experiments with IO_3^- containing iodine 129 had shown that when the iodine decays, the resulting XeO_3 is identical with XeO_3 synthesized directly from ordinary xenon. (It will be recalled that xenon used to be called an inert, or "noble," gas because it was thought to be chemically completely unreactive.)



SCHEMATIC VIEW OF ISOMER SHIFTS measured by Mössbauer spectroscopy shows how the transition energy, E, is altered by the chemical environment of the source atom and the absorber atom. The horizontal lines represent nuclear energy levels; for a bare nucleus the transition energy between the ground state and the first excited state is designated by $E_{t(n)}$. If the source nucleus is in chemical environment A, the ground state and first excited state may be shifted upward slightly, by $\delta E_{s,g}$ and $\delta E_{s,e}$ respectively. The transition energy is now $E_{t(s)}$. Normally the absorber nucleus is in a different chemical environment, B. If the displacement of the two levels, $\delta E_{a,g}$ and $\delta E_{a,e}$, is greater than it is in the source, the transition energy, $E_{t(a)}$, will also be greater. In another chemical environment, of course, the transition energy could be smaller. The energy difference between $E_{t(s)}$ and $E_{t(a)}$, as measured by Mössbauer spectroscopy, is called the isomer shift. Isomer shifts produced by different chemical environments clarify the nature of chemical bonds.



ISOMER SHIFTS OF TIN COMPOUNDS are plotted by using as a reference, or zero, point the Mössbauer resonance maximum of metallic tin in the alpha-crystalline state. Inorganic stannous (Sn^{2+}) compounds have positive isomer shifts. Organometallic tin compounds and inorganic stannic (Sn^{4+}) compounds produce isomer shifts that are negative.

The Perlows therefore used Mössbauer spectroscopy to examine the $XeCl_4$ and $XeCl_2$ produced by the decay of iodine 129 in the analogues of these two compounds. From the Mössbauer results they deduced that the structure of $XeCl_4$ is square-planar (square and flat), whereas the structure of $XeCl_2$ is linear. The second result is not surprising, but one might have thought that the true molecular ground state of $XeCl_4$ was tetrahedral rather than square-planar. When one compares the typical vibration period of such molecules (10^{-13} second) with the lifetime of the nuclear excited state (10^{-9} second), it is clear that the $XeCl_4$ molecule vibrates perhaps 10,000 times in its equilibrium configuration during the characteristic lifetime of the Mössbauer transition. It can be concluded that the square-planar configuration indeed corresponds to the configuration of the ground state.

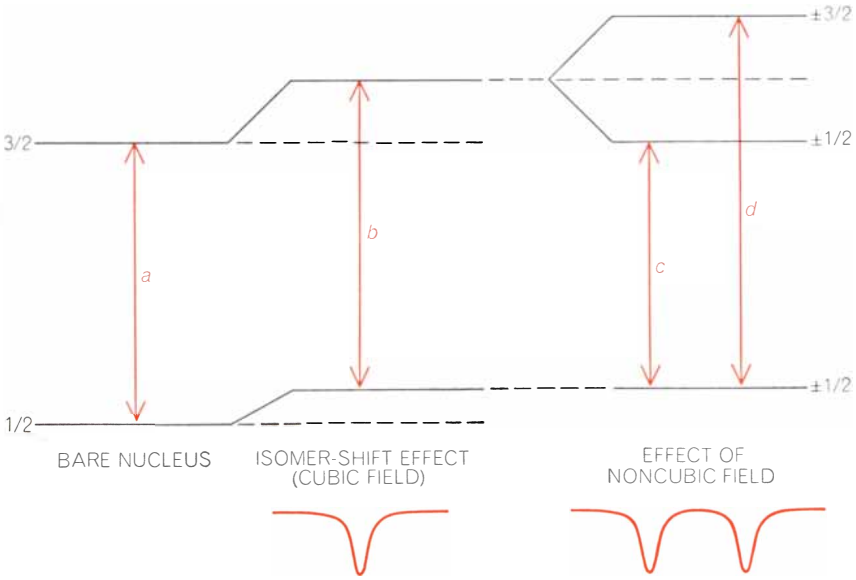
Mössbauer-effect spectroscopy has also been used extensively in the study of organometallic compounds in which the central atom is bonded to one or more surrounding groups by a metal-to-carbon bond. In 1961 H. A. Stockler, Wertheim and I reported results on the first Mössbauer experiments with such a compound: ferrocene, $(C_5H_5)_2Fe$. Since that time a very extensive body of information has been accumulated on the Mössbauer spectra of organometallics, particularly those of iron and tin. A major effort focused on the understanding of the structures of organo-tin polymers has been mounted in the past five years by a Russian research group working at the Institute of Chemical Physics

under the direction of V. I. Gol'danskii. Typical of the problems investigated by these workers is an examination of compounds of the type R_2Sn (where R represents an organic radical such as methyl, ethyl or phenyl). These compounds were known to be unstable when they were freshly prepared and to change markedly in physical properties when they were allowed to stand.

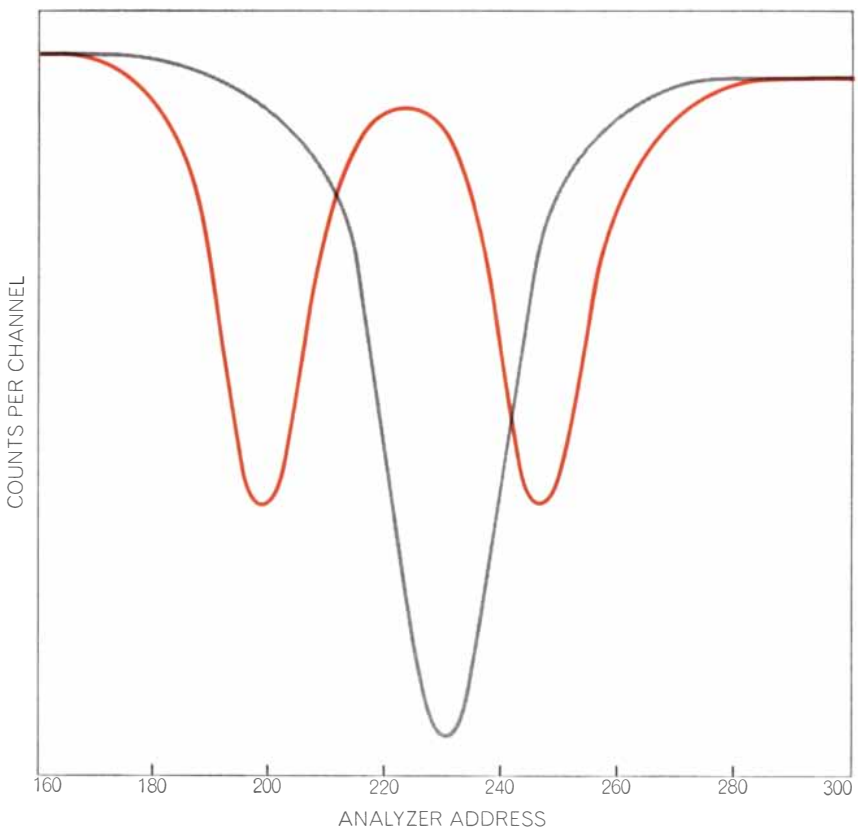
With Mössbauer spectroscopic methods, together with the data for a number of organo-tin model compounds, it was found that these presumed divalent tin compounds rapidly polymerize on standing to form long-chain molecules where the tin atom is tetravalent. (A divalent atom is one that is chemically bonded to two nearest-neighbor atoms; a tetravalent atom is one that is chemically bonded to four nearest-neighbor atoms.) The Russian workers have also reported the results of an extensive study of the angular dependence of the Mössbauer phenomenon and its relation to the strength of the bond between the tin atom and its nearest-neighbor atoms; this relation is now called the Gol'danskii-Karyagin effect. It is of particular promise for the study of molecules adsorbed on the surface of a solid. Such studies may be expected to shed additional light on the phenomena of catalysis and the mechanisms of heterogeneous reactions. Moreover, from detailed studies of single-crystal absorbers that are viewed in a Mössbauer experiment at various angles with respect to the crystallographic axes, additional structural information can be obtained.

One of the most promising areas of the application of Mössbauer spectroscopy to the problems of molecular-structure studies lies in its ability to bridge the gap between X-ray diffraction on the one hand and infrared and nuclear-magnetic-resonance spectroscopy on the other. Although X-ray diffraction provides the most unambiguous information on the structures of molecules and ions, it can be applied only to the study of well-defined crystalline solids that can be obtained as well-formed single crystals. Infrared and nuclear-magnetic-resonance spectroscopy can provide indirect information about substances in solution or in powder form; both of these techniques are generally faster than X-ray diffraction. The structural data obtained by these various methods have not, however, always agreed with one another; it is in resolving such apparent contradictions that Mössbauer spectroscopy can play a unique role.

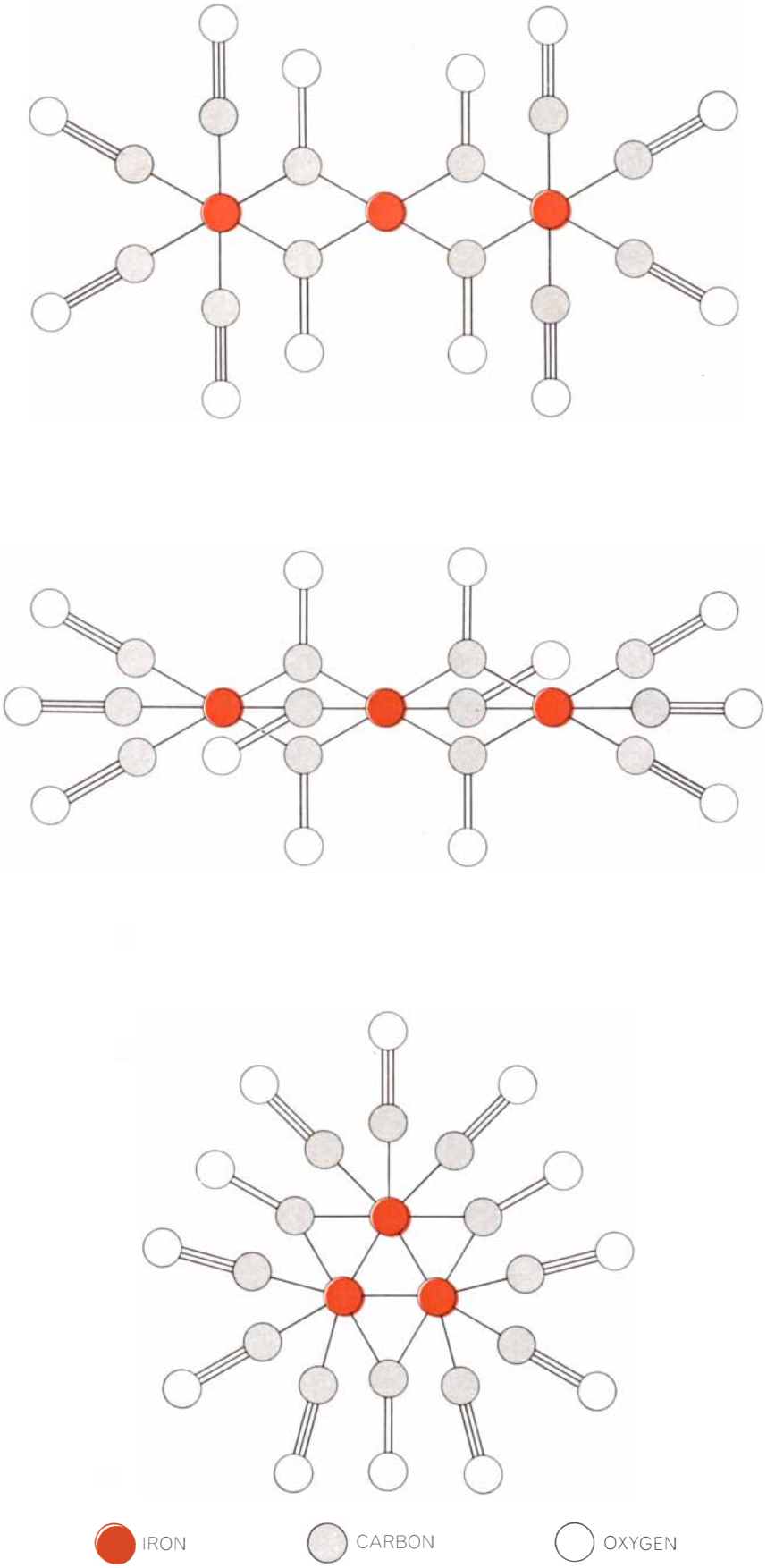
Although high-resolution Mössbauer



SPLITTING OF EXCITED STATE results if the chemical environment of the nucleus produces an electrostatic field that is noncubic. A bare nucleus passes from spin 1/2 in the ground state to spin 3/2 in the first excited state (*a*). In a cubic electrostatic field the nucleus makes the same transition, but the isomer-shift effect yields a slightly larger transition energy (*b*). In a noncubic field the first excited state is split into a doublet, yielding two possible transitions: one to spin 1/2 (*c*) and one to spin 3/2 (*d*). The difference between *c* and *d* is termed quadrupole hyperfine splitting. The curves at the bottom show the Mössbauer spectra that result: a single resonance line for *b*, a double line for *c* and *d*.



HYPERFINE SPLITTING (*color*) is depicted in the Mössbauer spectrum of the ion $Fe(CN)_5NO^{2-}$, in which the iron atom is surrounded by five cyanide (CN) groups and one nitrosyl (NO^+) group, producing a noncubic field. When all six surrounding groups are cyanide, the field is cubic and the spectrum consists of only one resonance line (*gray*).



PROPOSED STRUCTURES of iron dodecacarbonyl, $Fe_3(CO)_{12}$, were based on infrared spectroscopy and X-ray diffraction. Mössbauer studies showed that none is in fact correct. The Mössbauer spectrum and the new proposed structure appear on the opposite page.

spectroscopy can only be used to study solid samples, there is no reason the solids cannot be in the form of a frozen solution. In our laboratory we have obtained Mössbauer spectra of solids dissolved in solvents such as water and benzene (which form true crystals when they are frozen) and spectra of solids dissolved in such liquids as methyl pentane and methyl hydrofuran (which freeze to a glassy solid state). By comparing spectra obtained from such frozen solutions with spectra obtained from undissolved solids we have been able to resolve some of the apparent disagreements concerning the change in structure and conformation that occurs when a solid dissolves in various solvents.

Similar experiments along these lines have been carried out by a group of investigators at the Soreg Nuclear Research Centre in Israel. With Mössbauer spectroscopy they have studied in detail the bonding of molecular iodine in the solid state, in polar solvents (brown color), in nonpolar solvents (violet color) and in the presence of an adsorbent such as soluble starch (blue color). Such studies have clarified the electronic configurations that underlie the familiar color changes in iodine produced by different environments.

It is known, for example, that the maximum absorption of molecular iodine in the gaseous state occurs at about 5,200 angstroms, and that this characteristic absorption also takes place when iodine is dissolved in chloroform, carbon tetrachloride, carbon disulfide and a number of hydrocarbons. On the other hand, in benzene the characteristic absorption of iodine is shifted to 5,000 angstroms, in xylene to 4,950 angstroms and in acetone all the way to 4,600 angstroms. The Israeli workers (S. Bukshpan, C. Goldstein and T. Sonnino) have shown that both the isomer shifts and the quadrupole couplings found for molecular iodine in inert solvents such as hexane, carbon tetrachloride and argon are very similar to one another and to the value observed for pure molecular iodine. They find, however, that when iodine is dissolved in benzene, the quadrupole couplings and the isomer shift are considerably different; they have concluded that on the average about a fourth of an electron is transferred from the benzene ring to the iodine molecule. This observation confirms the earlier interpretation of visible-light spectroscopy that benzene and iodine form a complex in solution.

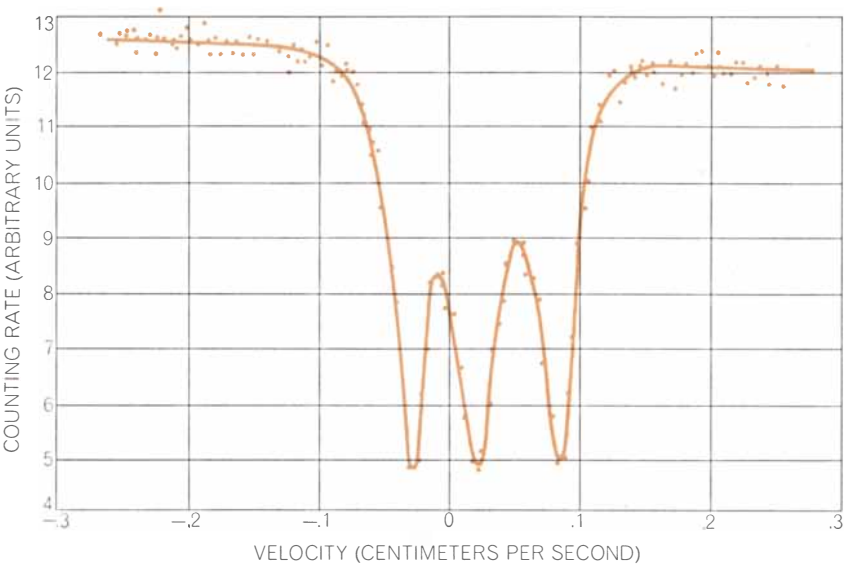
There has been considerable speculation concerning the structure of such complexes. In the two most likely struc-

tures the axis of the iodine molecule was thought to be either parallel to the benzene ring or perpendicular to it. Since the Mössbauer transition in iodine 129 involves a transition between spin states of 7/2 and 5/2, it is possible to observe eight lines in the Mössbauer spectrum. Detailed analyses of the position and intensity of these lines not only allow one to evaluate the isomer shift and quadrupole splitting but also, and more important, enable one to calculate from a single iodine spectrum the sign of the electrostatic-field gradient (that is, whether the field is oblate or prolate in shape) and the extent to which the symmetry of the electrostatic field is cylindrical with respect to the axis of the chemical bond.

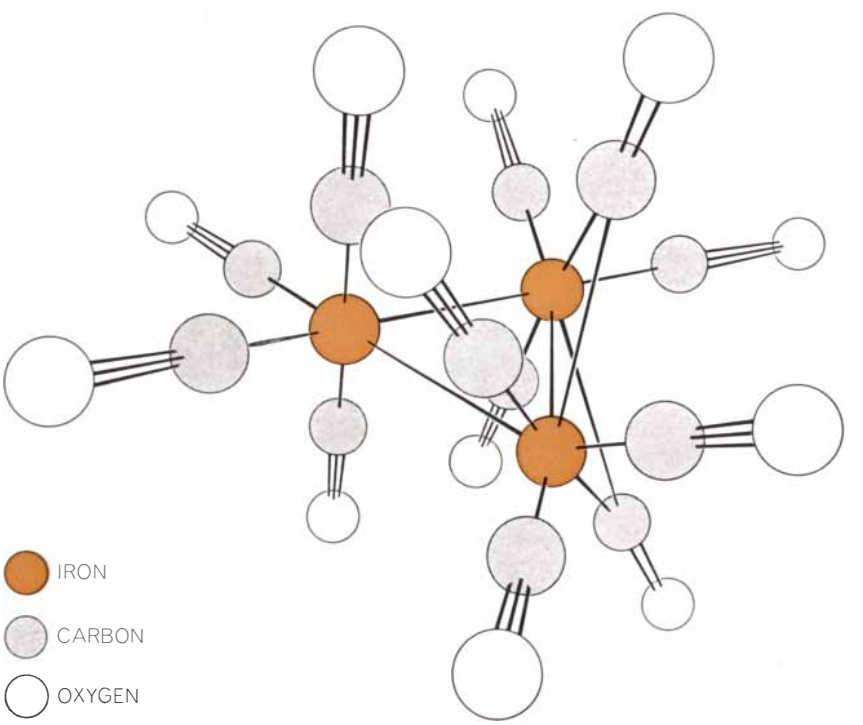
It is this last information that has been used to elucidate the probable structure of the iodine-benzene complex. The model in which the iodine molecule lies parallel to the plane of the benzene ring predicts lack of spherical symmetry along the bond axis of the iodine molecule, whereas the perpendicular model predicts cylindrical symmetry of the electrostatic field. The results of the Mössbauer experiments carried out by the Israeli group show clearly that the asymmetry is zero; in other words, that there is cylindrical symmetry along the iodine-iodine bond axis. On this basis the preferred model is the one where the iodine is oriented perpendicularly to the benzene ring.

As can be expected in any field of scientific research that is barely a dozen years old there are many unresolved problems and unexpected observations that are not yet understood. For example, a number of organo-tin compounds are known to lack cubic symmetry where the metal resides in the crystal lattice and thus should show an appreciable quadrupole splitting; actually these compounds yield Mössbauer spectra with only a single line. Typical of such molecules are $(CH_3)_3SnH$, $(CH_3)_3Sn–Sn(CH_3)_3$ and $(CH_3)_3Sn(C_6H_5)$. Tentative explanations involving empty bonding orbitals have been proposed, and the implications of these ideas are being closely examined in a number of laboratories. Investigators are also trying to understand the way temperature alters the magnitude of the Mössbauer-resonance effect, the isomer shift and the quadrupole-splitting parameter. In particular, such studies appear to be especially promising in distinguishing between molecules that exist as distinct isolated units and those that form polymeric chains, sheets and networks. In this context the application of Mössbauer spectroscopy to the study of polymers is one of the most fruitful new areas opened up by the technique.

In its brief period of exploitation Mössbauer-effect spectroscopy has shed considerable light on a number of chemical and physical properties of molecular solids. For those elements that have one or more nuclides with which gamma ray resonance fluorescence can be observed, the Mössbauer technique has earned for itself a secure place as a spectroscopic tool in the continued unraveling of the properties of matter.



MÖSSBAUER SPECTRUM OF IRON DODECACARBONYL cooled to the temperature of liquid nitrogen reveals three resonance maximums. The interpretation is that the molecule contains two iron atoms whose chemical environment is the same and one whose environment is slightly different. The two iron atoms with the same environment give rise to the two maximums on the outside. The third iron atom produces the maximum in the middle. The slight broadening of the central line seems to indicate quadrupole hyperfine splitting.



CORRECT STRUCTURE OF IRON DODECACARBONYL was determined by Lawrence F. Dahl and his co-workers at the University of Wisconsin on the basis of detailed X-ray studies. The two iron atoms on the right are identically bonded to other atoms in the molecule, whereas the third iron atom is bonded to a different assortment of atoms.

The Measurement of the "Man-Day"

Even as machines began to replace muscles as a source of power, sober investigators undertook to find out how much physical labor a man could be expected to do in a day. The effort continued into the 20th century

by Eugene S. Ferguson

Until well into the present century a significant part of all mechanical energy was supplied by men's muscles, even in the technologically more advanced countries. Men tramped in treadwheels, mounted the endless steps of treadmills, turned cranks and carried burdens. There were even more elaborate arrangements, such as the one where a man ran up a flight of stairs and jumped onto a suspended platform, which raised a burden nearly equal to the man's weight and returned him to his starting level.

A few years ago, when I was making a brief survey of the sources of mechanical energy in the 18th century, I was struck by the similarity between the studies of muscle power being made then and the studies that have been conducted in the 20th century under the banner of "scientific management." The similarity resides not only in the tone of the investigations—the curiously skewed view of the outsider toward the kind of work that he himself will never be called on either to do or to direct—but also in the lack of sophistication of method. In the 18th century the most casual and fragmentary data were being worked up, with the help of algebraic operations, into definite and precise conclusions. As recently as the early years of this century the American industrial engineer Frederick Winslow Taylor (whose biographer describes him as the "father of scientific management") and his followers were still taking the same approach. Moreover, the use of men as power sources, although it was justified by convenience in the 18th century (before small steam engines, internal-combustion engines and electric motors were available) was quite out of date in the 20th century. Yet enthusiastic investigators were slow to recognize that muscle power is not an economical power source (a man working for a year can deliver about $3 worth of mechanical energy, calculated at a rate of two cents per kilowatt-hour), and that the time had come when men should be users of power devices rather than suppliers of power.

Because the muscle-power investigators of the 18th century were the precursors of the 20th-century scientific managers, it would have been fitting for both schools to adopt as their patron saint the 17th-century Italian physiologist Giovanni Borelli. Borelli, regarding an animal as a machine, explained muscular movements in terms of levers and cords. He saw the entire body as a complex assemblage of mechanical linkages and joints.

This approach to the mechanical capacities of a man or a horse enjoyed a brief flurry of interest. In 1702 Antoine Parent of the French Academy of Sciences sought to analyze the body in mathematical terms. "One could by this theory," he wrote, "calculate the force of this prodigious number of machines which operate separately or together in the body of the animal; one would [then] know precisely, or very nearly, what is the force of one in combination with the others." Neither Parent nor anyone else, however, pursued the matter seriously.

Although muscle-by-muscle and limb-by-limb calculations held a certain appeal for the mathematician then, as they might for a computer specialist today, the most extensive analyses actually carried out (at least until 1900) were ones where the body was considered as a whole. The results sought were the maximum daily exertion that might be expected from men and horses, considered simply as sources of power. At the beginning interest was divided between manpower and horsepower, which were essentially interchangeable for many tasks.

A consciously scientific approach to manpower and horsepower appeared in 1699 in the first volume of the *Mémoires* of the French Academy. A paper by Philippe de La Hire concluded that the horizontal pushing force of a man was 27 pounds. La Hire derived the force geometrically, regarding it as the horizontal component of the man's weight as he leaned into the work he was doing. From this La Hire deduced the pulling force of a horse by remarking that "one must be content with the general experience that a horse pulls horizontally as much as seven men."

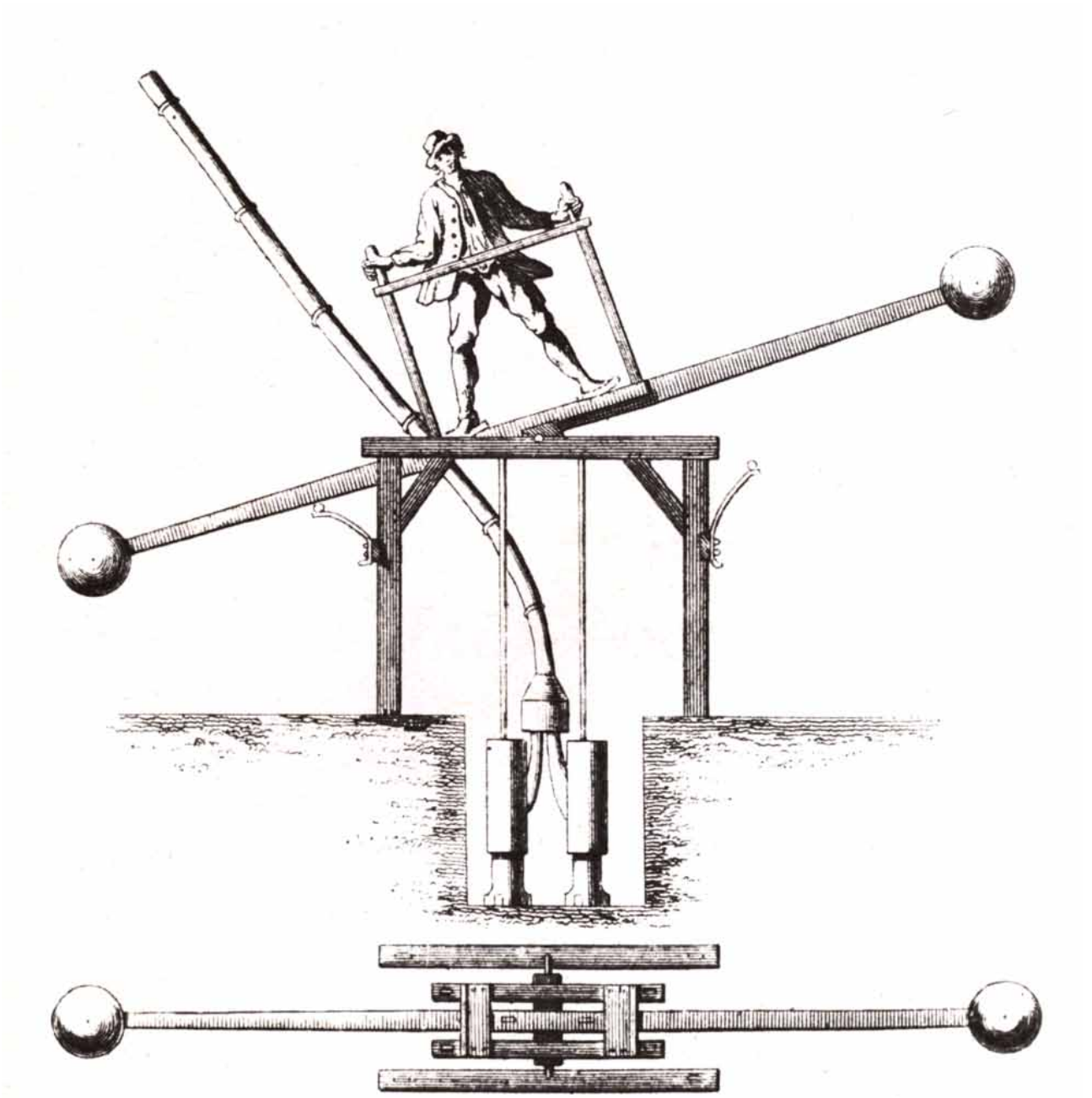
In the same volume Guillaume Amontons gave a man's force as 25 pounds. He said this was the force exerted by a glass-polisher as he pushed his polishing pad back and forth a foot and a half in a one-second cycle for 10 hours a day. Amontons observed that the force was equivalent to raising continuously a weight of 25 pounds at three feet per second. It is interesting to note in passing that Amontons arrived at the ultimate definition of power (the rate at which a weight is raised) still used today, although in his time the vocabulary of science lacked the terms "work," "power" and "energy." The vagueness of terms throughout the 18th century caused no difficulty for the calculation or comparison of a day's work, however, because neither kinetic energy nor momentum entered the calculations.

Amontons used a man-to-horse ratio of six rather than La Hire's seven. Ratios quoted by various authors ranged from one horse equals 2½ men (Georgius Agricola in 1556) to one horse equals 14 men (one Schulze of the Berlin Academy in 1783). In 1819 Abraham Rees's *Cyclo-*

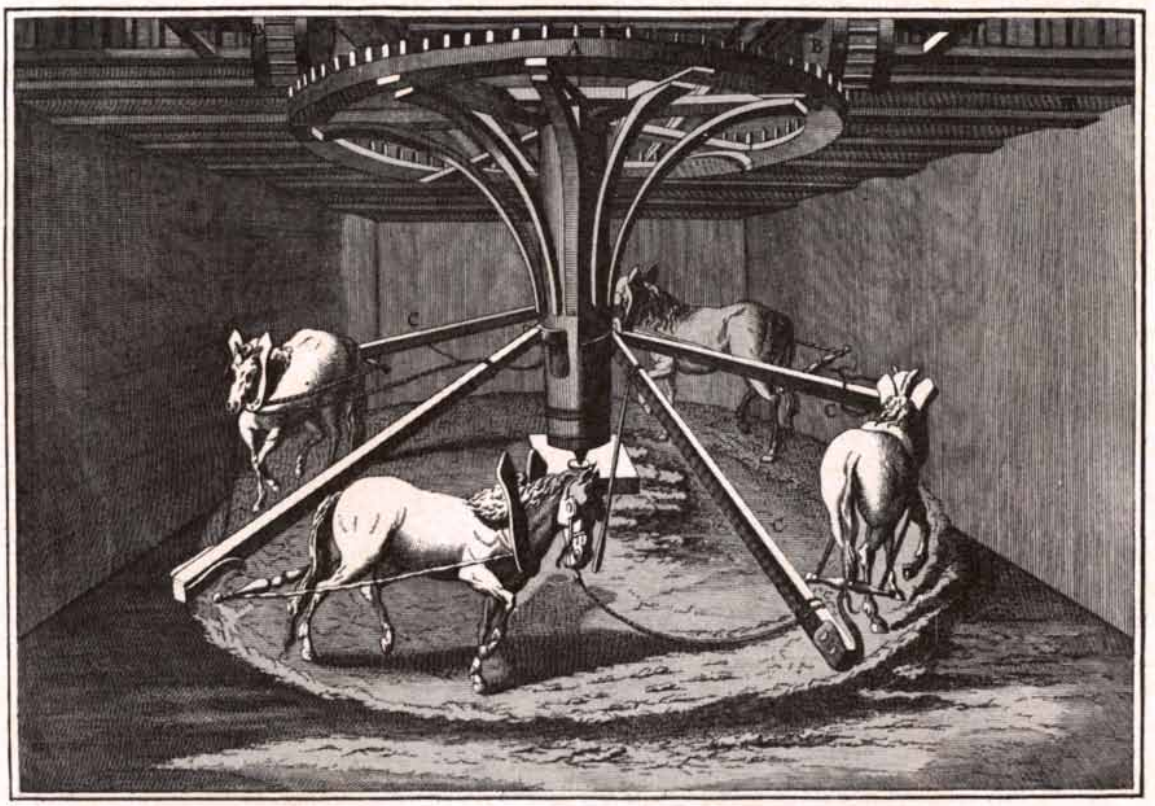
paedia summarized a mass of conflicting data and pronounced a "true standard" ratio of 5.87 for the rate of doing work. A horse, however, was expected to work only eight hours a day, whereas a man worked a 10-hour day, so that the "true standard" ratio for daily work was one horse equals 4.7 men.

Except for Agricola, Continental writers tended to find higher man-to-horse ratios than English writers. An explanation for this discrepancy was offered in 1734 by the English lecturer John Théophile Desaguliers. Five Englishmen, he said, were equal to one horse, whereas it took seven Frenchmen or Dutchmen to equal the same horse.

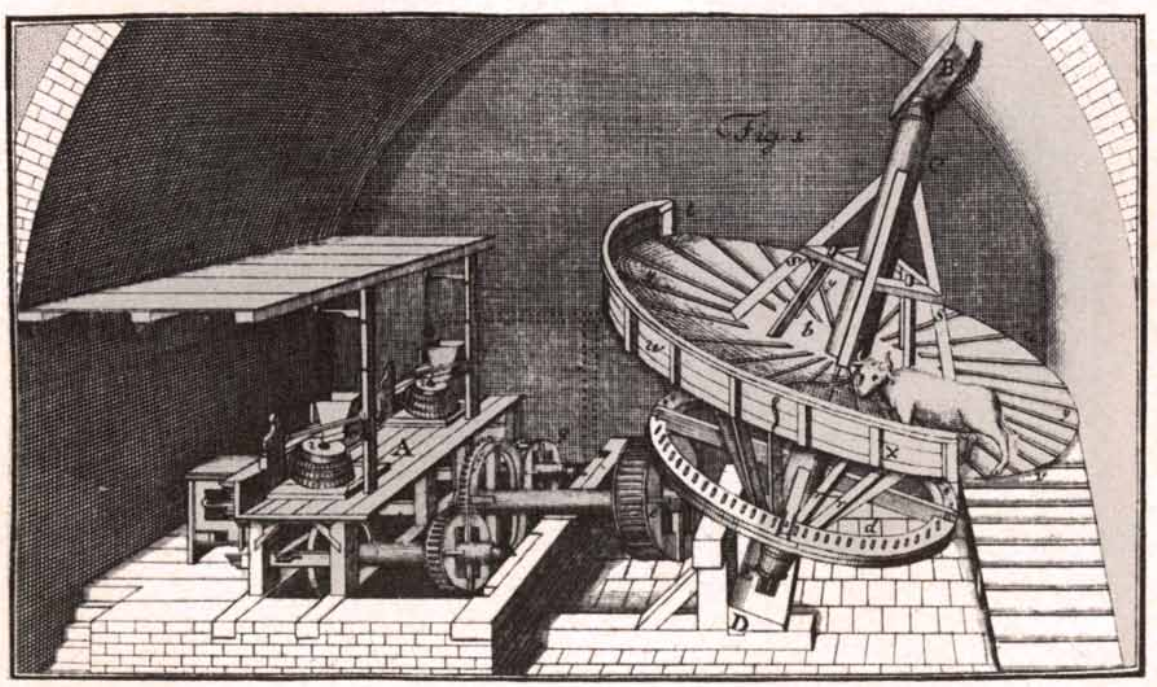
With the advent of James Watt's rotating-shaft steam engine in 1782 horsepower became detached from horses. Watt settled on 33,000 foot-pounds per minute as the power a steam engine replacing one horse would supply. He made no tests of horses, however, relying apparently on the rule-of-thumb figures supplied by a Manchester millwright. Because Watt's figures exceeded the ability of nearly all horses except perhaps the ones used in London breweries, a debate on the size of a "true"



HUMAN MUSCLE POWER provided the energy to drive this two-cylinder water pump depicted in an 18th-century French book, *Architecture Hydraulique*. The operator supplied the power by rocking back and forth on the balance beam. In this picture a crucial connection is lacking: piston leading upward from right-hand cylinder should be shown attached by a pin to the balance beam.



HORSE ENGINE, a major power source until it was replaced by the steam engine, was the model for the unit of power called horsepower. James Watt, acting in 1783 on figures supplied by a millwright, stated that a horse could pull 150 pounds at a velocity of 2.5 miles per hour, thereby working at a rate of 33,000 foot-pounds per minute. In reality a horse cannot do that much work continuously.



INCLINED TREADWHEEL could be driven by men or animals. In this representation, which appeared in *Theatrum Machinarum Molarium* (1735), a single animal is providing the power. Treadmills of this type were frequently illustrated in books on machinery throughout the 17th and 18th centuries. The first known portrayal of the device was published in the latter part of the 16th century.

horsepower continued until well into the 19th century. In retrospect it is odd that no serious challenge to Watt's standard of horsepower was ever sustained.

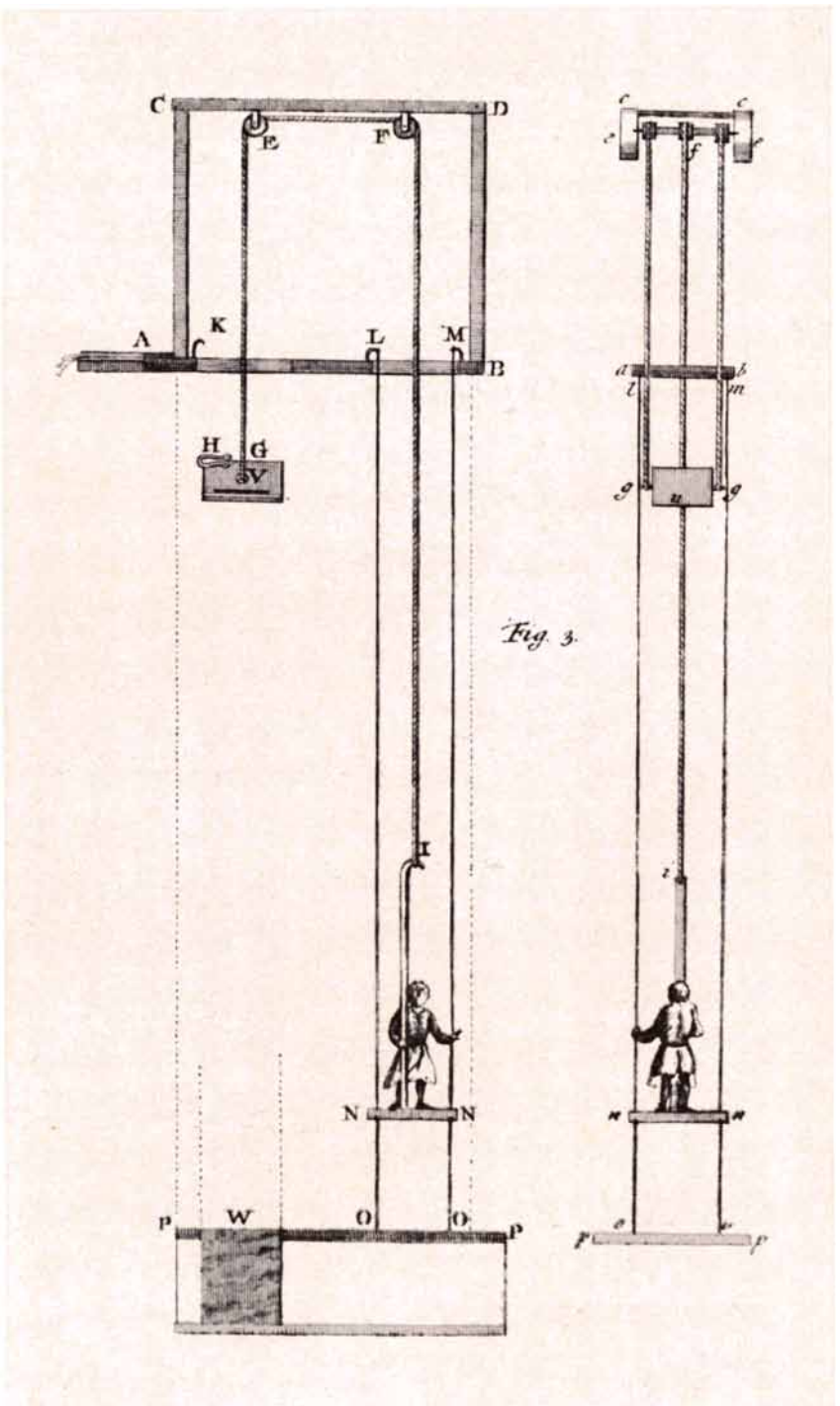
As horsepower took on a new meaning its relation to manpower was largely forgotten, and manpower became a subject of separate inquiry. Several mathematical analyses of manpower appeared during the 18th century in the publications of the French and German academies, and empirical studies appeared in the transactions of the Swedish Academy and in the lecture books of such British investigators as Desaguliers, James Ferguson and others. In 1798 the French engineer and physicist Charles Augustin de Coulomb, who is famous for his work in electricity, published an elaborate study of manpower that typified the approach of scientists to man as a work-producing machine.

Coulomb determined quickly—and apparently intuitively, as had Desaguliers and others—that a man could deliver the most work in a given time by running up stairs and returning on a descending platform that, through a rope-and-pulley arrangement, raised a load nearly equal to the man's weight. Desaguliers in 1744 had described a device of this kind that would raise 140 pounds of water twice a minute through a vertical distance of 21 feet. (Desaguliers added: "A Tavern-Drawer [a waiter], being used to run up and down stairs, is very good for this work.")

If Coulomb had happened to read Desaguliers's book, his inquiry might have taken quite a different turn, but there is no evidence that he ever heard of the book. Coulomb simply wondered how much climbing a man might be able to do on a stairway during a working day. At about this time Coulomb saw a young man climbing an extraordinarily long stairway cut in a rock slope and noted that it took him 20 minutes to ascend about 150 meters. Coulomb offered to pay the man to see if he could make the ascent 18 times in six hours. The climber refused, stating that he would not only become exhausted but also be laughed at for climbing the same stairway 18 times in a day.

When Coulomb had nearly despaired of obtaining his basic data, he learned that his friend Jean Charles de Borda had led an expedition to the Peak of Tenerife in the Canary Islands. Pressed for details, Borda told Coulomb that some marines on foot had reached an elevation of 2,923 meters in 7¾ hours. Here was the kind of information Coulomb wanted. Assuming a body weight of 70 kilograms, he announced that a fair day's work was 2,923 meters times 70 kilograms, or 205,000 kilogram-meters.

Desaguliers's tavern-drawer, scampering up the 21-foot stairway twice a minute, would have ascended 5,950 meters in 7¾ hours—slightly more than twice the climb made by Borda's marines. Another measure of the distance a man could climb in a day was provided by John Robison, a friend of Watt's, who described a rocking-beam water pump that, he said, was powered easily for 10 hours a day by a young man who ran back and forth along the top of the rocking beam. Robison's young man, who weighed 135 pounds, carried a 30-pound weight to augment his own weight and thus in-



SUSPENDED PLATFORM lifted water by means of energy supplied by a man who ran up a flight of stairs, which are not shown, and got on the platform at level *L*, thereby causing the platform to descend, raising the water box to the point *K*, where the water was dumped.

crease the work he could deliver. Reduced to Coulomb's terms the young man would have carried his 30-pound weight to the Peak of Tenerife in just over three hours, and his fair day's work would have been 553,000 kilogram-meters.

One more comparison is in order. In 1818 Sir William Cubbit introduced English prisoners to the treadmill, which was designed to employ men in grinding grain or in providing power for other machines. Each prisoner had to climb the treadmill a total vertical distance of 8,640 feet (2,630 meters) in six hours. The feat was the equivalent of climbing the stairs of the Washington Monument 16 times, allowing about 20 minutes for each trip. In comparable figures, however, Cubbit's program worked out to be the lowest of the four estimates I have discussed: 184,000 kilogram-meters.

Coulomb, having arrived at an estimate of a fair day's work, asked next how much work a man could do if the weight of his body could not be utilized. As an example he posed the problem of carrying a quantity of firewood upstairs. What was the optimum size of a porter's load in order to get the maximum amount of wood upstairs in a day? Presumably if the load for each trip were made lighter, more trips might be made in a given time. Coulomb reasoned that if he could develop a suitable equation, he might obtain the optimum load that would lead to the maximum day's work.

Once again Coulomb's data were, to put it mildly, informal and casual. He had often employed a particular porter, of less than average robustness, to carry firewood 12 meters upstairs to his apartment. The porter had never been able to carry more than six wagonloads a day, and each time he finished he told Coulomb that he could never do as much work as that day after day.

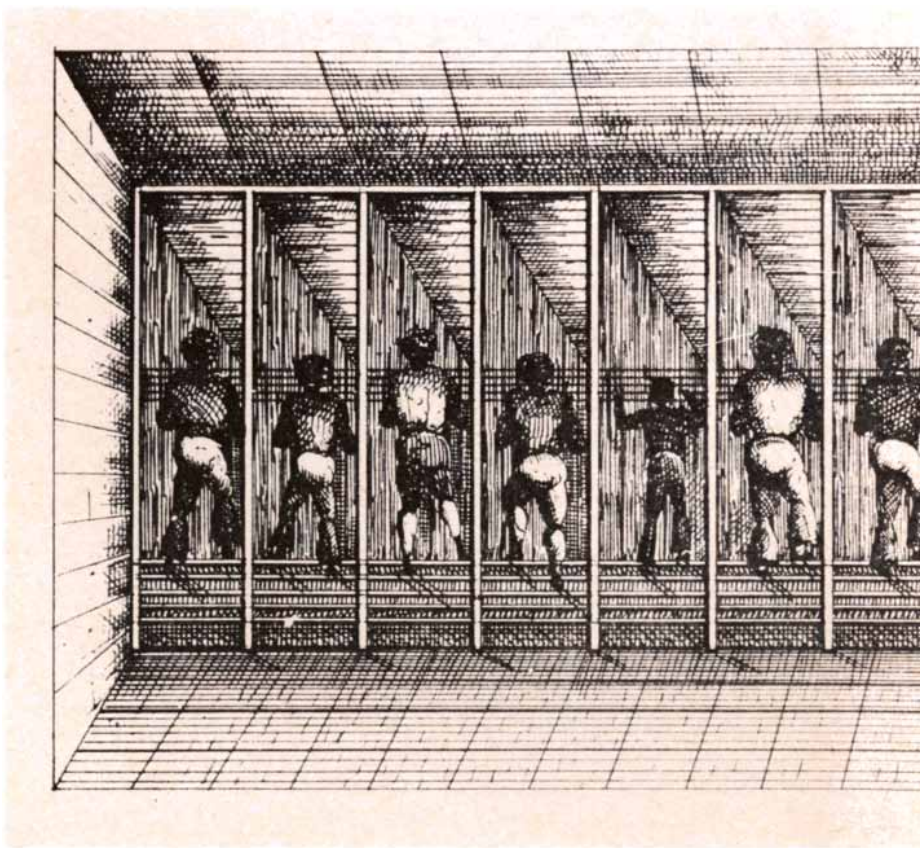
Coulomb noted that the porter made 66 trips a day with an average burden of 68 kilograms. Thus the total work done during the day was the useful load (68 kilograms) plus the man's weight (70 kilograms) multiplied by the number of trips (66) multiplied by the height (12 meters), or 109,000 kilogram-meters. Comparing this figure with the energy required to climb the Peak of Tenerife without a load (205,000 kilogram-meters), Coulomb assumed that the difference (96,000 kilogram-meters) represented the loss of work due to carrying a load.

Without justifying this assumption, Coulomb assumed further that the quantity of work lost was proportional to the load. If the load were zero, no work would be lost but the useful work would be zero. If the load were 145 kilograms, the porter could not lift it and the useful work would again be zero. Somewhere between these extremes was an optimum load that would yield the maximum useful work. On the basis of his assumptions Coulomb wrote and worked out a series of equations that showed the optimum value of the load to be 53 kilograms.

A test of Coulomb's conclusion may be helpful. The actual burden carried by the porter (68 kilograms) multiplied by the number of trips (66) multiplied by the height (12 meters) gives 53,800 kilogram-meters of useful work. Coulomb's optimum burden of 53 kilograms would result in useful work of 56,000 kilogram-meters, an increase of 4.1 percent, but the number of trips in a day would be increased by a third, from 66 to 88. Thus to satisfy Coulomb's calculations the porter would make 22 more trips in a day. The same increase of useful work could be attained, however, by carrying just three more 68-kilogram loads.

Coulomb the scientist merely recorded his conclusions, observing that porters carry heavy loads in order to be thought strong and that they probably could not be made to appreciate his argument anyway. I have a feeling that a man such as Taylor, advancing the cause of "scientific management," would not have abandoned the argument so readily. Had Coulomb's porter come under Taylor's direction, he would have found himself trotting faster in order to squeeze 88 trips into a working day.

In 1872 Lammot du Pont made an extensive study of manpower in the Brandywine black-powder yards near Wilmington, Del. In this study, which has been carefully analyzed by Norman Wilkinson, my colleague at the Hagley Museum, Du Pont recorded the weight of powder ingredients and their containers, measured the distances moved (both horizontally and vertically) and calculated the daily work done by men in the several operations. He found that the actual work being done varied, depending on the operation, from 4 to 50 percent of what he regarded as a fair day's work. It may be remarked that Du Pont had none of Coulomb's difficulties



WORK ON TREADMILL was part of the discipline of prisoners at the House of Correction at Petworth in England early in the 19th century. The plate was among papers pub-

in determining a fair day's work. He could simply refer to tables in a handbook. He used the French *Aide-Mémoire,* compiled for the guidance of artillery officers, and U.S. ordnance manuals derived from the *Aide-Mémoire.* Du Pont commented that because some of the figures were based on the work performance of French soldiers, a fair day's work probably should be at least twice the figure given in the handbooks. Men in the U.S., he said, worked twice as hard as Frenchmen.

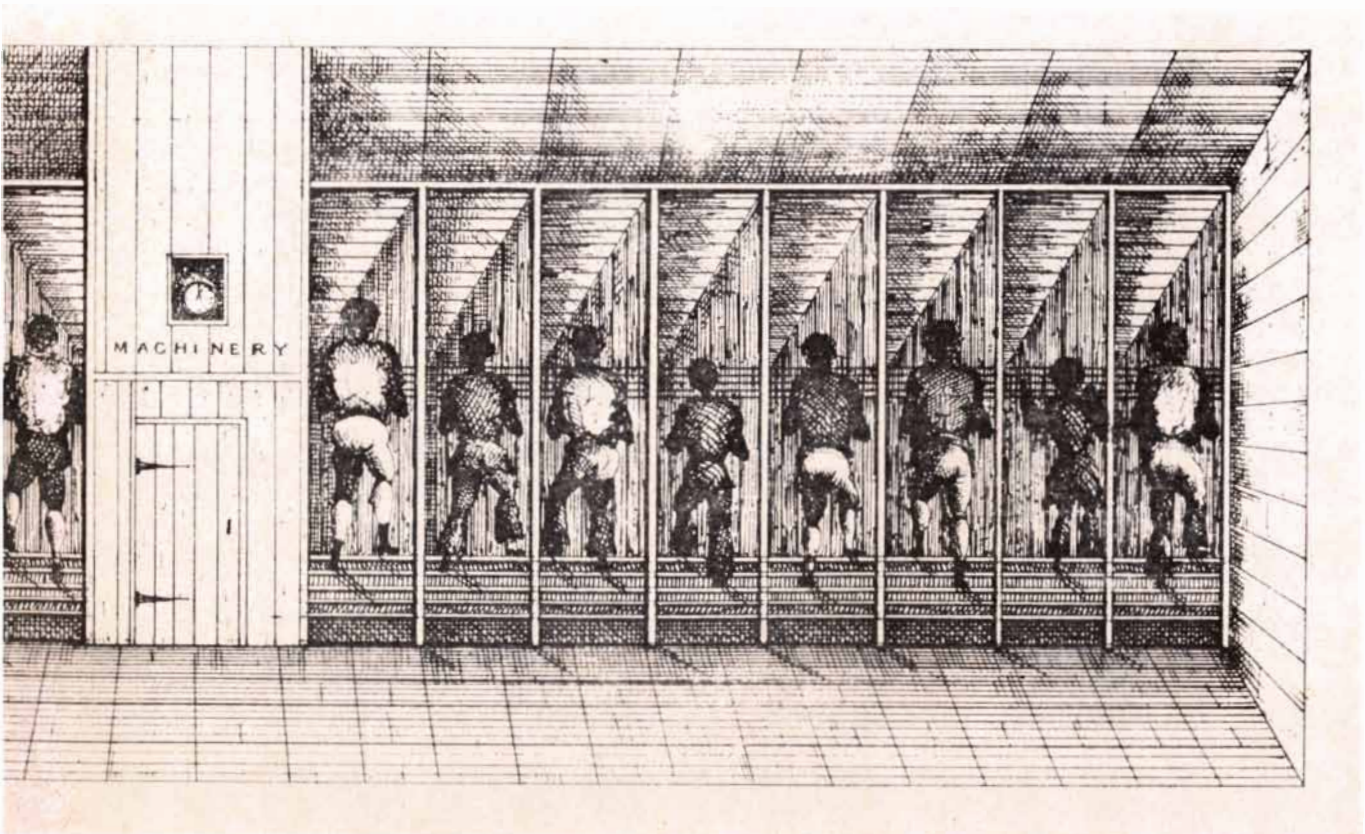
Although I have made no systematic analysis of the manpower tables contained in 19th-century handbooks, it is evident even on cursory inspection that the same wildly conflicting data appear again and again in successive handbooks. Because numbers in a column do not indicate the validity of the conclusions reached by Desaguliers, Coulomb, Robison and others, the uncritical user of a handbook can only perpetuate the haphazardness and caprice of the authorities quoted.

The state of affairs was exemplified by the article on "Force" in Rees's *Cyclopaedia* of 1819. There one finds the several conclusions of Coulomb, surrounded by the figures of Amontons, Daniel Bernoulli, Leonhard Euler, Desaguliers and others, representing the accumulation of data over the entire 18th century. Alexander Jamieson's English handbook of 1832 warned the reader that the data on muscle power were "so variable as to hardly admit of calculation," but as late as 1919 John C. Trautwine's American civil engineer's handbook described without comment Robison's rocking-beam pump of 100 years earlier, still operated by a young man with a 30-pound weight.

Certainly the working man of the 19th century was not helped by all the testing. Henry Mayhew, in *London Labour and the London Poor,* published in 1861, sketched in graphic detail the anatomy of physical labor in Victorian England. We need not be detained by Mayhew's moralizing. It is enough to follow his description of the scuffling and scrambling that took place on the London docks every morning as a foreman picked his crew from a waiting crowd of thousands, most of whom would be turned away without work. Some of the men picked turned the cranks of winches, others pushed hand trucks back and forth and still others spent an eight-hour shift in crews of a half-dozen or so working an enormous, casklike treadwheel that powered a cargo crane. Making 40 lifts an hour from the ship's hold, stamping time and occasionally singing together as the day wore on, the men had delivered by the end of the day less than the equivalent of one kilowatt-hour of mechanical energy apiece.

Charles Dickens, much closer to the truth than the objective scientists were, had a memorable passage on manpower testing in *Hard Times,* first published in 1854. "So many hundred Hands in this Mill; so many hundred horse Steam Power. It is known, to the force of a single pound weight, what the engine will do; but not all the calculators of the National Debt can tell me the capacity for good or evil, for love or hatred, for patriotism or discontent, for the decomposition of virtue into vice, or the reverse, at any single moment in the soul of one of these quiet servants, with the composed faces and the regulated actions. There is no mystery in it; there is an unfathomable mystery in the meanest of them, forever."

Taylor's mission in the early years



lished by the House of Commons in 1835 during an investigation by the Select Committee on Gaols and Houses of Correction. The useful work being done by the prisoners was not specified. A similar treadmill at Gloucester County prison ground grain.

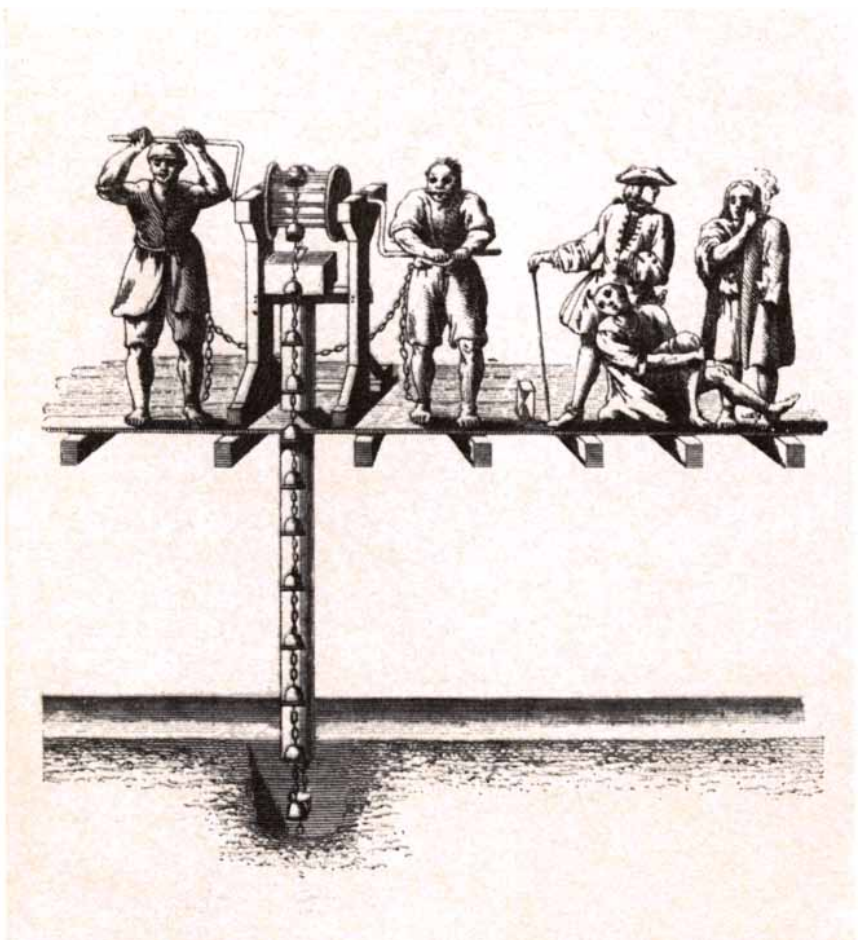
of the present century was to reorganize manual labor to make it more efficient. Later his successors became less interested in muscle work and more interested in motion study and in providing machines that would help to speed up industrial operations. In the beginning, however, Taylor spent much time on the question of what constituted (in foot-pounds) a "proper day's work." The question was of particular importance to Taylor because of his basic assumption that all working men were "soldiering"—doing less than they might.

Taylor searched for a principle that would enable him to calculate scientifically and thus unequivocally a proper day's work under any conditions. His first hypothesis was that fatigue was directly proportional to the foot-pounds of work expended. Daniel Bernoulli had stated the same hypothesis 150 years earlier, although it had been refuted later by Coulomb. Taylor's own data also refuted the hypothesis, but he had gathered so many findings that he turned the problem over to the American engineer Carl Barth ("A better mathematician," Taylor said, "than any of the rest of us") to see if he could find some other law that Taylor was convinced must be embedded in his hard-won data.

Sure enough, Barth soon emerged with a law "so simple," Taylor said, "that it is truly remarkable that it should not have been discovered and clearly understood years before." Taylor continued: "This law is confined to that class of work in which the limit of a man's capacity is reached because he is tired out. It is the law of heavy laboring, corresponding to the work of the cart horse, rather than the trotter."

Barth's law held that the heavier the load carried or pushed by a man, the more rest he required between efforts. For example, when 92-pound pigs of iron were handled, the man must be entirely free of load during 57 percent of the day. When the load grew light enough so that he could carry or push it all day without collapsing, the Barth law ceased to be useful and some other law (never quite stated) was necessary to determine a man's capacity for work.

Physiological testing was an alternative approach to the question of a fair day's work, although it too yielded only "cart horse" laws. To the investigators Francis G. Benedict and Edward P. Cathcart, who in 1913 measured the metabolism and work output of bicycle riders, the possibilities of the physiological approach were exciting. Concerning the results of their tests Benedict and Cathcart wrote: "[They] have a practical value not only for athletes, but for those who are accomplishing large amounts of work. It is of vital importance to the contractor, to the railroad constructor, and to other large employers of labor, that their human machinery as well as their mechanical appliances work to the highest degree of perfection.... A carefully worked-out series of experiments for studying the mechanical efficiency of the human body... will, if properly made, furnish fundamental data that ultimately should prove of the greatest value in a scientific adjustment of diet, hygienic conditions, and the application of the muscular work of man to levers and other mechanical appliances."



CRANKED WATER PUMP employed the labor of prisoners in the 18th century. It was called a chaplet pump from the close-fitting chaplets that drew water up the pipe during cranking. Hourglass on the platform was a timer; men at cranks were spelled after an hour.

A feeble voice of reason was raised by B. S. Greenfield in *Cassier's Magazine* in 1911. Greenfield tried to show that muscle was not an economical power source compared with power devices. Even he, however, was under the spell of the efficiency purveyors. "Like all rules," he said, "this one, too [on the inefficiency of muscle power], has its exceptions. In this age of specialization, particular men are adapted for particular purposes. The best disposition of individual talent is a matter for scientific study and research." Greenfield must have been thinking of Taylor's celebrated ore-carrier named Schmidt. Taylor, using the science of management in all its subtlety, had picked Schmidt as an ore-carrier because, as Taylor said, Schmidt was "so stupid and so phlegmatic that he more nearly resembles in his mental make-up the ox than any other type."

As recently as 1940 C. A. Koepke and L. S. Whitson described in the magazine *Mechanical Engineering* their study "Power and Velocity Developed in Manual Work." They were careful to say that their goal was not to make employees work faster or expend more energy but rather "to produce more with a reserve available at the end of the day to permit full enjoyment of their leisure time."

I have tried to explain and support my impression that the science of muscular manpower for industrial purposes has been casual and for the most part insignificant, notwithstanding the sallies that reputable workers have made into the field. The various data and conclusions have been widely disseminated, but never to my knowledge were the results thought worthy of systematic criticism by any scientist or engineer. Nor have I been able to find any case before the advent of Taylorism where the measurements of muscle power had any discernible effect on the way human labor was actually employed. Du Pont's measurements were fully recorded, for example, but no change in the powder operations can be traced to his study.

Scientific management in its early years was directly in the tradition I have traced over a period of 200 years. On the other hand, the undoubted power of scientific management to increase the productivity of working men rests on a fundamental change in approach. The attention of efficiency-seekers shifted from the question of finding ways to speed up a manual task to the much more productive problem of providing new and improved tools to increase a man's output far beyond any possible improvement in his muscular efficiency. Thus one might say that the manpower scientists had been asking the wrong questions, and that such increases in industrial productivity as had occurred owed nothing to this line of inquiry.

I am still fascinated by what appears to be the constant of the science of manpower: the clinical attitude of those who measure work to those who do it. Whatever effect the arguments of Borelli and others that man is a machine may have had on theologians and other people, the idea of a man-machine was a fundamental assumption of the investigators whom I have discussed. They may occasionally have noticed that men have nonmechanical attributes, but up to the present day this observation has had no effect on their attempts to make workingmen more productive. The psychology of the workman is perhaps receiving more attention today than his physiology, but the new techniques are no less manipulative than the old ones were.

The unstated assumption of engineers and economists alike is that increased productivity is an unquestionable good. Few would dispute the notion that man has increased his power over nature by putting larger and larger amounts of inanimate energy at the disposal of workmen. It is well to recall what C. S. Lewis said in *The Abolition of Man:* "What we call Man's power over Nature turns out to be a power exercised by some men over other men with Nature as its instrument." It is on this note that a balance sheet of the costs and benefits of muscular energy and inanimate energy might be drawn by an investigator having broader vision than those who have so far tackled the subject.

MEASURE OF MUSCLE POWER was made in 1699 by Guillaume Amontons of the Paris Academy of Sciences with men who polished glass. A pad, pressed against the glass by a bow, was pushed to and fro by the laborer. Amontons found that the horizontal force required was about 25 pounds, and so he stated that a day's work equaled a 25-pound force moving three feet per second for 10 hours.

MATHEMATICAL GAMES

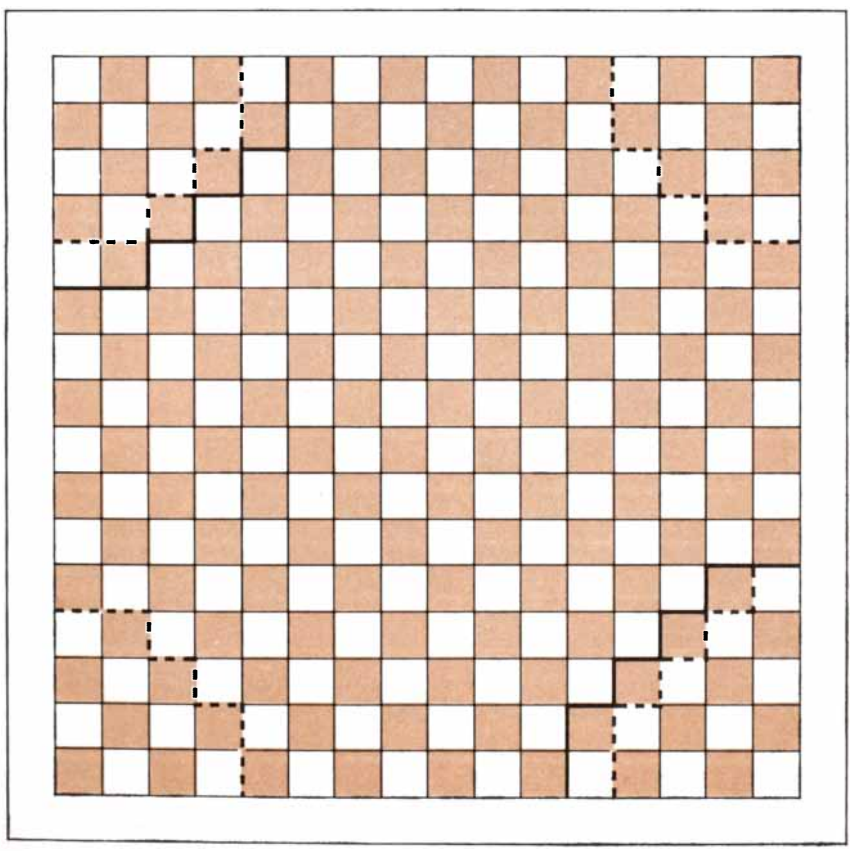
New puzzles from the game of Halma, the noble ancestor of Chinese checkers

by Martin Gardner

Two new families of puzzles based on a long-neglected counter-moving game have recently come to light. Each family of puzzles offers a series of unsolved problems and the opportunity to devise ingenious proofs that some solutions are impossible. The puzzles stem from *Dialogue on Puzzles*, a splendid collection of unusual problems by Kobon Fujimura and Michio Matsuda published this year in Japan. (Unfortunately the book is not available in English.) Fujimura has translated the puzzle books of Sam Loyd and Henry Ernest Dudeney into Japanese and is the author of several delightful books that contain his own original puzzles. The two new counter-moving puzzles are derived from one problem created by Matsuda.

Matsuda's problem exploits the simple rules of a popular late-19th-century British proprietary game called Halma, after the Greek word for leap. The game was invented in 1883 by George Howard Monks, a 30-year-old Harvard Medical School graduate who was then pursuing advanced studies in London. He later became a prominent Boston surgeon. Halma is still played in Britain but, although it was issued here in 1938 by Parker Brothers, it has never caught on in this country.

The traditional Halma board has 16 cells on a side [*see illustration below*].



The Halma board

If two players are competing, each begins by placing his 19 counters in a section called a "yard." There are two yards, one at the top left corner of the board and the other at the bottom right corner. The counters are identical except that the two sets are of contrasting colors. The goal is to occupy the opposing player's yard, and the first player to move all his counters into the opposite yard is the winner. Two kinds of move are allowed: (1) A "step." This is a move, like the move of a chess king, to any one of the eight adjoining cells. (2) A "hop." This is a leap over another counter, as in checkers, except that the leap may be made in any direction, either orthogonal or diagonal. The jumped piece is not removed.

A connected chain of hops counts as a single move. It is not compulsory to make a hop. A player may continue a chain of jumps as long as possible or stop wherever he pleases. The color of a jumped piece does not matter; a chain of jumps may be a mixture of friendly and enemy counters. Steps and hops may not, however, be combined in the same move. Players alternate turns, moving one counter at a time.

Halma can also be played by four people, with each player having 13 counters. The yards are at the four corners of the board behind the boundaries indicated by the broken lines in the illustration. The four-player game can be each man for himself, with each seeking to reach the diagonally opposite yard, or pairs of opposite (or adjacent) players can be partners who help each other, and the first pair to yard all 26 of their counters is the winner. Halma strategy is so complex, however, that the game is best when only two people play.

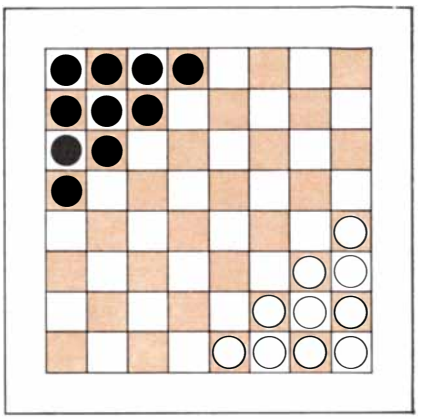
Of many later games based on Halma the two most popular in the U.S. have been Camelot and Chinese checkers, both of which appeared on the market in the 1930's. Camelot was a revival (with minor changes) by Parker Brothers of a late-19th-century Parker game called Chivalry. Chinese checkers, which has no connection whatever with China, is played on a hexagonal-cell board that is usually shaped like a six-pointed star. The hexagonal tessellation allows steps and hops in only six directions. A French version of Halma, known as Grasshopper, can be played on a standard checkerboard [*see top illustration on opposite page*]. It is an excellent game.

To prevent a stubborn player in games of the Halma type from forcing a draw by keeping a man permanently in his own yard it is wise to add extra rules.

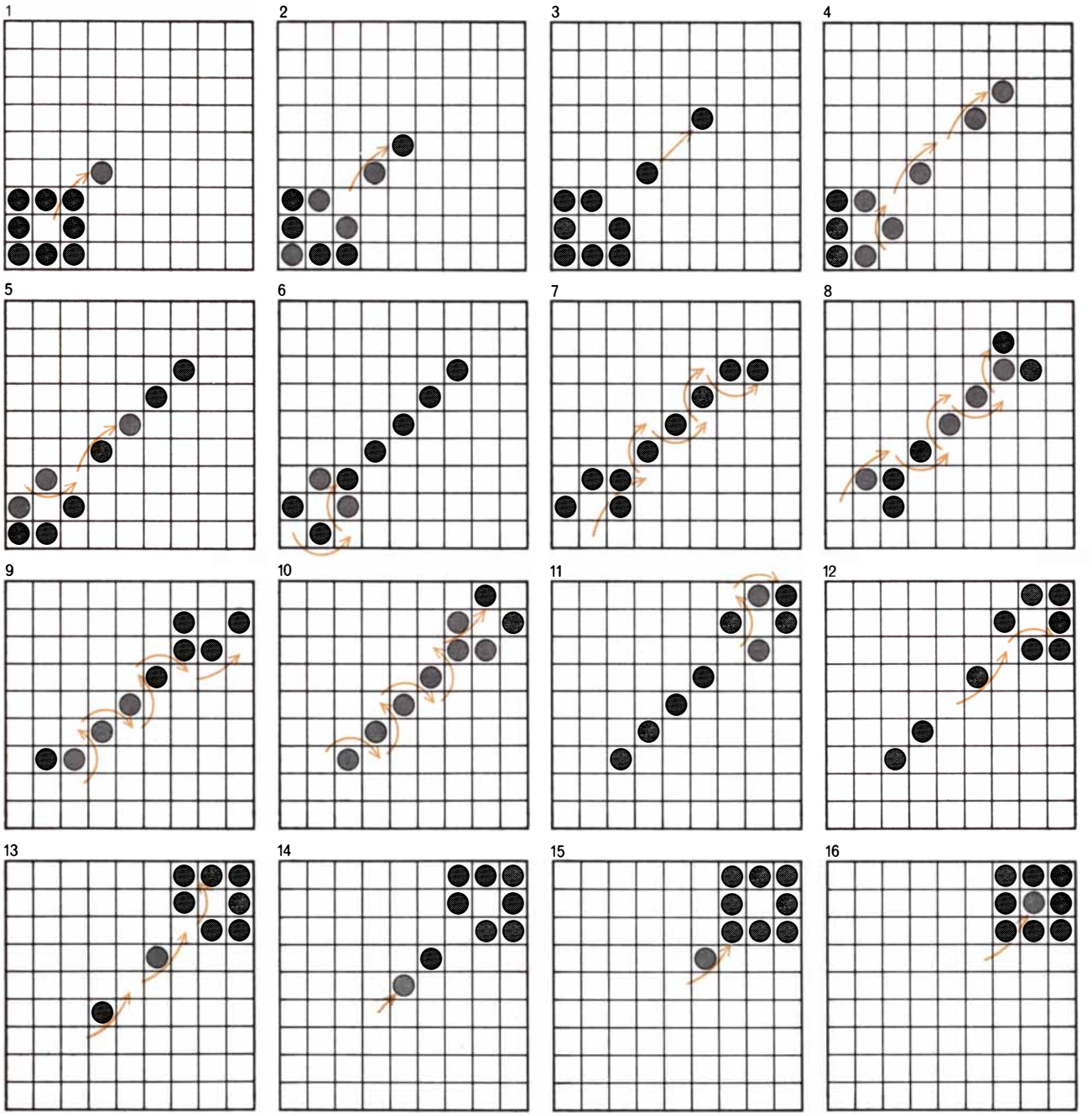
Sidney Sackson, the New York City game inventor and game collector, suggests the following. If a counter can leave its own yard by jumping an enemy counter, or by a chain of jumps that starts with a leap over an enemy counter, it must do so, although once out of the yard it may stop jumping at any desired spot. After a counter has left its yard it may not rest in the yard again, although it may hop across it.

The Halma problem devised by Matsuda for the Japanese chessboard, which has nine cells on a side, begins with nine counters in a square array at the board's lower left corner. How few moves of the Halma type, Matsuda asked himself, are needed to transfer the nine counters to the same formation at the upper right corner? He found a solution in 17 moves, but this was reduced to 16 moves [*see illustration below*] by H. Ajisawa and T. Maruyama. The 16-move solution is believed to be the minimum one.

When I saw this elegant solution, I at once began tackling the same problem on the Western chessboard with eight cells on a side and on smaller square boards with seven and six cells on a side. Using the technique of first establishing a diagonal ladder—a basic strategy, by the way, of all games of the



Grasshopper



Solution to Matsuda's problem on the Japanese chessboard

Halma type—the best I could achieve was 15 for the chessboard, 13 for the order-7 and 12 for the order-6. I have been unable to prove that any of these are minimum solutions. It is not hard to show that at least 12 moves are necessary for the order-8 square, 10 for the order-7 and 11 for the order-6.

Next I experimented with a similar transfer of the nine counters, on the same three boards, to the lower right corner instead of the corner diagonally opposite. The order-6 board has many solutions in nine moves, one of which is shown in the illustration below. Nine is obviously minimal because each counter must move once. (It is necessary that at least one counter hop to and from the fourth row on its way to the other yard, consequently nine-move solutions cannot be achieved on a three-by-six board.) On the order-7 board 10 moves will do it. This too is readily seen to be minimal since the first piece to move must move at least once again to reach the adjacent yard.

Thirteen moves will solve the problem on the order-8 board. That 12 are necessary is evident from a simple parity check. The six counters in column 1 and column 3 can hop only to column 7, therefore three of the six must each make at least one step move. I tried vainly for weeks to find a 12-move solution until Donald E. Knuth, a mathematician at Stanford University, came to my rescue by devising a proof of impossibility in 12 moves. It is too involved to give here, but it is based on the necessity for one of the original four corner counters to step to a different color, the fact that the reverse of a solution is another solution and other considerations. Readers may enjoy searching for minimum solutions to the six transfer problems. None will be given next month. But if someone succeeds in lowering the smallest number of moves known for one of three diagonal-transfer problems or manages to prove that the numbers given are indeed minimal, I shall report the results in a later column. (If there are too many letters, I shall probably be unable to reply except by summarizing them in this department.)

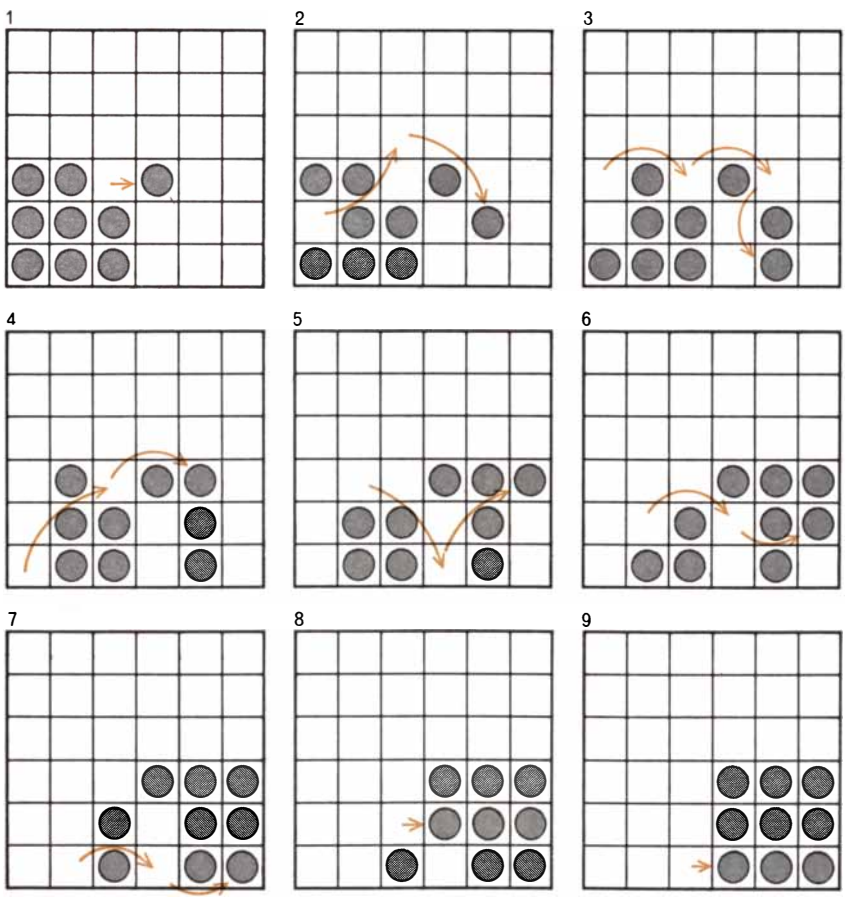
The second family of puzzles suggested by Matsuda's problem is devised by removing every jumped counter from the board. The goal is to remove all counters but one, the last counter reaching a specified cell, and do it in a minimum number of Halma moves. Such problems are similar to those of the classic peg-solitaire game discussed in an earlier column (reprinted in my book *Unexpected Hanging and Other Mathematical Diversions*) except that the greater freedom of movement allows for much shorter solutions, and proofs of minimum solutions are usually much more difficult.

Consider, for example, the puzzle on a five-square board that was first issued in 1908 by Sam Loyd [*see "a" in illustration on opposite page*]. He labeled each counter with the name of a hopeful in that year's presidential election. The idea was to eliminate eight men, leaving one's favorite on the center cell. Loyd allowed Halma moves but did not count a chain of jumps as being one move. Eight jumps are clearly minimal and there are many such solutions for each counter. Henry Ernest Dudeney, in his *Amusements in Mathematics* (Problem 229), improved the puzzle by disallowing step moves, counting jump chains as single moves and allowing any counter to end at the center. He gave a four-move solution that is surely minimal, although I know of no proof. Counter 5 jumps 8, 9, 3, 1; counter 7 jumps 4; 6 jumps 2 and 7; then 5 returns to its original cell by leaping 6.

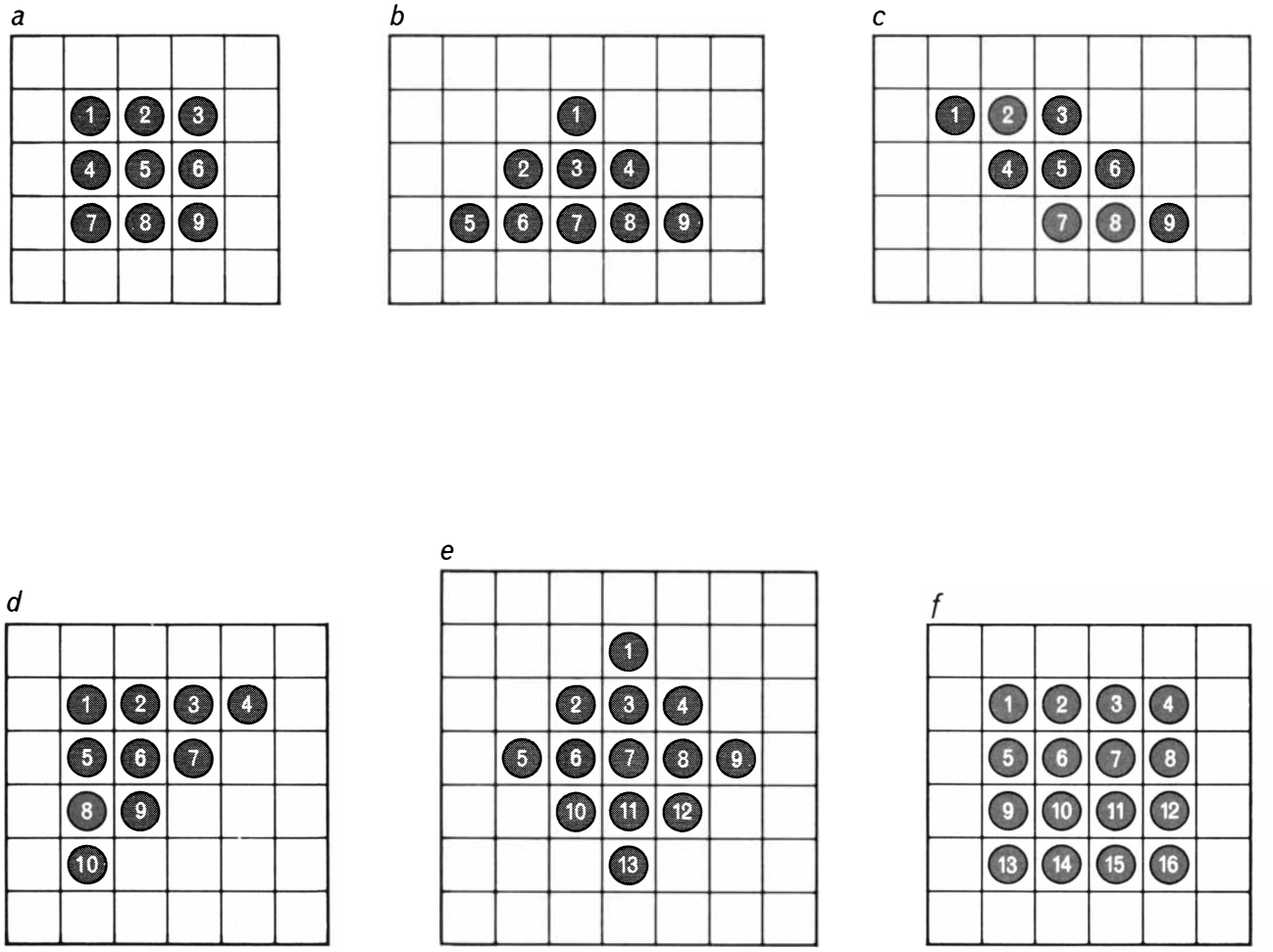
Let us combine the rules of the two rival puzzlists by allowing both steps and hops, as in Halma, and counting a chain of hops as one move. Each hopped counter is of course removed. Can the reader find one of the many three-move solutions that leave the last counter on the center cell? The solution to be given next month is an elegant one that begins with two step moves and ends with an eight-jump chain.

Similar problems are found in *b, c, d, e* and *f*. All will be answered next month: *b* is to be solved in three Halma moves, the surviving counter on the center cell; *c,* in three moves, last counter on the cell occupied by counter 1; *d,* in a minimum number of moves, last counter on the triangle's center cell, and *e* in three moves, surviving counter at the center. Problem *f,* the most difficult of the lot, calls for three moves that end with the lone counter on one of the four center cells.

I shall eventually report on any better solutions readers may find for these six problems, or on any new Halma-type problems of special interest. The field is so unexplored that it is a challenge to



Orthogonal transfer on an order-6 board



Six Halma solitaire problems

devise and solve new puzzles and then see if one can prove by simple arguments that the solution actually is minimal. I have not the slightest notion, for example, how few moves are required on an order-7 board with 25 counters in a square array in the center to leave the last counter on the center cell. I have avoided trying this problem for fear of accomplishing no other work for the next month or so.

The answers to last month's problems are as follows:

1. The simplest nonconvex polyhedron with unit-square faces is the 30-face solid formed by attaching a unit cube to each face of a unit cube. Jean J. Pedersen (whose methods of braiding solids with straight strips were last month's topic) found a way to braid this solid with three strips, each crossing once diagonally over every face of the solid.

2. A regular tetrahedron can be colored with four colors only in two ways, each a mirror reflection of the other. The simple formula that applies to all five Platonic solids is to divide the factorial of the number of faces by twice the number of edges. For example, the cube can be colored with six colors in $6!/24 = 30$ ways, the octahedron with eight colors in $8!/24 = 168$ ways, and so on.

3. A cube can be colored with three colors, each color going on two faces, in six ways: one with all pairs of opposite faces alike, two ways that are mirror images with all like colors on adjacent pairs of faces, and three ways with just one pair of opposite faces alike. Only the first three ways can be plaited with three five-square straight strips in the manner explained last month.

I was mistaken in the August issue when I reported that John L. Selfridge had a proof of his assertion about the "fork" rule in go-moku. The assertion, he has since informed me, remains a conjecture. He reports, however, that a solution *has* been found for his "four-by-infinity" ticktacktoe. This is played on a strip that is four cells high and infinitely wide, the winner being the first to get four of his marks in an orthogonal or diagonal row. Carlyle Lustenberger, in his master's thesis in computer science at Pennsylvania State University, developed a computer program with a winning strategy for the first player on a four-by-30 board. The actual lower bound for the width is a few cells shorter, but I have not yet obtained the details.

The three-by-infinity board is a trivial win for the first player on his third move; indeed, the same win can be achieved if only one cell is added to the side or corner cell of the traditional order-3 ticktacktoe field. The five-by-infinity board remains unsolved. If a win for the first player could be found on this board, it would, of course, solve the go-moku game when it is played on an arbitrarily large square, with no restrictive rules.

Next month I shall discuss reader corrections and comments on the quickie problems of July, at least one of which (the Pentagon problem) was incorrectly answered.

THE AMATEUR SCIENTIST

Experiments with wind: a pendulum anemometer and miniature tornadoes

Conducted by C. L. Stong

How strong is the wind? The question is readily answered with an anemometer. In most of these instruments the flow of air around an obstruction develops a force that varies with wind speed. The force determines the position of a pointer on a scale that is calibrated in units of speed. One popular anemometer consists of a small windmill that spins an electric generator. The output of the generator varies with the velocity of the windmill and is measured by a calibrated meter.

Many anemometers of this type have been built by amateurs. The instruments are easy to make and convenient to use but difficult to calibrate. The problem of calibration has now been solved with a portable anemometer that can also be used as a secondary standard. The instrument was developed a few months ago by P. L. Clemens while he was serving as visiting professor at the Von Karman Institute for Fluid Dynamics at Rhode-Saint-Genèse in Belgium. Clemens discusses the calibration of anemometers and the construction of his new instrument as follows:

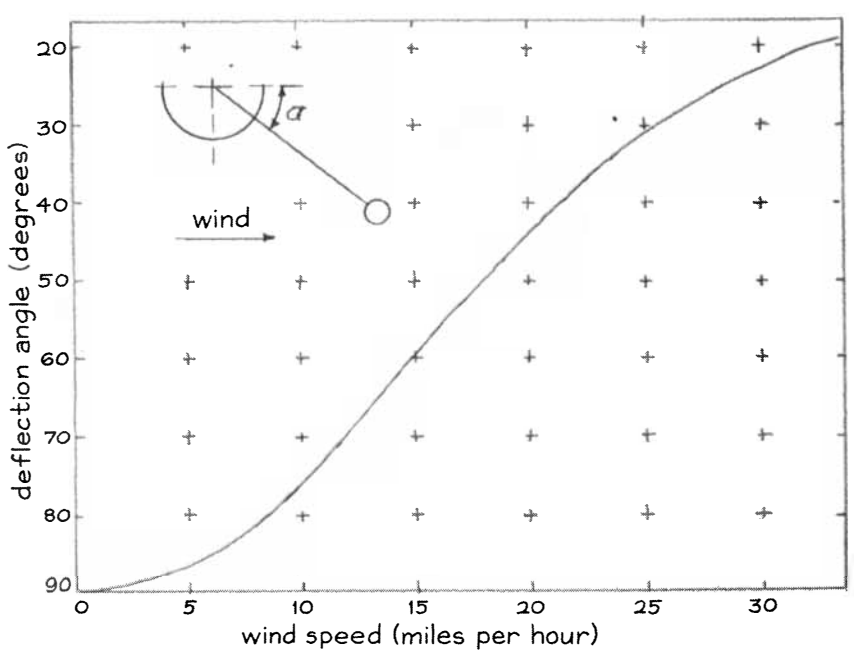
"The techniques of calibrating anemometers tend toward two extremes: accurate but expensive and simple but inaccurate. Wind-tunnel calibrations fall in the first category. Good wind tunnels are not readily available, and the cost of their operation is beyond the resources of most experimenters. For this reason many amateurs have resorted to a calibration procedure of the second kind. In that procedure the instrument to be calibrated is supported outside a moving automobile. The scale is graduated by reading the speedometer as the vehicle accelerates through a series of test velocities.

"It is difficult to imagine a more hazardous and unreliable method of calibration. The details of the procedure tend to distract the driver even though others make the observations and record the data. Moreover, the data are likely to be in error. Automobile speedometers are rarely accurate at low velocities, which are of most interest in the anemometry of sports. Attempts to average out the movement of the local air mass by such expedients as heading into the wind while making one set of observations and then reversing course for another set usually fail because of variations with time in the direction and speed of the local air. In addition the anemometer under calibration is immersed in a field of aerodynamic flow disturbed by the automobile. The velocity of the air in this field usually differs substantially from the gross velocity of the automobile. Experimenters who rely on this method of calibrating are lucky to emerge from the experience with a scale error of less than 30 percent.

"It was in response to the need for a simple and reasonably accurate method of calibrating anemometers that I undertook the design of the instrument I shall describe. It is a pendulum anemometer, consisting of a pendulum bob suspended at the center of a protractor. When the pendulum swings in the plane that contains the velocity vector of the wind, the resulting force deflects the pendulum from the vertical at an angle that varies with wind velocity. The angle is a measure of the speed of the wind.

"The basic principle of the device dates back at least to the 15th century. My contribution consists in making a pendulum anemometer that can be duplicated exactly with inexpensive materials. The device was calibrated in a high-precision wind tunnel. The calibration can be transferred directly to all exact copies of the instrument. The copies can be used either as secondary standards for calibrating anemometers of other types or as primary instruments for measuring air speed.

"The force that deflects the pendulum from the vertical arises primarily from the flow of air around the bob. If a spherical bob is tethered by a suspension of negligible area, the deflecting force is independent of the angle the pendu-



Calibration graph of the anemometer

lum makes with respect to the vertical, and the sensitivity is a function of the ballistic coefficient of the bob. The first consideration in the design of such an anemometer is the selection of a sphere capable of generating reasonable deflection angles through the anticipated range of wind velocity.

"The central problem with my instrument was finding a readily available and inexpensive sphere manufactured to close tolerances. Table-tennis balls proved to be ideal. Manufacturers are obliged to meet rigid specifications of diameter and weight that have been established by the International Table Tennis Federation. The median diameter (37.7 millimeters) may vary by no more than 1.3 percent and the weight (2.465 grams) by no more than 2.56 percent.

"In choosing the suspension cord that supports the pendulum bob one must pay attention to the properties of the cord that might influence the performance of the anemometer. The cord should have a smooth surface, negligible weight and a small diameter. My first experiments were made with monofilament nylon cord having a diameter of .08 millimeter and weighing .011 gram per meter. This cord is available in sporting-goods shops and is commonly used to tie fishing flies. The breaking strength is about 400 grams. Monofilament nylon thread is also available in shops that sell sewing supplies. After my initial experiments I used cord of .2-millimeter diameter with no observable difference in performance.

"The cord must be firmly attached to the ball. The attachment should add minimum weight to the assembly and should introduce minimum aerodynamic interference. To make the attachment I pierced the ball with a sewing needle at two diametrically opposite points. (The perforations also create two shallow indentations.) A needle threaded with the monofilament cord is passed through the ball. The free end of the cord is fastened to the ball with a dab of plastic cement. After the cement has hardened, surplus cord is trimmed as close as possible to the surface. Use a cement that does not attack the ball chemically. Test weighings indicate that the cementing operation, when performed with reasonable care, adds less than a milligram to the mass of the ball.

"The upper end of the suspension cord is passed through the index hole of an ordinary plastic protractor. The protractor serves as the scale for measuring the angular deflection of the pendulum with respect to the horizontal. (This may seem to conflict with the previous statement that the angle is measured with respect to the vertical. Mathematically the angles are complementary. Measuring with respect to the horizontal is a convenience in that it conforms to the usual scale markings on commercially made protractors.)

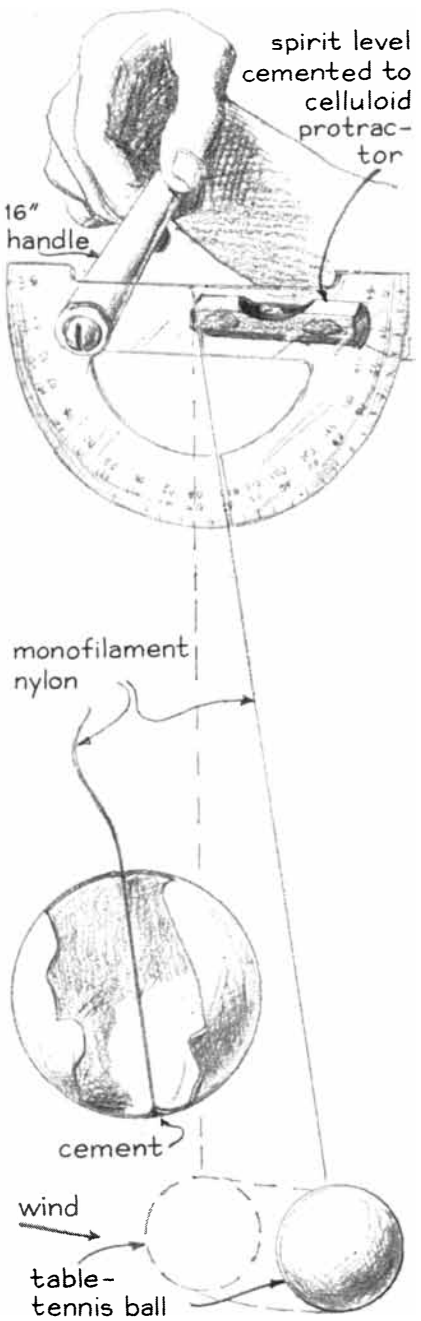
"Adjust the length of cord between the upper surface of the ball and the index hole of the protractor to 30 centimeters (12 inches) and attach the free end of the cord to the rear surface of the protractor with cement. Similarly, cement an ordinary spirit level parallel to and near the base line of the protractor [*see illustration at right*]. A baton about 40 centimeters long should be attached to the assembly. The baton can be made of wood dowel stock about half an inch in diameter. The baton enables the observer to support the instrument beyond the zone of disturbed air that surrounds his body. Wind-tunnel measurements indicate that the presence of the observer has a negligible effect on the measurements if he remains at least three body diameters toward one side of the instrument and does not move upstream.

"The aerodynamic characteristics of the instrument were determined by a series of measurements made in a wind tunnel. From these data I derived an equation that expresses the calibration at standard conditions of atmospheric pressure and temperature. Air speed is equal to a constant multiplied by the square root of the cotangent of the pendulum angle indicated by the protractor: $u = 19.59(\cot \alpha)^{1/2}$, in which u is the air speed in miles per hour and α is the angle. The resulting calibration is listed in the accompanying table [*next page*]. The data are also plotted as a graph [*see illustration on opposite page*].

"Significant error may be introduced as atmospheric pressure and temperature depart from standard conditions. For maximum accuracy such departures must be taken into account. The equation, as modified to include these corrections, is $u = 31.72[(\cot \alpha)(T + 273)/P]^{1/2}$, where T is the temperature in degrees Celsius and P is atmospheric pressure in millimeters of mercury.

"In using the instrument one stands with the right shoulder facing into the wind. Grasp the baton in the right hand and hold the instrument at arm's length. Level the protractor and read the deflection of the pendulum directly from the scale. The contrast between the cord and the scale can be increased by applying a dab of colored enamel to the cord in the zone where it crosses the scale.

"As with any anemometer, the observer should select an open area, free of obstructions to windward. Velocity gradients and turbulent eddies can be expected downwind from buildings, trees, shrubbery, fences and the observer himself. By the same token do not expect to make accurate measurements near the edge of a boat. Rain or spray that wets the ball increases its weight and decreases accuracy. The bob responds quickly to gusts and lulls, causing the pendulum to oscillate. The knack of reading maximum and minimum indications of the oscillating pendulum to



P. L. Clemens' anemometer

find the average value of the angle comes with practice. Under most conditions the accuracy of the measurements is better than 6 percent."

V. G. Blanchette, an engineer of Pass Christian, Miss., has stirred up a tempest in a baking pan, thereby enabling experimenters to probe the mechanism of violent whirlwinds without leaving the kitchen. The required materials include only a table, an electric fan, a vacuum cleaner and a shallow vessel holding water. Blanchette writes:

"It is possible to set up in the laboratory or at home a small-scale demonstration that characterizes the extremely vigorous and dynamic conditions associated with tornadoes. The equipment utilizes low air velocities to develop an aerodynamic funnel of such vigorously circulating winds that materials at the surface are drawn into the vortex. Theoretical considerations of the convergent airflow forces in the model lead to possible explanations of how and why tornadoes develop and may explain other unusual tornado-like phenomena.

"The model tornado is created by mounting the suction tube of a vacuum cleaner horizontally about 4½ inches above the top of a flat table and directing the breeze of an electric fan at right angles across the suction tube [*see top illustration on page 112*]. Face the outlet of the vacuum cleaner away from the table to prevent the high-velocity exhaust from disturbing the air in the vicinity of the model. Put the fan 10 to 15 feet from the model and adjust it to create a mild breeze, not a stiff wind.

"Turn on the fan and the vacuum cleaner. Tornado-like winds will form between the top of the table and the inlet hose after some experimental adjusting of the velocity of the cross breeze. To detect the vortex put a shallow pan of water on the table directly under the hose. A shallow baking pan holding about an eighth of an inch of water works well.

"At the point where the tip of the vortex darts to the surface the water is pulled up into a hump that marks the lower end of the 'static line,' around which the winds rotate. The hump can be seen easily (by the refraction of light) as an image at the bottom of the pan. The hump disappears when the fan is turned off.

"At certain adjustments of the crosswind the funnel of the miniature tornado wanders randomly, striking here and there on the surface of the water as the terminal point of the static line swings in response to local air movement. At other adjustments it remains almost stationary for relatively long intervals. The height of the hump can be observed by sighting horizontally across the surface of the water. Usually it stands from a quarter of an inch to half an inch high.

"Occasionally a small drop of water is pulled from the top of the hump. The surface of the water also circulates around the small area adjacent to the static line. The circulation is relatively sluggish, however, and does not suggest the violent motion of the air at higher elevations along the static line.

"After the model has run for a time the end of the vacuum hose becomes damp. This condition indicates that moisture is being drawn into the hose. Caution: Do not lower the hose to the point where it would suck water into the vacuum cleaner.

"More dramatic effects can be created by replacing the pan of water with a surface of powdered material such as dry plaster of Paris. To make this ex-

ANGLE	MILES PER HOUR	METERS PER SECOND	ANGLE	MILES PER HOUR	METERS PER SECOND
55	16.4	7.33	20	32.5	14.5
56	16.1	7.20	21	31.6	14.1
57	15.8	7.06	22	30.8	13.8
58	15.5	6.93	23	30.1	13.5
59	15.2	6.79	24	29.4	13.1
60	14.9	6.66	25	28.7	12 8
61	14.6	6.52	26	28.1	12.5
62	14.3	6.39	27	27.5	12.3
63	14	6.26	28	26.9	12
64	13.7	6.12	29	26.3	11.8
65	13.4	5.98	30	25.8	11.5
66	13.1	5 85	31	25 3	11.3
67	12.8	5.71	32	24.8	11.1
68	12.5	5.57	33	24.3	10.9
69	12.1	5.43	34	23.9	10.7
70	11.8	5.29	35	23.4	10.5
71	11.5	5.14	36	23	10 3
72	11.2	5	37	22.6	10.1
73	10.8	4.85	38	22 2	9.91
74	10.5	4.69	39	21.8	9.74
75	10.1	4.54	40	21.4	9.57
76	9.79	4.38	41	21	9.40
77	9 42	4.21	42	20.7	9.24
78	9.04	4.04	43	20.3	9.08
79	8.64	3.86	44	19.9	8.92
80	8.23	3.68	45	19.6	8.76
81	7.80	3.49	46	19.3	8.61
82	7.35	3.29	47	18.9	8.46
83	6 87	3.07	48	18.6	8 32
84	6.36	2.84	49	18.3	8.17
85	5.80	2.59	50	18	8.03
86	5.18	2.32	51	17.6	7 89
87	4.49	2.01	52	17.3	7.75
88	3.66	1.64	53	17	7.61
89	2.59	1.16	54	16.7	7.47
90	0	0	55	16.4	7 33

Calibration table of the anemometer

periment dry the hose and spread the powdered material on the table over a 12-inch area. Turn on the vacuum cleaner and adjust the fan to create a gentle cross breeze in front of the powdered area. Simultaneously sight horizontally across the table to see the material ejected from the surface. When the velocity of the crosswind is properly adjusted, a thin funnel will develop around the static line and suck powder into the swirling air above.

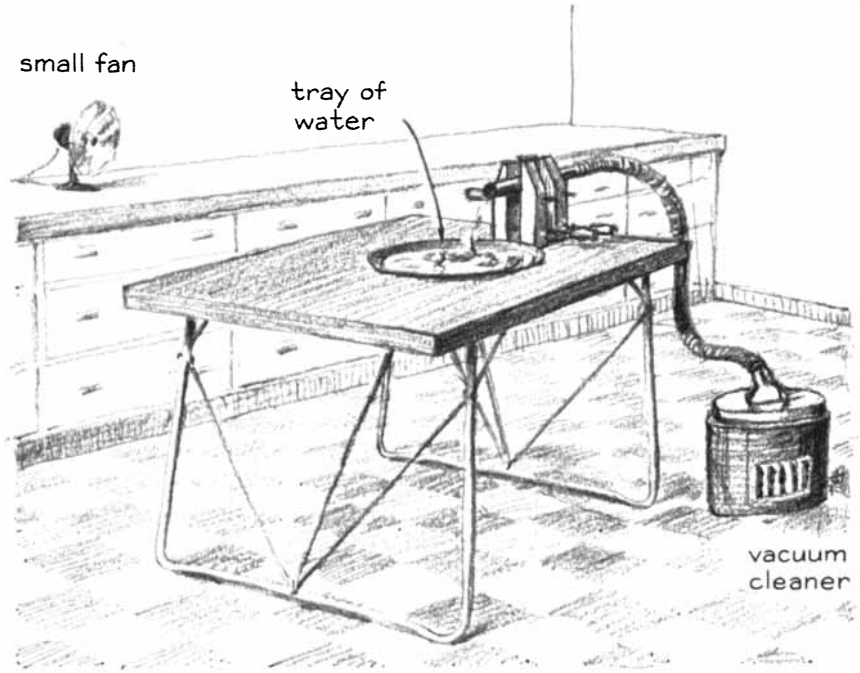
"The flow lines can be made visible with smoke. Put the source of smoke at the surface near the static line. At first the smoke may appear to move lazily, with little tendency to flow in any particular direction, but when the apparatus is in proper adjustment, a typical 'twister' will develop that is impressive to observe.

"Why does the whirlwind develop? When the vacuum hose is positioned at a substantial distance from other objects, air enters the opening in a uniform, symmetrical flow. Velocity increases as the flow approaches the hose [*see middle illustration at left on next page*]. When the hose is near the table, which represents the ground plane, the vertical flow becomes asymmetric. A static line forms from a point on the ground plane and curves upward, entering the hose at a point near the bottom [*see middle illustration at right on next page*]. The static line represents the backbone of the model.

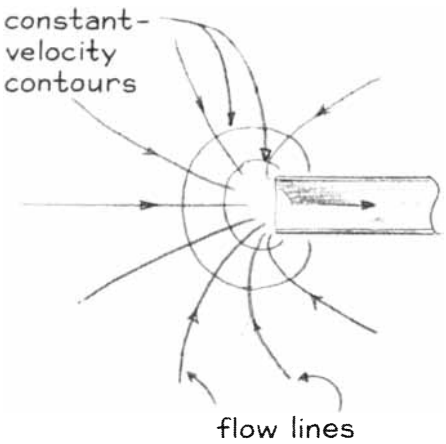
"Surrounding the static line is a pattern of continuous flow lines that curve upward and converge toward the static line. The air velocity increases as the flow lines converge. The flow into the hose will not by itself form a swirling wind, although it does meet two basic conditions associated with tornadoes: high-level horizontal flow, which is simulated by the flow of air into the low-pressure sink at the hose, and an unusual area of vertical flow surrounding the static line. The third basic condition, which is essential for the development of a tornado, is a horizontal flow near the ground plane. In the model the crosswind is provided by the fan.

"The velocity of the crosswind must not be high or it will warp the high-level flow excessively. Even a gentle cross breeze significantly affects flow lines near the surface. The crosswind contributes an additional velocity vector that is perpendicular to the normal flow lines, as at point *A* in the illustration.

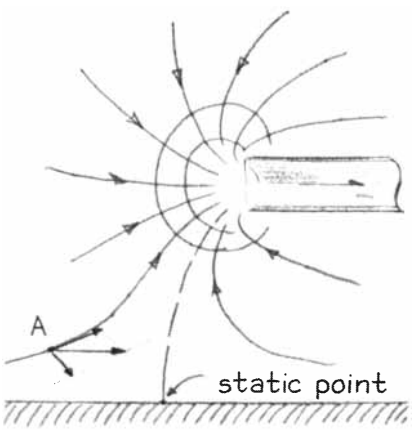
"The horizontal displacement thus induced evolves into a circulation around the static line and initiates the



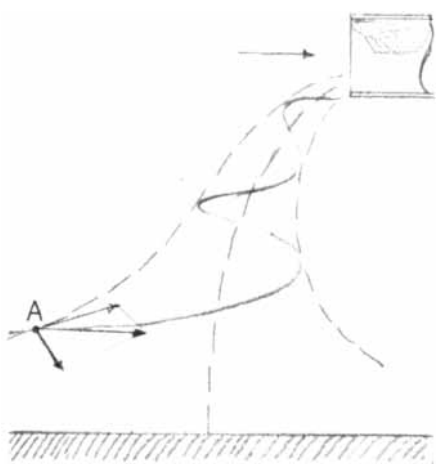
V. G. Blanchette's apparatus for generating miniature tornadoes



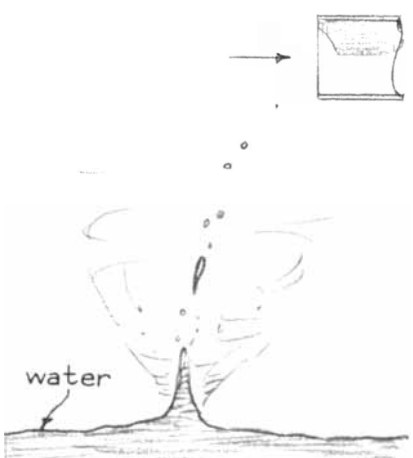
Pattern of airflow near the hose



"Static line" (broken) and related flow



Development of spiral flow



Miniature tornado

converging spiral [*see illustration at bottom left on this page*]. The velocity at any point *A* can be resolved into two vector components. One component represents upward movement that converges with adjacent flow lines. The second component represents circulation around the static line. By the principle of the conservation of momentum the velocity of the second component increases inversely with the radius of the circulation. In effect, both sets of forces combine to increase the velocity as air rushes up the spiral.

"The velocity can become impressive. For example, the velocity of a mass of air circulating at a radius of 2½ inches increases from 15 feet per second to 150 feet per second when the radius is reduced to 1/4 inch. In theory the mass can approach sonic velocity as the radius is further reduced.

"The high-velocity rotation reduces the pressure on the static line below the entrance of the hose, with the result that flow lines converge farther down the static line. The process evidently continues until pressure at the surface in the swirling core is significantly lowered. The result resembles a miniature tornado [*see illustration at bottom right on this page*].

"The model demonstrates a number of features that are characteristic of full-scale tornadoes. As in nature's storm centrifugal force creates a partial vacuum at the center of the funnel. Rotation can occur in either sense, clockwise or counterclockwise, depending on the local winds. The tip of the downward-projecting funnel may wander in the air or dip to the surface, where it reacts vigorously over a relatively small area.

"Although the motion appears to be random, it is governed by forces that displace the static line. Occasionally the tip of the funnel drifts as much as 18 inches from the vacuum hose, creating a track in the powdered surface that extends to the edge of the table. A larger model would demonstrate that two or more funnels can appear simultaneously, because the pattern of local airflow can generate more than one static line.

"For these reasons I am convinced that continued study of the model would result in data and measurements that would improve our understanding of tornado-like phenomena. Some of the experimental problems could be eased by scaling up the apparatus to a size sufficient for generating whirlwinds measured in feet instead of inches. Such models, apart from their possible value as demonstrations, would make fascinating playthings."

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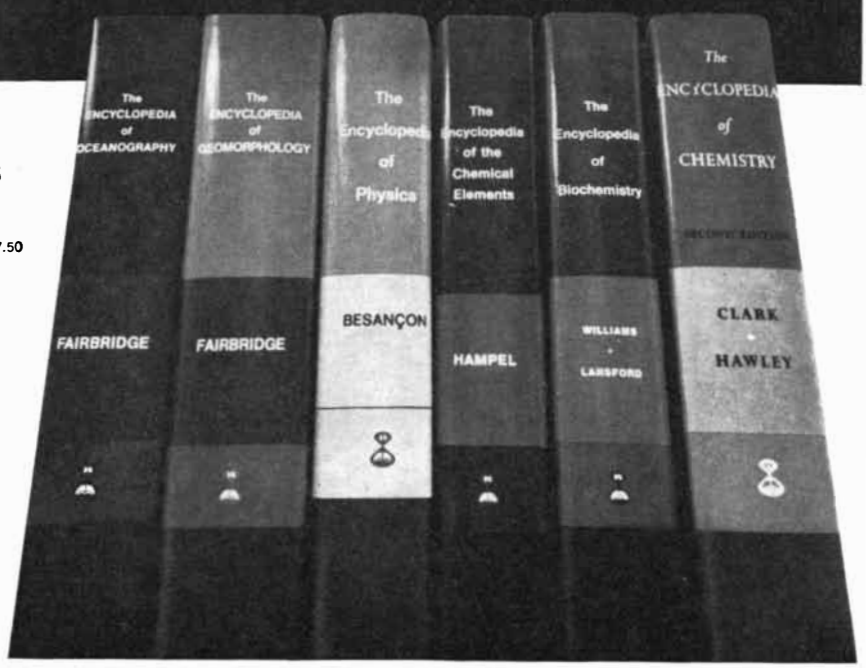

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BOOKS

The biology of the elephant, the art of marine salvage and other matters

by Philip Morrison

THE NATURAL HISTORY OF THE AFRICAN ELEPHANT, by Sylvia K. Sikes. American Elsevier Publishing Company, Inc. ($30). Nothing about the largest living species of land animal, the African elephant, is a commonplace. It may weigh six tons; it cools its great bulk by the use of its huge ears, both as fans and radiators; its familial devotion is as adaptive as it is touching; it seeks out the easily fermenting fruit of certain palms to enjoy the delights of alcohol; its very droppings weigh up to two kilograms a lump. This substantial book is worthy of the species; it combines meticulous documentation and personal field experience with independent, bluntly expressed opinion. It presents the findings of an acutely observant anatomist with long experience both at elephant-watching and elephant autopsy.

Dr. Sikes has spent decades in Africa, both east and west. She earned her doctorate with a research project carried out with rifle, scalpel and sampling bottle on the plains of Kenya; she followed the elephant for four years as a means of studying cardiovascular disease in free-living wild animals. She inscribes her book to two skilled professional hunters, Mohammedu Shehu in the west and Mutarimbo Ndete in the east, "who watched and hunted elephants with me." Her first elephant, a rogue, attacked at close range and was killed with a single bullet to the brain. She recommends that technique still; an elephant so killed falls to the ground almost without a sound, so that other elephants nearby may be taken unaware. After each kill there were six to 12 hours of autopsy, weighing, measuring, sampling, searching for parasites. How do you weigh a dead elephant in the bush? "Most field workers [hoist] the carcass piece by piece with a block and tackle mounted on a strong tripod, and carrying a spring balance capable of weighing up to one or two tons." The author corrects such a butcher's weighing by adding 5 percent for fluid loss, although her instantly killed specimens bled little and did not usually defecate. One can expect, given the variations of recent eating and drinking (a big bull may drink 22 gallons of water at a time), a spread of plus or minus nearly 500 pounds.

This is a definite treatment of the elephant, not merely a hunting adventure. To ignore the hunt would belie reality and omit one of the indispensable techniques of study, but the theme of the book is the entire life of the species from birth to copulation to death. The elephant is discussed from pillar-like leg to sensitive trunk, first as an individual organism, then as a social animal in its environment and finally with respect to its exploitation by men. The book ends with a typical example of Dr. Sikes's iconoclasm and scholarship, paraphrasing Holy Writ to make a strong case for its being an elephant beside the Jordan (or perhaps in North Africa) that was the Behemoth of the Book of Job, not a gross, snuffling hippopotamus or some mythical monster.

What elephantine wonders are here for the reading! There is a new technical method (worked out by the author) for finding the age of the elephant by its molars. There is a photograph of a polished section of tusk revealing the elegant lozenge texture of the dentine that distinguishes elephant tusk from all other ivory: hippopotamus, narwhal, walrus and wild boar. There is a diagram from a Ceylonese zoologist of the sensory points on the skin of the Asiatic elephant that are "used by the mahouts for elephant control." The Asiatic species, peripherally present in the book, is often a source of comparison, since its literature is in many ways more complete. One cannot any longer accept the tale that the African elephant is untamable; at Gangala-na-Bodio in the Congo there has been a trained elephant herd for 40 years. There to this day you can hire elephants for logging and land clearance at "very reasonable sums." The fan-eared beasts are shown pulling an enormous wagon heaped with fodder. (This is to say nothing of Hannibal's war elephants, nor of Aristotle nor even of P. T. Barnum, to mention only two famous men who knew the adaptable qualities of *Loxodonta africana*.) There is a graph of fetal weight against time since conception, and to enrich it an X-ray picture of a tiny fetus, then a tender color photograph of a fetus at about six months (weighing less than three pounds but all elephant), then a fetus at term after 90-odd weeks of growth *in utero* (weighing more than 200 pounds and with hooves, not yet lost through walking). There is also a charming shot of the firstborn of twins rising to its feet with its mother's help, and the first step of the calf Africano, taken about three years ago in the private zoo of Dr. von Opel of Kronberg in West Germany. We see a big wild elephant standing on its hind legs to snatch fruit from a high branch, and we have an eyewitness account by the author of an "apparently totally blind" old cow she saw near Lake Chad in 1962, living within a large herd, "feeling her way with her trunk tip as a blind person uses a white stick. She fumbled almost on top of us, and we could see that both her eyes were completely opaque. She fumbled past, continuing on her way, apparently completely unaware of our presence."

The book presents maps and herd-structure charts, and a lively critique of the practices of the ecologist elephant-cullers who now crisis-manage the crowded game parks of modern Africa, where gallery forests and their watercourses are becoming too few for the migrating herds. We cannot hope for much room for elephants in a world now crowded for man, but we can expect that the national governments of Africa will conserve the "finest elephant stock available within well-run ranch-type national parks."

There is a photograph of the hunter Mohammedu Shehu aiming his long muzzle-loader, intent, knowing and poised, like a Kentucky rifleman out of our own past, but we miss a picture of

Dr. Sikes, who has given us this modern natural history, which knits theory and experience, calm detachment and deep affection.

MARINE SALVAGE: THE UNFORGIVING BUSINESS OF NO CURE, NO PAY, by Joseph N. Gores. Doubleday & Company, Inc. ($12.50). "Wedges of gold, great anchors, heaps of pearl,/Inestimable stones, unvalued jewels,/All scattered in the bottom of the sea." So dreamed the Duke, the brother of Richard III, imprisoned in the Tower. It is the epigraph of this thick, meaty, fascinating book, and it outlines the purpose of most marine salvage: to reclaim cargo lost at sea. Add the scrap iron of the ships themselves, amphoras and a hydrogen bomb (the most elaborate feat of salvage yet, costing some $84 million), and the purposes are spanned. This account is the work of a successful mystery writer who knows men, words and the sea; his tale is swift, always sensible and often admiring, and it is first-class reading for anyone who is caught by the salt spray and the way men try to extend their will beyond the environment of their species.

The underwriters' exchange called Lloyd's of London governs the economics of this trade, suspended as it is between sober marine engineering and sheer adventure. Lloyd's contracts have formed the law of admiralty, extending far beyond even that empire on which the sun never set. The standard contract provides the subtitle of the book; worldwide practice is based on "the principle of 'no cure—no pay.' " The salvor's task is dominated, like all work at sea, by wind and wave, but in addition it is burdened by darkness, pressure, the grip of mud and sand, the lack of air, the inexorable two-way instabilities of gravity—buoyancy and dead weight—and the outsize scale of ships, more massive than anything man makes except buildings (and nowadays *Saturn V*).

Salvage is as old as Crete, but the modern story begins more or less in Portsmouth harbor, where the Royal Navy has been based since long before the Spanish Armada. In 1782 the 108-gun *Royal George* capsized there while heeled over for repairs. It was 1840 before she was raised, with the help of the hard-hat diving dress newly invented by Augustus Siebe. Siebe, Gorman and Company still make similar diving dress.

Salvage is mainly lift. One used simply to grunt the load up by pulling hard on the cables divers somehow got under and around the wreck. Then tide lift was ingeniously used: the ropes to the surface vessels were pulled tight at low tide, and when the tide came in, the sunken vessel was lifted from the bottom and could be moved toward shallower water. Then pontoons: big, cheap tanks that were flooded, roped tight to the wreck and then blown dry with high-pressure air. From 1924 to 1931 there was the dogged, unyielding salvage of the scuttled German fleet in Scapa Flow by "the incomparable" Ernest Cox and his men. They patched the hulls of 32 sunken warships and airfloated them, mainly belly up, the ships acting as their own pontoons. Before the battle cruiser *Seydlitz* could be brought up stably she was raised 40 times sideways! They financed the effort as they went by selling steel from the ships for scrap.

Cox and the ingenious and tireless Commander Edward Ellsberg, who with his men improvised and scrounged all around the northern coast of Africa to make ports usable for the Allied campaigns of World War II, are Gores's heroes. At present we find deep-sea submersibles, underwater television, plastic foam, sonar servomechanisms and scuba divers entering the trade. But the sea still rules, and operations there cannot ever be as neat as the planned Newtonian ventures of the cislunar void.

Gores presents 31 chapters of good stories, with an unfailingly intelligent appraisal of both the physics and the human situations around the salvage. He writes with life and sense; he provides 13 pages of bibliography, mostly from newspaper stories, but very few footnotes. This is a book to enjoy; its photographs too are out of the ordinary. You can see the sunken *Maine*, pumped bone-dry behind her cofferdam, lying on the floor of Havana harbor.

As a mere passing comment Gores gives a convincing explanation of the famous mystery of the *Mary Celeste*, found in 1872 in mid-Atlantic sailing smoothly ahead, deserted, with no crew, lifeboat or papers, yet intact and undamaged. Her cargo was casks of crude alcohol; a harmless explosion belowdecks must have alarmed the captain, who set off in haste with all hands in the open boat, only to be lost at sea in a storm hundreds of miles away. It was also the owner's theory.

Finally, among the hundreds of anecdotes of good fortune and bad, of valor and deceit, here is one to astonish. After World War I the United States Navy submarine *S-5* came to grief; trying to surface off the East Coast, she was able to blow clear her aft tanks, but the forward ones stayed waterlogged. Then she hung nose down in the open sea. She had no working radio, no escape gear, no free hatch or torpedo tubes, although her stern was sticking out a little. The crew sent up a telephone buoy, and its ringing sounded over the empty waves, to be answered after 35 hours by an investigating boat from a troopship that had by chance passed so close that someone had heard the sound of that lonely ringing telephone! They still had a couple of hours of air left aboard, and the clever engineers of the *General Goethals* were able to cut a hole through the submarine's double hull just before the air gave out.

FUTURE DEVELOPMENTS IN TELECOMMUNICATIONS, by James Martin. Prentice-Hall, Inc. ($14). The capacity of a single telecommunications channel has risen exponentially, without visible deviation from a straight line on a semilog plot, from the days of Samuel Morse and Charles Wheatstone in the 1840's right through 1960. The doubling time runs just under six years; far from plateauing out, the curve in the 1970's appears to be rising even faster than one would expect. That is the foundation for the argument of this interesting book, aimed at general reader and technical reader alike, "to take all the facts that seem relevant to telecommunications, explain them to the reader, and piece by piece build a picture of where we are going." One section of the volume is conservative, expecting no surprises, looking only a decade ahead; others are more extrapolative, pushing gingerly up to 1990.

Public voting by wire, fire alarms, telegraphy, meter reading, credit systems and such functions require only minimum channels, even narrower than the four kilohertz of the normal telephone. Multiply them for use by the entire population and real demands on channel capacity are made. Large wall-screen television might take 50,000 kilohertz. In between are an enormous variety of links among people and machines. Digital transmission allows time division among messages sharing a single wide-band channel much more effectively than analogue multiplex schemes do, and modern integrated electronics promises the needed logic circuits cheaply in mass production. On these two pillars the pyramid will rest.

It is quite a structure. Its precursors are existing proposals, such as the Bell Picturephone, so far a rather laggard entry for all its bandwidth. There is a switched microwave data-handling network, local and long distance, in the

stage of corporate proposal, which would connect any two subscribers in the U.S. within three seconds, ready to handle about 5,000 bits per second to anyone at prices well below Bell's. (The Advanced Research Projects Agency of the Department of Defense links 10 of its own contractors' computer centers now.) It turns out that digital messages might be handled better, not by physically switching circuits in space to give you a complicated line direct to your addressee but on the "hot potato" principle. In such a system all messages are constantly relayed from network node to network node, wherever they find any free path, and are copied down and taken out of circulation only by the computer that finds its code address passing by. (A count of the number of junctions that have handled a message goes along with the message, growing with time, so that messages with some fault in the address need not circulate in the network forever.) Communications satellites, computer switching, personal transceivers—first for all vehicles (learn French on the train, or play chess on plane trips) and later for all persons (for shopping, for credit, for memorandums); such possibilities are discussed with carefully supported extrapolations. There are six million radio and television transmitters in the U.S. right now, 40 percent of which are mobile. It is not too difficult to imagine this number rising 50 or 100 times in a couple of decades.

Naturally such a computer network would constantly keep track of all its mobile subscribers (with a few pulses automatically emitted now and again from each set) in order to know which short-range radio transmitter to best reach them on. It would resort to land lines and satellite links whenever it could; the simple, crowded radio links would usually reach out only a few miles. Costs are not impossible; even with present methods $200 would build such a personal set. You can buy a briefcase radio-telephone in New York today for $2,550, and the Metroliner uses one rather primitive version of the automatically switching radio network; it radios train calls to the most effective transmitter among the nine along the route, not always using the closest one.

The author of this book, behind his hardware exterior, is something of an artist. Martin writes simply and often even personally, and he has chosen many excellent photographs and helpful diagrams. Like any good artist, he suits form to content. His form is computer-like in many respects. First, he is remarkably productive; with a little help from his friends he has put out roughly a book a year for nearly a decade. Second, his work is assembled modularly from subroutines. Entire pages reappear from book to book, and from a few other sources, particularly the President's Task Force on Communications Policy. Third, there are plenty of bugs, as in every computer product. We see wrong dates, read of interesting illustrations that never appear and so on. Debugging is not completed before the next model comes out. All of this is familiar enough. We can set aside such honest foibles, because Martin has served plenty of tasty food for thought. His notion of widespread computer amateurs is appealing and rings true, and one of his summary sentences has a prescient sound even out of context: "This prospect is dismaying to many older people (those who read the book in the 1970's) but strangely enough, a new generation of students is emerging that appears to welcome it!" No one who is intrigued by telecommunications, and no one who wants to look squarely at what that technology can do (whether it will or not is less clear) will be disappointed in this book.

NAVAHO MATERIAL CULTURE, by Clyde Kluckhohn, W. W. Hill and Lucy Wales Kluckhohn. Harvard University Press ($25). There is an old ritual need for eagle feathers; sometimes one can rob a nest and rear the kidnaped young until they are bravely feathered. Or a hunter who knows Eagle Way, so that he can sing the right songs, hides in a pit, covered with sticks and earth, at one end of which he tethers a live rabbit. When the eagle strikes, the hunter catches it by the feet, calling it by its sacred name. Prairie dogs are good food; it sometimes pays to place a piece of mica in a split stick and set the stick where it will reflect sunlight down the animal's burrow. When the prairie dog comes out, half-blinded, it is more easily shot with a barbed arrow. The oldest form of hogan seems to be a conical arrangement of forked sticks interlocked at the apex and covered with mud plaster. Red dye, known as "mountain mahogany, its juice," is made from the pounded and boiled root bark of that shrub, mordanted with juniper ash. It is a fast red for buckskin. Salt is gathered near where the Little Colorado flows into the Grand Canyon, and in an old volcanic cone called Zuñi Salt Lake. People still make the trip; no other salt will do for ceremony. Many people prefer the lake salt, saying that store salt is too bitter. Four-ply buckskin "big shirts," the layers glued together, were used as body armor in war. The intricate string figures we call cat's cradle are made by everyone, except during the summer, "when the Spider People . . . are at rest." The patterns represent constellations, the first hogan, animal figures such as the owl, lightning, mountains and many more. "Little girls did not always know how, but tried."

So reads this unusual book: 263 such distinct material "traits" are fully described, most of them with drawings or photographs, as they were found in several regions of Navaho territory by some 20 fieldworkers. To each such field account of a trait, observed or reported by informants during visits made between 1933 and 1966, the authors add a careful comparative paragraph using the entire literature, most often the dictionaries of the language compiled by the Franciscan Fathers at St. Michael's in Arizona around 1910.

Several general conclusions flow from this fascinating detailed account of how an entire people conducted the tasks of providing food, clothing and shelter, of waging war and safeguarding health, of conducting ceremony and cure, of playing music, ornamenting the body and making toys for children. The Navahos are admirable and selective borrowers; coming from the barren sub-Arctic, they learned weaving from the Pueblos, the rearing of livestock from the Spanish and Mexicans, the use of cotton cloth from the Americans. Their bitter confinement at Fort Sumner tended to unify the way they do things, and the effects of this unification are felt a century later. Change continues, perhaps faster than ever. "Differential acculturation," say the authors, "is about at an end, and in a relatively short time the material culture of the Navaho will become homogeneous." Roads, pickup trucks, radios and literacy are diffusing the heritage to all, even to the isolated west beyond the Hopi lands, where the "old" traits are still strongest.

FROM CONCEPTION TO BIRTH: THE DRAMA OF LIFE'S BEGINNINGS, by Roberts Rugh and Landrum B. Shettles, with Richard Einhorn. Drawings by Rhoda Van Dyke. Harper & Row, Publishers ($12). The work of two New York medical-faculty men, one a radiologist and embryologist and the other a man with wide experience in clinical obstetrics and gynecology (he has examined more than 20,000 women), this well-illustrated book is intended for the literate general reader, particularly if the reader is having, or hopes to have, a

baby. (Fathers are not excluded.) The text and its striking pictures—photographs in color and black and white, and drawings—present an up-to-date account of the development of the new human being day by day and week by week. The writing is not oversimplified, but it is low in jargon, the mark of the science writer of the team. A second part of the volume verges on a manual, with a balanced regime for the times of pregnancy, the crisis of birth and the "interconceptional period." There are chapters on contraception and on human genetics, with a strong and explicit chapter warning of the dangers of drugs and disease to the fetus. The book is almost uniformly interesting and precise; its only fault is that familiar professional blandness which implies without saying so that a physician can do no wrong, and that a physician is always available to answer every question.

The birthmark, a usually unimportant red or wine-colored patch, is the commonest birth defect: it is found in about half of the total of 6 percent of all children who are born with some noticeable wound. Congenital heart abnormalities are the most serious of the commoner defects. Often caused by rubella or similar insults in the early months of pregnancy, they affect about one birth in 60. Next seems to be the sickle-cell trait, a condition mainly affecting black infants, with a frequency as high as 10 percent in that population, or about one in 100 of all U.S. births. This abnormality of the hemoglobin molecule impairs oxygen absorption, sometimes so seriously as to present the risk of death in circumstances of unusual stress, such as exercise at high altitude. Its effect is usually small, but when both parents donate the gene, the result is an anemia that is often fatal. The sickle-cell trait is thought to provide protection against the malaria parasite, so that whereas it is a defect in the American environment, it is highly adaptive in tropical Africa.

The deformities of ancient omen—cleft palate, hydrocephalus, clubfoot, mongolism, deaf-mutism and the like—amount to less than 1 percent. Prematurity from spontaneous abortion, affecting approximately one pregnancy in 10, is the main source of mortality. No infant under 25 weeks has ever survived, and to "have even a slim chance of survival" the fetus must be more than seven months old and weigh more than a kilogram.

The germ cells that hand on the genetic scripture are formed from the yolk sac at about 21 days, when the embryo is less than an eighth of an inch long. Here we have photographs of the embryo at that time. These 100 cells will eventually give rise to the millions of ova or to the million million sperm cells formed during life, the choice being fixed at the instant of conception by the presence or absence of one quarter-size chromosome in the single effective spermatozoon. The photographs that are somehow the most touching are a series showing the plate of embryonic tissue, with its five tiny buds, that becomes the diminutive but clearly human hand or foot after 12 weeks of gestation.

ATLAS OF SCANNING ELECTRON MICROSCOPY IN MEDICINE, by Tsuneo Fujita, Junichi Tokunaga and Hajime Inoue. Igaku Shoin, Ltd., and Elsevier Publishing Company ($24.50). ELECTRON MICROSCOPES, by J. A. Swift. Barnes & Noble, Inc. ($6.50). High magnification takes us into a new and strangely intimate world. Up until the past few years all the pictures we saw of that world, whether made with visible light at a thousandfold magnification or with electrons at 100 times that enlargement, seemed less photographic, for all their authenticity, than maplike. The small depth of field restricts such views to what are really two-dimensional sections. The tracery of the ultrastructure is as compelling to the eye as it has been valuable to study, but an immediate sense of structure in space does not arise from those pictures. Ingenious and patient reconstructions must be made, building up the real world from long ribbons of flat sections from contour maps, as it were. The immediacy of the look through the low-power dissecting microscope, so familiar on the laboratory bench, or even through the low-power instruments of the 17th-century pioneers, is gone. Such was the price of high definition at high power.

No longer! Now we can see the world magnified tens of thousands of times not in a mere map projection but with the depth and the volume of photographs made of a prized specimen cupped in your hand. It is the scanning electron microscope, available since the early 1960's, first from an English manufacturer and now from many other sources as well, that makes this possible. The scanning instrument sacrifices some of the resolution of the best electron microscopes of the more familiar kind. It currently settles for an improvement in resolution over the best optical work by only one factor of 10 (a resolution, say, of 200 angstroms), but its field of sharp view is almost as deep as it is wide, and its magnification is easily variable, from

that of a strong hand lens to values approaching 100,000 diameters.

Three Japanese biomedical workers have compiled this new atlas aimed at stimulating research and helping students. They modestly observe that it will "perhaps amuse general readers as an 'Album of Nature.' " They need have no doubt. We are given about 200 micrographs over a wide span of subjects of biological and medical interest. Here is a pile of staphylococci, living up to their name by looking like a bunch of grapes on the table, a twining set of human metaphase chromosomes like a low relief in clay, spermatozoa like eyedroppers, a hair rising like some strange scaly palm tree from a pitted and leaf-strewn jungle floor of scalp (the leaves will be dandruff!) and almost a whole flea (the dog variety, since nowadays it is easier to collect than the human one). Robert Hooke would have enjoyed seeing the herringbone serrations on the curving tip of the flea's sucking needle. Until a still wider atlas of the scanning microlandscape is made, an "Album of All Nature," this well-produced volume will bring its three authors the attention of many a reader far from the laboratory.

Electron Microscopes, the second book listed here, is unusual. Concise (it has only 95 pages) and nonmathematical, with many summarizing and block diagrams (the reader may be a little put off by a few overregimented atomic orbits), it tells in some detail the main points of electron-microscope theory, describes the parts of the instrument and their function, the many specialized techniques and accessories, and some of the prospects of change for both scanning and electron microscopy. There is even a buyers' guide to features of the principal makes. The origin of the image of the scanning microscope is very clearly outlined, with options for picking up secondary electrons, transmitted electrons, back-scattered electrons, overall current from the specimen or its backing, and X rays, Auger electrons or even visible light excited in the atoms of the specimen by the tiny scanning-beam spot. This versatility of signal, with the power of electronic techniques for making shrewd use of such time-varying information, is bound to give a wide range of possibilities in the near future for instruments of many uses, prices and capabilities. Even more spectacular images lie in the future. Already one transmission microscope, operating at very high voltage, can resolve down to the range of a few atom diameters and may achieve high contrast without the heavy-atom staining that has become common.

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BIBLIOGRAPHY

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

THE PHYSIOLOGY OF STARVATION

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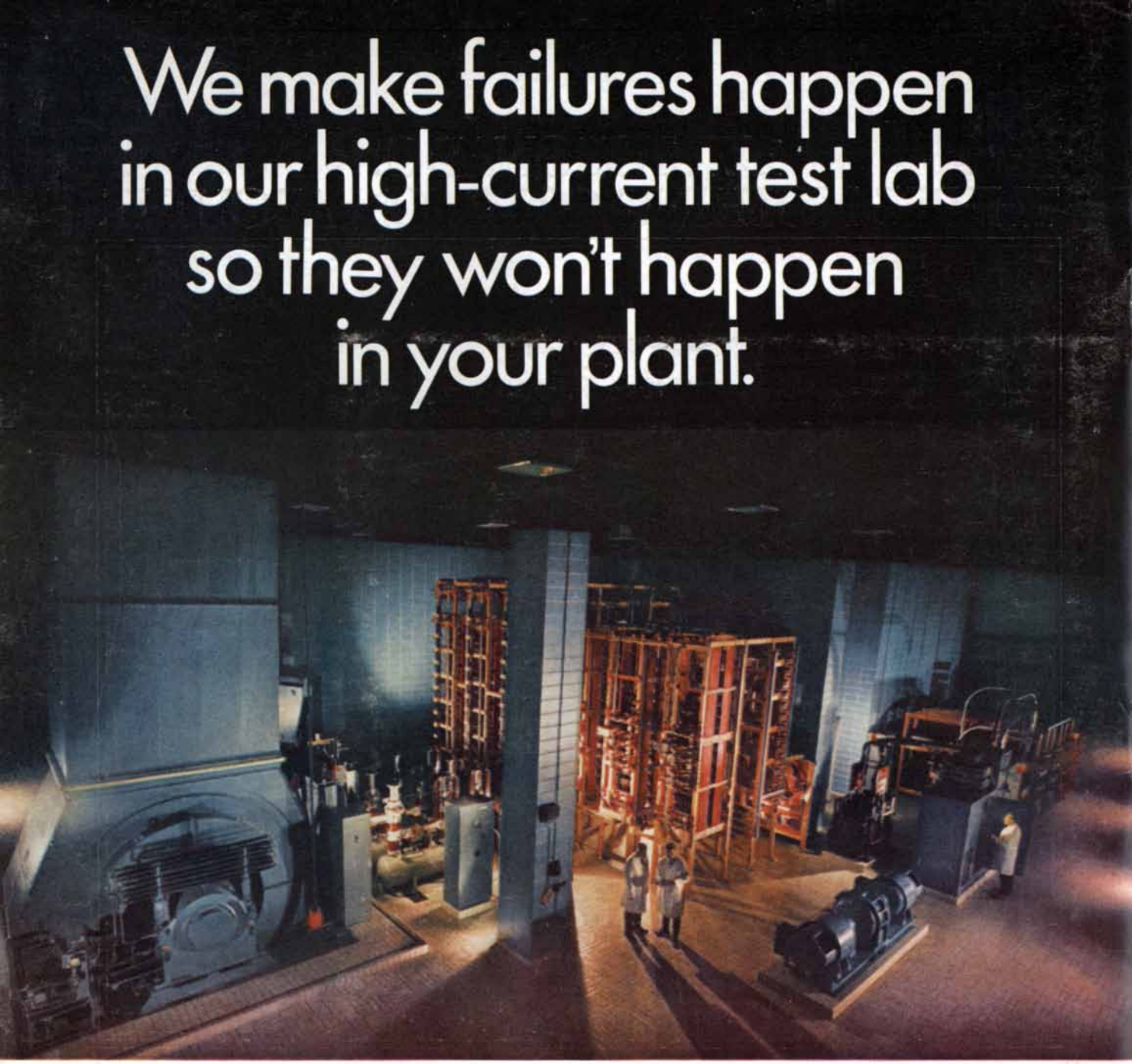

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