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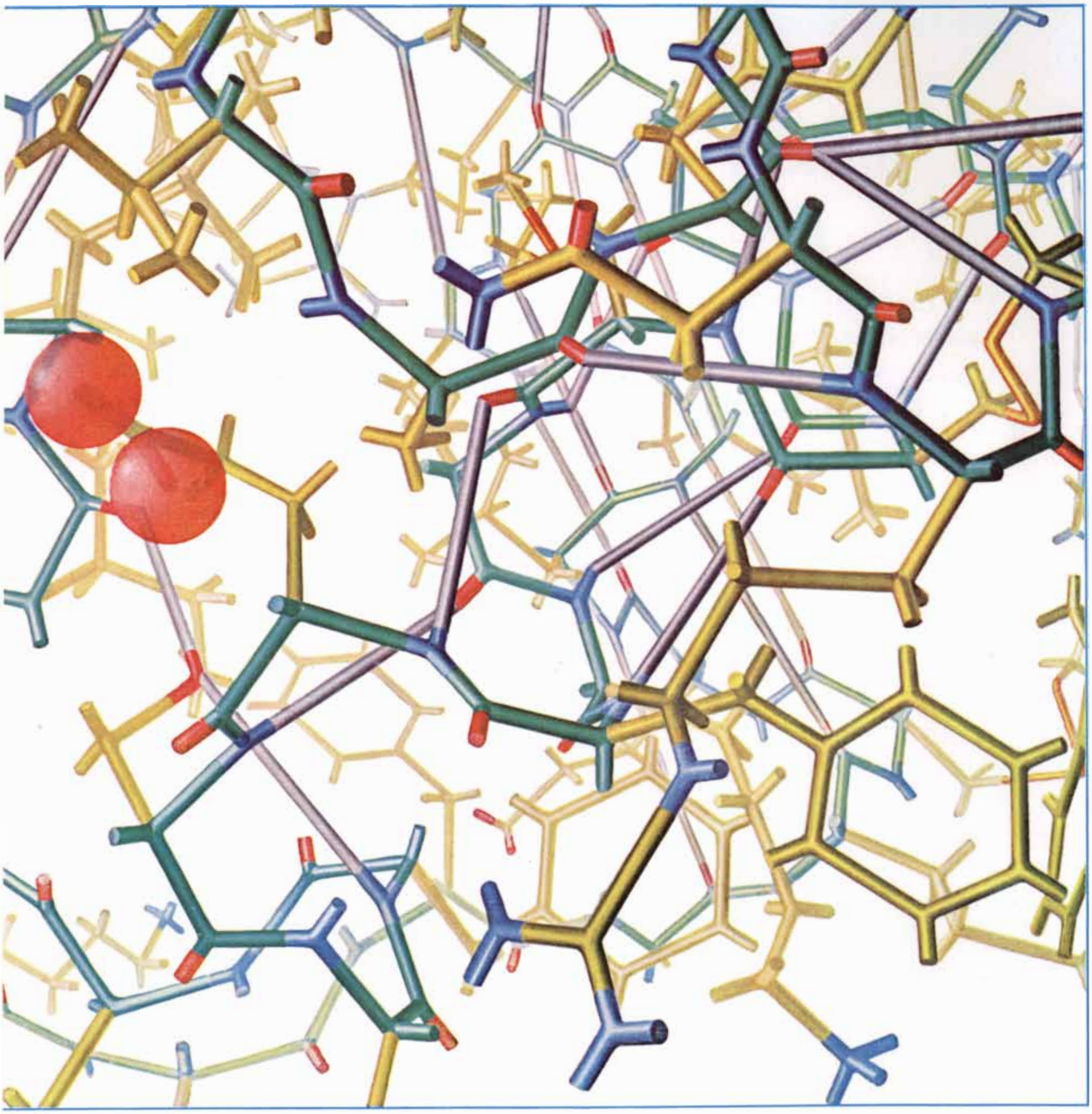

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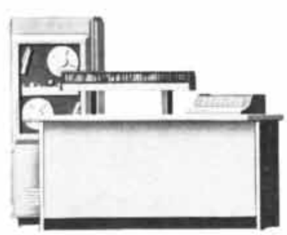

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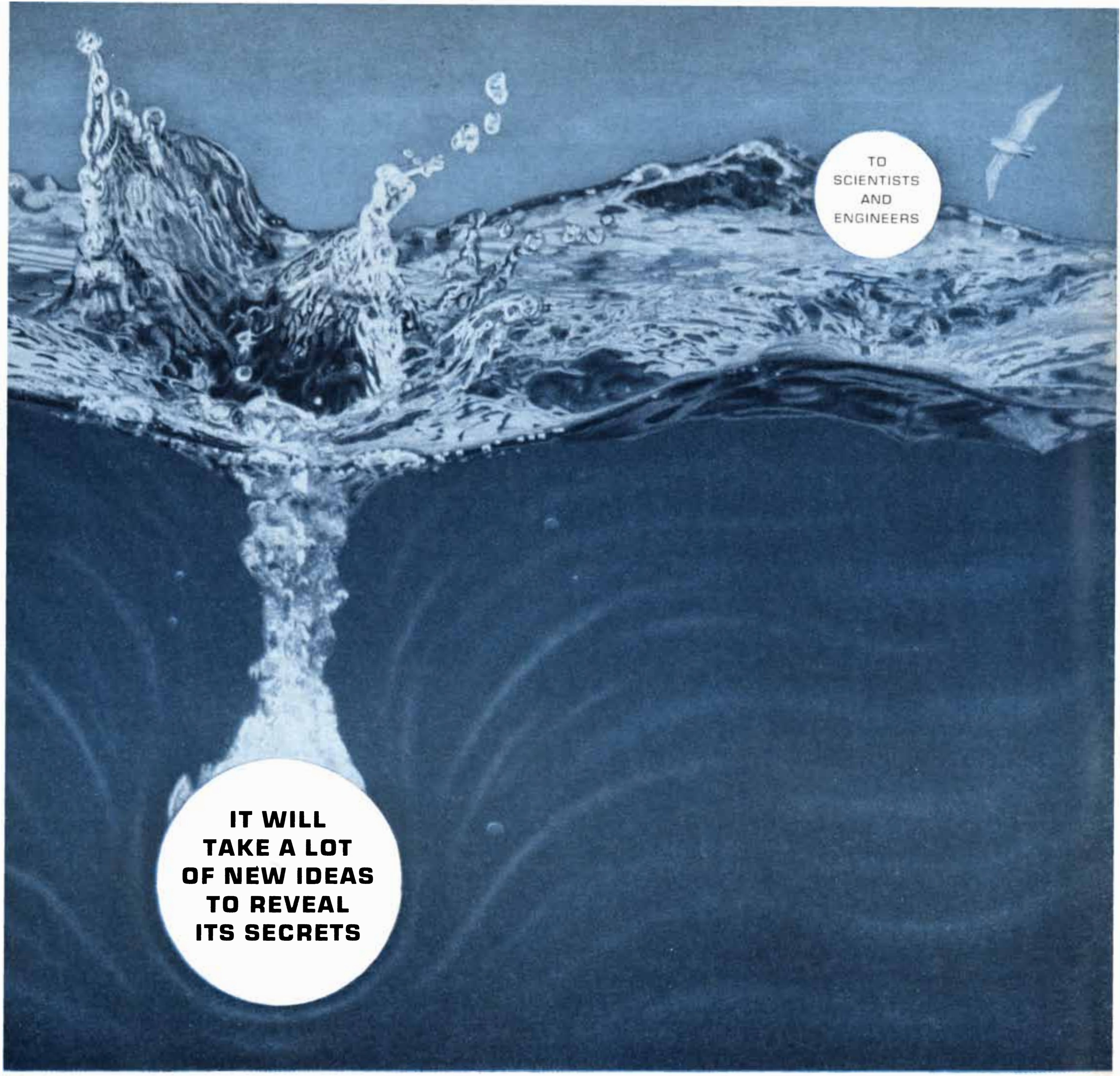

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ARTICLES

DEPARTMENTS

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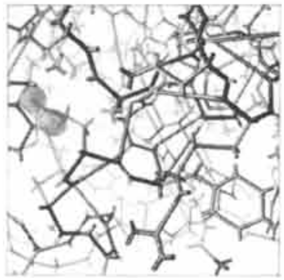

THE COVER

The painting on the cover shows a small part of a three-dimensional model of the molecule of lysozyme, the first enzyme whose complete molecular structure has been worked out (see "The Three-dimensional Structure of an Enzyme Molecule," page 78). The model is shown overall on pages 80 and 81. On page 82 is another detail of the model showing how the lysozyme molecule fits the molecule of its substrate: the substance on which it acts. The model was built by David C. Phillips and his colleagues at the Royal Institution in London. The red balls on the cover are two of the four oxygen atoms that play a special role in enabling the enzyme to cleave the substrate molecule. The green rods show the arrangement of carbon atoms in the main polypeptide chain of the enzyme molecule; the yellow rods trace the carbon atoms in the side chains. The blue rods are nitrogen atoms, the red oxygen atoms, the orange sulfur atoms and the gray rods hydrogen bonds.

THE ILLUSTRATIONS

Cover painting by Irving Geis

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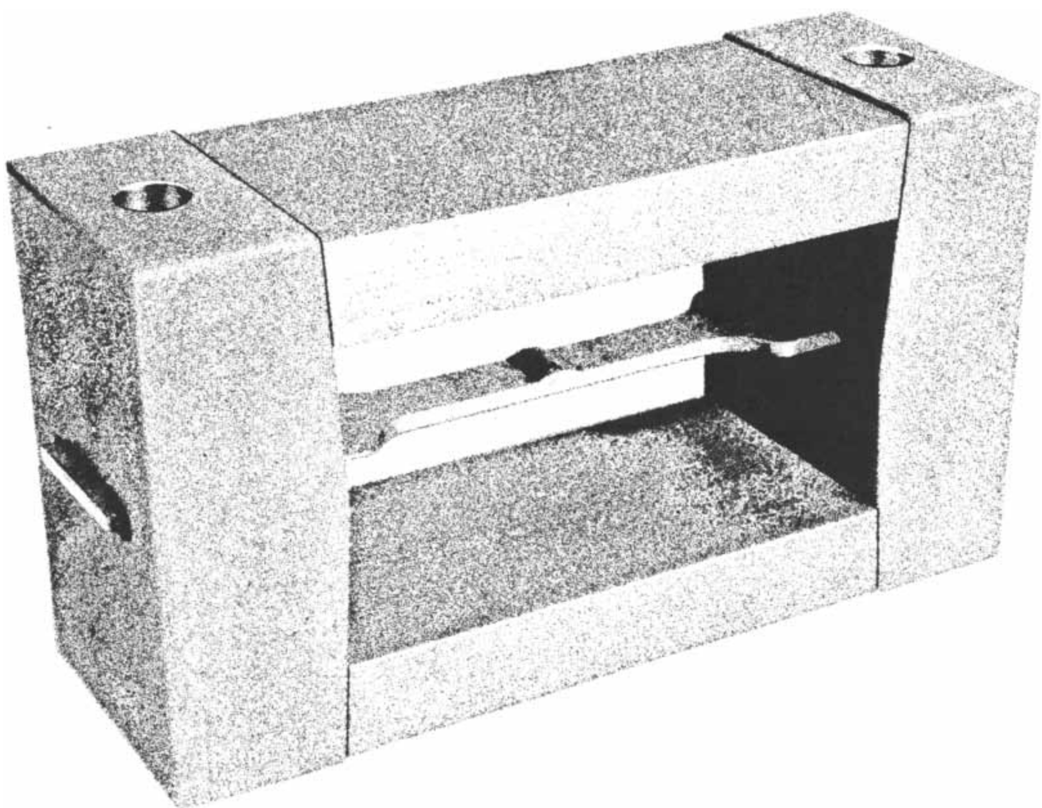

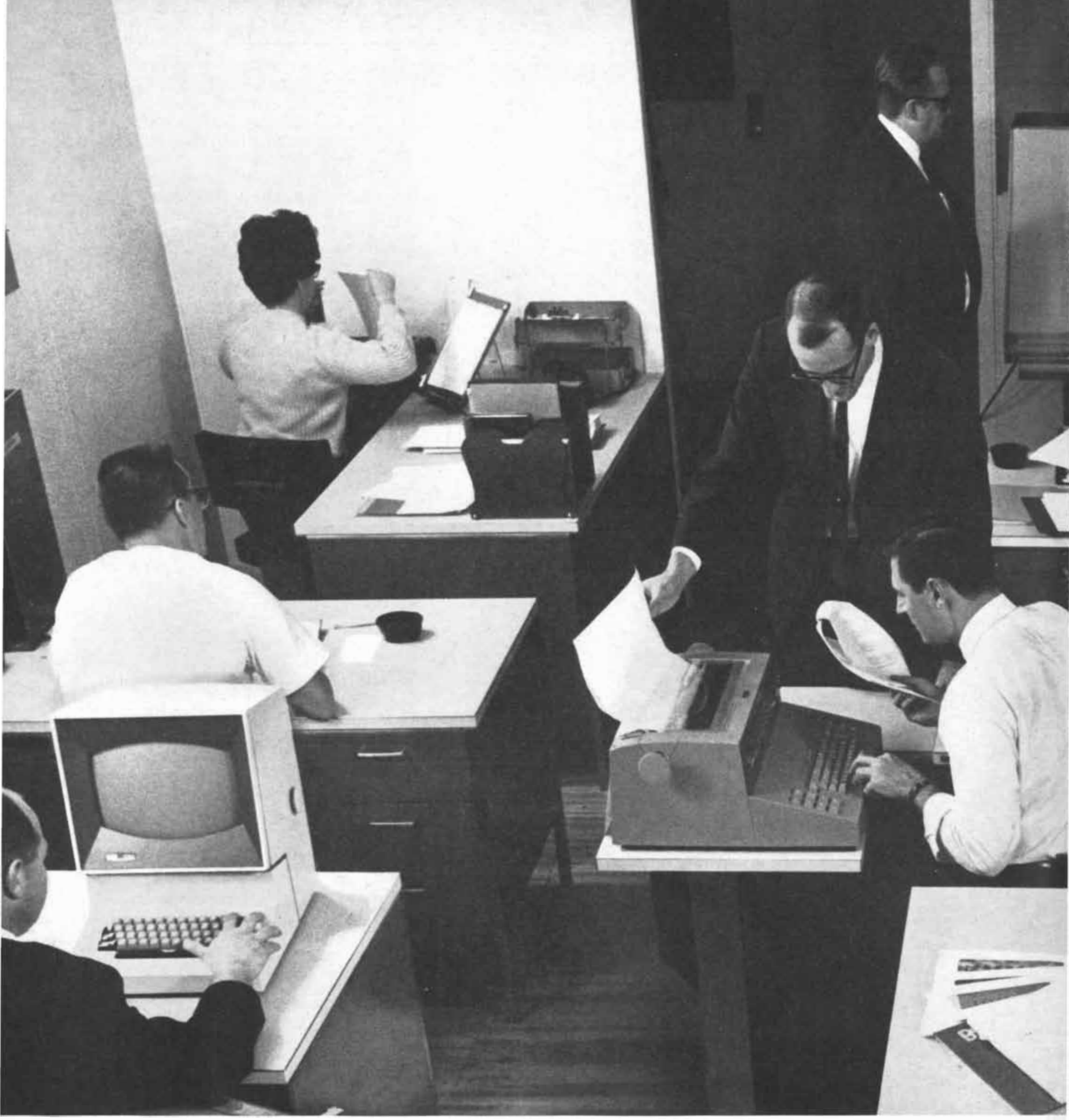

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LETTERS

Sirs:

Congratulations on an excellent presentation of information processing in your September issue.

In spite of its high quality, it seems to me that the presentation points up a need for ready access to information about the topic and about developments both past and present.

Thus in relation to developments of the past I note that John McCarthy says that Howard Aiken and I developed relay computers in the late 1930's. In point of fact, Aiken's Mark I (opened to the public in 1944) was not a relay computer but used the standard IBM rotary decimal switches as "accumulators." There were several relay computers of earlier date, including one put into service at the Bell Telephone Laboratories in 1939 and demonstrated over telephone lines between Hanover, N.H., and New York in 1940. This very inflexible device used Boolean logic and a binary-coded decimal system (the "excess-3" code). Others of the Bell Laboratories series were put into service between 1941 and 1946, and were also Boolean devices utilizing relays. They introduced the "bi-quinary" code, self-checking circuits, taped programs and data, the floating decimal and other features.

As an instance of present developments that were not included in the comprehensive survey, I mention the extensive work in applications of computers to medicine that is in progress in many centers. In consideration of the number of people affected and the vital import of the effect on them, it is my opinion that medical applications rank very high among the uses of the computer. Yet aside from a mention of computer listing of medical topics I find no reference to this work.

Through personal contact at the Dartmouth Medical School, I happen to know of computer work on models of the kidney, of the urethra, of the perfusion of blood, of neuromuscular systems simulating nonlinear functions such as self-optimization, control, sexual response and others, as well as work in the clinical in-line computation of radiation-therapy dosage. The kidney problem is receiving attention at the University of Michigan, at Tufts University and perhaps elsewhere. The dosage calculation has been programmed at the University of Cincinnati, at Tulane University and at other centers. At still other centers, including those maintained by IBM and the General Electric Company at least, computers are being applied to aspects of diagnosis, of blood flow and of the analysis of electrocardiograms and electroencephalograms.

Finally, I hope your readers are not misled into thinking that developments such as time-sharing are taking place at only one center. An excellent time-sharing system has been developed, and is being extended constantly, under the direction of Professor Thomas Kurtz at the Dartmouth Computing Center. For several years this facility has enabled up to 30 or more users to operate simultaneously, from stations scattered about and beyond the campus.

GEORGE R. STIBITZ

Dartmouth Medical School
Hanover, N.H.

Sirs:

Anthony G. Oettinger's article "The Uses of Computers in Science" [SCIENTIFIC AMERICAN, September] is a lucid and stimulating review of the actual and potential uses of large digital computers in linking experiment and experimenter. When he comments on approaches to artificial intelligence, however, he is guilty of a rather crass non sequitur. He

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states: "Whether or not such systems, if they are achieved, should have anything like the structure of the human brain is as relevant a question as whether or not flying machines should flap their wings like birds."

Inasmuch as nonflapping flying machines have been with us for some time, whereas systems meriting the "intelligent" epithet are still quite some distance away in the future, it simply does not follow, as Oettinger seems to suggest, that we are now in possession of the necessary hindsight to sneer at the computer equivalent of the flapping wing. I submit, on the contrary, that we are at the very beginning of the road to artificial intelligence—roughly where flying stood when Leonardo da Vinci wrote: "A bird is an instrument working according to mathematical law, which instrument it is within the capacity of man to reproduce."

The view implied in Oettinger's dismissal of brain analogies, that we have already reached the ultimate (or near ultimate) in computer organization and hardware and that all the remaining problems lie in the field of programming, is completely unwarranted and indeed naïve. The tedious complexities of even the most advanced programming language are such that, in the words of another of your contributors, Christopher Strachey, "the whole thing is [close] to collapsing under the weight of its own complexity." Strachey states: "The present-day computer is itself a stumbling block to the use of programs that are written hierarchically."

Present-day computer organization is a stumbling block to a great many other things besides hierarchical programming, and further radical developments in components, memory and, above all, organization not only are certain to take place but also are indispensable if we are to get within hailing distance of machine intelligence.

It is not my purpose here to outline those approaches to artificial intelligence not wedded to serial, digital computers. The argument is essentially between those who maintain (as a leading exponent of the digital approach maintained to me) that "a thousand neurons equal one crummy flip-flop" and those who believe in effect that a thousand flip-flops equal one crummy neuron.

It is far too early in the game to be dogmatic. The fast, versatile digital computer is here; let us see what can be done with it. Those who are looking at biological prototypes for inspiration (even the human brain, *horribile dictu*) will not deny the programmers their

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early and impressive successes. (Impressive in terms of intellectual effort going in rather than in intelligence coming out, I should say.) It is of more than purely historical interest to note that the fathers of the modern digital computer, from Norbert Wiener and John von Neumann down, were themselves heavily influenced by brain and neuron analogies, which later neurophysiology has shown to be quite false. Nevertheless, these analogies served an undeniably fruitful purpose. Is it unreasonable to hope that, from the far more detailed and rapidly expanding insight now available on biological modes of information processing, similarly powerful inspiration will be drawn by those workers in artificial intelligence who are not willing to concede the distinctions between "hardware" and "software," "memory" and "processor" and other artifacts of barely 20 years of machine evolution, following on the heels of a billion years of intelligence evolution?

T. P. Brody

Westinghouse Electric Corporation
Pittsburgh, Pa.

Sirs:

I enjoyed "The Uses of Computers in Science," by Anthony G. Oettinger. For what it's worth, I present the following observations on parsing pathological sentences such as "Time flies like an arrow":

Time Flies Like an Arrow:
An Ode to Oettinger

Now, thin fruit flies like thunderstorms,
And thin farm boys like farm girls
narrow;
And tax firm men like fat tax forms—
But time flies like an arrow!

When tax forms tax all firm men's souls,
While farm girls slim their boyfriends'
flanks;
That's when the murd'rous thunder
rolls—
And thins the fruit flies' ranks.

Like tossed bananas in the skies,
The thin fruit flies like common yarrow;
Then's the time to time the time flies—
Like the time flies like an arrow.

Edison B. Schroeder

International Business Machines
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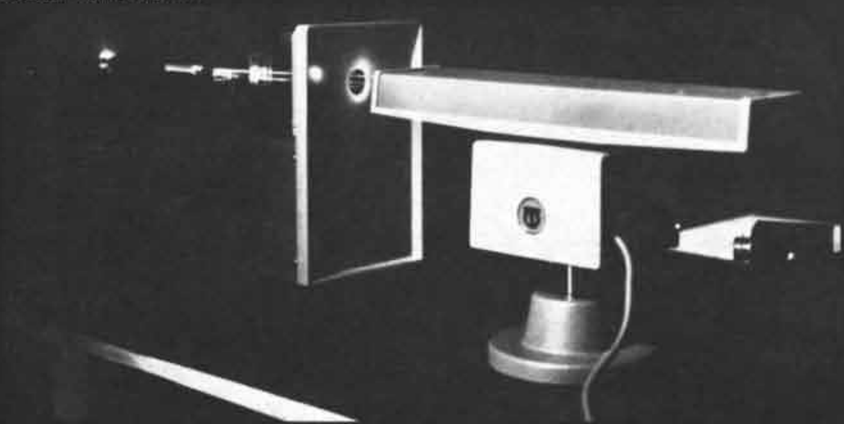
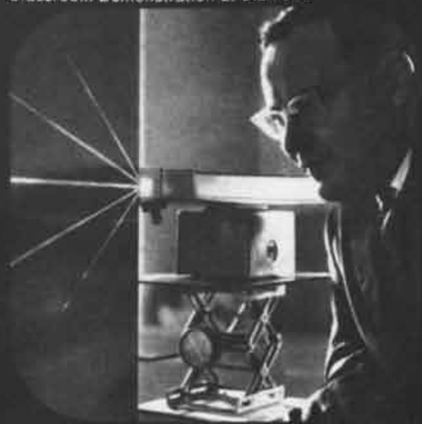
Chicago, Ill.

Optical Alignment at OTI



Classroom Demonstration at Stanford



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☐ *Systems*—That's Lee Groper, at Beckman's Spinco Division, with the 170. It's a component being investigated for use with their Model E Analytical Ultra-centrifuge. (Actually, we modified it for Spinco and named it the 171 Detachable Head Laser—worth a few dollars more, whenever continuous on-line use may require instant head replacement.) Adaptability? The high-intensity light beam may be modified, modulated, and focused down to 0.005". We'll work with you on systems applications.

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☐ *Mechanical Alignment*—Bob Fisher's responsibility at Granger Associates is in experimental optical communications, utilizing gallium arsenide photoemissive diodes. But the 170's ruggedness and versatility take it out of the lab, as well. In railroading, heavy construction, petroleum exploration, and other applications limited only by your own imagination—wherever a very straight line is required.

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Mechanical Alignment at Granger Assoc.

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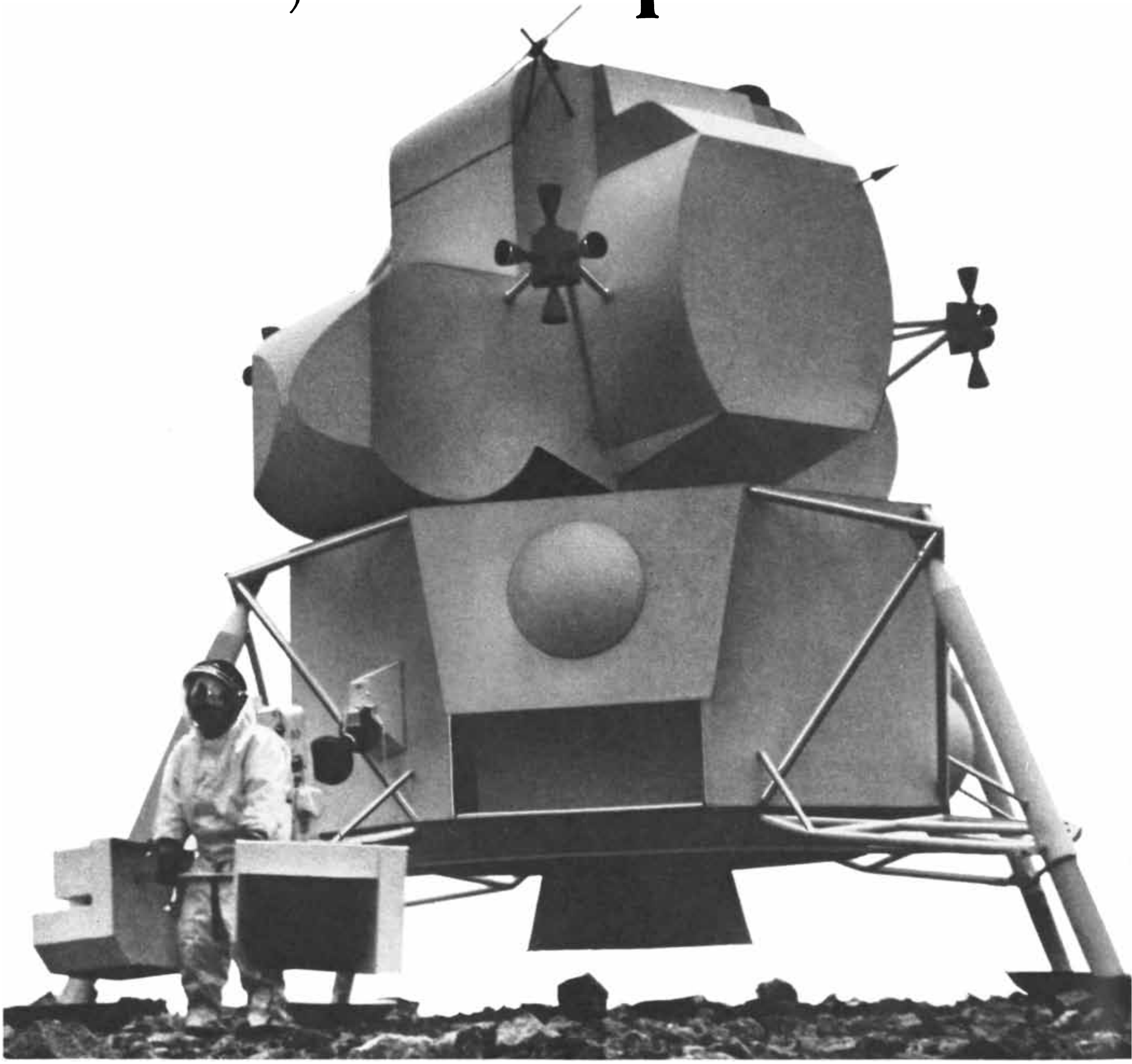

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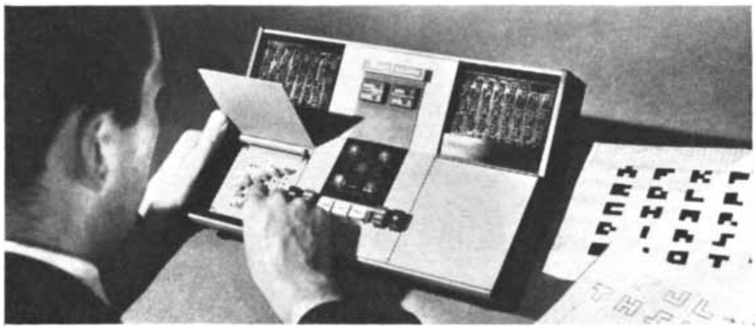

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER, 1916: "Germany and her allies have lost in military availability eight million men in round numbers, out of a potential strength of sixteen millions; eight million men are needed to man the various fronts; and the monthly loss is about 4 percent of the whole. The Entente has lost as many as Teutonia—but out of a conservative potentiality of twenty-eight million. From about now onward the balance must inevitably begin to sway to the final decision regardless of local successes anywhere. The beginning of the end has come and arithmetic is not to be denied."

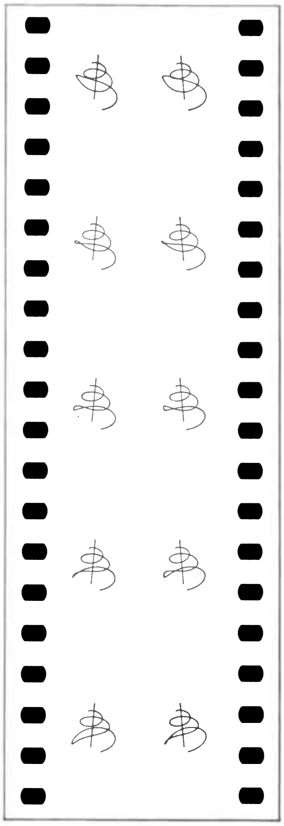
"Ever since the discovery of X-rays, in 1896, scholars have been divided in opinion regarding their nature. One school, led by Prof. W. H. Bragg, held that the rays consisted of high-speed particles, so small and so fast that they could penetrate solid bodies. The other school considered the X-rays to be the same in nature as ordinary light, i.e., electromagnetic waves, and the principal evidence in favor of this view was the fact that X-rays cannot be bent or deflected by the strongest electric and magnetic fields. The question has now been settled in favor of the wave theory, and it is a beautiful example of scientific open-mindedness that Prof. Bragg, the champion of the corpuscular theory, was one of the first to accept the decisive evidence and has become the chief exponent of the wave theory which he so long opposed."

"The future use of the selenium cell in astronomy is discussed by M. Fournie d'Albe in a recent contribution to *Scientia*. The author finds that a selenium cell having a surface of 100 square centimeters would theoretically be capable of registering the light of a 28th-magnitude star, which is, of course, far fainter than any visible in the larger telescopes. For such observation, however, an exposure of several days would be required, and this would be difficult to accomplish. On the other hand, with

Report from

BELL LABORATORIES

A 3-D Glimpse of the Hearing Process



THE MOVIE shows the basilar membrane as a "stereo pair" of spiral lines. The sequential frames shown here represent the motion of the membrane responding to the sound "oo" in the word "too" as pronounced by R. C. Lummis, one of the scientists responsible for the film.

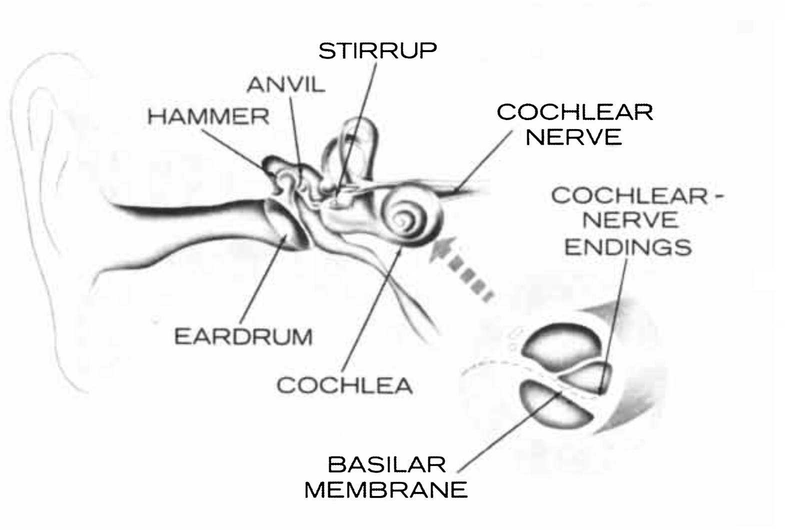
To view this illustration in 3-D, place a sheet of paper on edge between one stereo pair. Position your head so each eye sees only one image. The pictures should then seem to converge and appear three-dimensional.

For screen projection, polarized light and polarized eyeglasses are used to obtain a 3-D image.

THE BASILAR MEMBRANE is a lengthwise partition in the spiral, fluid-filled cochlea (figure). Sound, from the eardrum by way of the hammer, anvil, and stirrup, produces vibrations in this membrane. The end nearest the stirrup resonates at the highest audible tones (approximately 20,000 Hz); the end near the apex of the spiral resonates at the lowest (approximately 20 Hz).

The cochlear nerve terminates near the membrane and, by sensing the vibration at each point, converts the mechanical motion into nerve impulses which the brain perceives as a sound.

Because of its filtering and analytical functions the basilar membrane is a center of interest in hearing research. Since it is embedded in the skull, direct study is extremely difficult.



At Bell Telephone Laboratories, basic research in voice communications does not end with telephone equipment. For instance, three scientists here have made a stereoscopic motion picture showing how the ear's principal transducer—the basilar membrane—moves in response to sound.

A number of steps were involved: First, equations describing the membrane's response were converted to digital form, suitable for machine computation. Next, a program was devised so a computer could determine the precise motion of each point on the membrane as a function of any complex sound input. Finally, the resulting data were processed with another program which introduced the parallax effects inherent in binocular vision.

The output was a series of pairs of stereoscopic images. The computer drew these on the face of a cathode-ray tube where they were automatically photographed to form the frames of the movie.

In this film, the membrane's movements (actually microscopic) are greatly enlarged and slowed down for detailed examinations. Thus we have developed a promising tool for the study of hearing. For example, movies made in this way could help us evaluate theories of the basilar membrane's role in converting sound to nerve impulses. (Several complex mathematical relationships have been proposed; now we may see them in simulated action and measure their properties.)

The scientists who made this film are Robert C. Lummis, A. Michael Noll, and Man Mohan Sondhi. The membrane-response equations from which they began were originated by James L. Flanagan, also of Bell Laboratories. His work was based on anatomical measurements made by Nobel laureate Georg von Békésy of the University of Hawaii.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

an exposure of only one second such a cell is much more sensitive than the eye. The author believes that we can virtually increase the diameter of our greatest object glasses tenfold by substituting a selenium cell for the human eye at the eyepiece of the instrument. Thus it should be possible to detect stars about five magnitudes fainter than any now observable."

"The word 'vitamine' has come into our vocabulary since the latest dictionaries were published. Etymologically it means an amine that is essential to life, and it was coined by C. Funk as a generic name for a group of substances, of unknown chemical composition, small quantities of which appear to be a necessary constituent of a wholesome human diet, in addition to proteins, carbohydrates, fats and inorganic salts. An absence or insufficiency of vitamine in the diet brings on diseases now known as 'avitaminosis' or deficiency diseases of which scurvy and beriberi are the principal representatives. Science already recognizes two vitamines—viz., antiscorbutic vitamine, which prevents scurvy, and antineuritic vitamine, which prevents beriberi in man and polyneuritis in birds. Dr. Atherton Seidell has obtained a cheap and stable vitamine from autolyzed brewer's yeast, and this preparation is now in the process of being tested clinically."

Scientific American.

NOVEMBER, 1866: "An old subscriber in Texas, who has emerged from a five-years' non-intercourse sleep, occasioned by the war, and who has just received a package of our papers, writes as follows:—'I think a great deal of the Bible and its truths. I can read it over and over, always finding something new and instructive. I really think it is the same for SCIENTIFIC AMERICAN. It is suitable for all, rich and poor. By it even ministers of the Gospel will find they can be interested and instructed.' "

"In one of our recent issues we commented on the experiments at Shoeburyness with the Woolwich nine-inch gun and the Palliser chilled shot, expressing the opinion that the London *Times* was not correct in deducing, from the penetration of eight inches of iron plating with its 18 inches of teak backing, the conclusion that the superiority of iron-clads was ended. We stated that

it was doubtful if the Shoeburyness target was equal in resisting power to our monitor turrets of 12 inches of iron, which could be increased to 24 inches. Mr. John Bourne, in a letter to *Engineering*, agrees with these remarks. He says: 'In my opinion, the side armor of modern iron-clads should be not much less than 18 inches thick, backed by three or four feet of oak. The turret should be 24 inches thick. Why should we, with our knowledge of the growing power of ordnance, so adjust our means of resistance as to be hardly able to withstand even its present force?' "

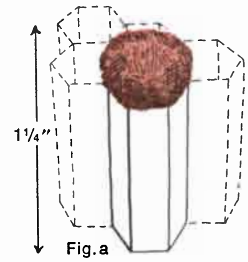
"The electrical power of the Atlantic cable is now furnished by a twenty-cell Daniell's battery. The two cables have been joined, making a line of 3,700 miles, and signals have been passed through this entire distance in little more than a second of time. The only power used was that given by a battery consisting of a lady's silver thimble filled with acid, into which were placed a bit of zinc and a bit of copper."

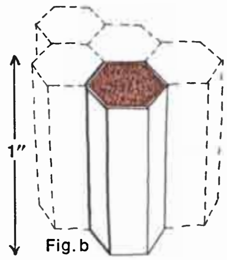
"Krupp's great steel works at Essen cover 400 acres of ground, consume 750 tuns of coal daily, use the steam of 120 boilers, burn 7,000 flames of gas and give employment to above 8,000 men and boys. The establishment last year turned out upward of 50,000 tuns of cast steel, one third of which was made into guns, the rest into bars, shafts for engines, axles, railway bars, tires of wheels, plates for boilers and ships."

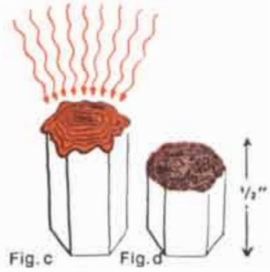
"M. Niepce de St. Victor, in a paper addressed to the Academy of Sciences on the reproduction of natural colors by photography, describes a process for reproducing black together with all the other colors. The silver plate chlorized must first be dipped into a bath containing an ounce of an alcoholic solution of soda for every two ounces of water, to which a small quantity of sodium chloride is then added. The temperature of the bath is to be 140 deg. Fah., and the plate is only left in for a few seconds, when it is taken out, washed and warmed until it acquires a bluish-violet hue. The plate is now coated with a varnish composed of dextrine and chloride of lead. In this way all the colors of the original, including white and black of more or less intensity, are reproduced according as the plate has been prepared, and as the blacks of the copy are either dull or brilliant."

"Dirt is destructive, as well as disgusting."

The life of an Apollo Heat-Shield Rod — a scientific prediction —







On earth:
Unlike the heat shields of all earlier space vehicles, the heat shield of the Apollo moon vehicle is not a continuous heat shield at all. It is, in fact, 370,000 heat-shield rods laminated together in a honeycomb matrix.

The rods are formed when the epoxy novalac ablator material, chosen for its ability to ablate and char in a very special manner, is gunned into the open cells of the nylon-phenolic fiberglass honeycomb (Fig. a). The ablator material is strengthened by quartz fibers and lightened by tiny phenolic microballoons.

Curing in an oven hardens the originally putty-like ablators into a purple-brown-colored beaverboard-like material. Oven curing also causes the epoxy to firmly bond itself to the walls of the honeycomb cells and to the stainless-steel skin of the Apollo.

The resulting ablator-honeycomb laminate is machined to a smooth, flush surface (Fig. b), contoured from 3-inch rod thicknesses at the front corners of the Apollo that receive the brunt of reentry heating to less than 1-inch on the afterbody.

Weight conservation is vital: an extra half inch of height on each rod would add 500 lbs. to the vehicle.

Trip to the moon:
The rods face extreme hazards during their two-weeks in space: "cold soak" at −150°F in the shadow-side of the Apollo is the most severe. "Cold soaking," puts the rods under severe tension. The plastic ablator material shrinks much more than the metal structure of the Apollo, and each rod is pulled from all sides.

Now is when the honeycomb structure pays off. Large slabs of ablator would surely crack under Apollo conditions. But the small dimension of the ⅜ inch rods reduces the stresses. Even if cracks develop during the two weeks, the honeycomb will hold them reliably locked to the Apollo skin.

Return to earth:
The return to the Earth's atmosphere is short and white hot. If the reentry angle is on the steep side, the outer ends of the rods will be put to their maximum use. They'll absorb heating rates as high as 400 BTU/ft^2-sec and be ablated away to half-height in about a minute. If the reentry angle is on the shallow side, the rods will be put on trial to their full depth. For while the heating rates will now only be 150 BTU/ft^2-sec and it will take as much as 5 minutes for them to be ablated to half height, the longer duration will cause the heat to penetrate further.

The epoxy-novalac absorbs the heat by decomposing (Fig. c) and leaving carbonaceous char which acts as a radiator throwing additional heat back into space. The hollow phenolic microballoons also act as insulators to hold the 5000°F char temperatures from the Apollo skin.

In minutes it's all over and what's left of the rods (Fig. d) parachute down with the Apollo to end their useful lives with a slight sizzle as they splash into the sea.

Avco has openings in many projects and research areas, including lasers, artificial circulatory aids, advanced ballistic missile decoy systems, scientific satellites, and high-performance turbines. If you'd like more information, write: Avco Corporation, 750 Third Avenue, New York, N. Y. 10017.

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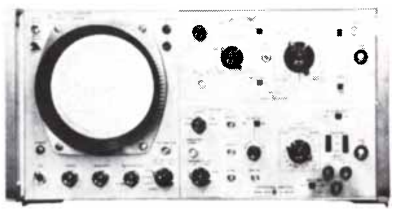
AVCO

When Repetitive High-Speed Phenomena Can't Be Observed Directly...

they often can be revealed with gratifying precision by *sampling* them, and observing the sample. At Hewlett-Packard, sampling technology as a measuring finesse is honed to its finest edge. Seven years ago, the HP 185A Sampling Oscilloscope gave information technologists a new wedge into the unknown. With ingenious sampling techniques, practically implemented, this instrument enabled scientists and engineers to convert suspected phenomena (occurring three-quarters of a *billion* times a second) into observable, measurable, useful events. Subsequently, this pioneer instrument was speeded up to observe a billion, then four billion cyclic events per second. With "micro-time" being compressed further in nanosecond (10^{-9} second) and picosecond (10^{-12} second) computer and other circuits, the HP 185 family of oscilloscopes, now superseded, has sired a new generation of faster, smaller, more precise oscilloscopes, and several wholly new instruments which perform measurement feats never before achievable.

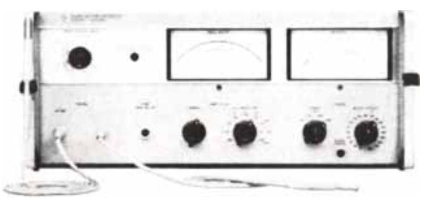
What's new in sampling oscilloscopes?

With the development and introduction of new sampling plug-in modules, the 140A and 141A Scopes can now measure to 12.4 GHz (12.4 billion cycles per second), far beyond technology that was new only yesterday. The 140A is a standard plug-in scope. The new 141A is a variable-persistence storage scope. The first practical, commercial instrument of this kind, it presents flicker-free views of short transient signals, common to circuitry in information processing systems. Both of these scopes accept the new sampling plug-ins, forming a wide variety of compact, high-performance sampling instruments. Choice may be made of 1, 4 or 12.4 GHz bandwidth. And, for the first time in sampling scopes, delayed sweep (for rapid pinpointing and enlargement of waveform details) is built in. A special-purpose plug-in also gives the versatile 140A and 141A Scopes Time Domain Reflectometer capability. TDR, pioneered by HP, is now an essential to the design and production of micro-miniature circuits, giving fast answers to circuit problems, easily translated into engineering units.



How about sampling voltage and phase?

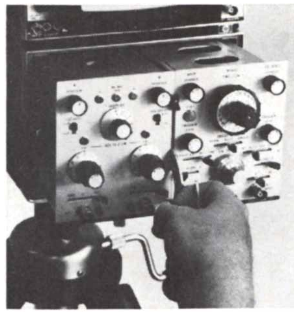
Sampling techniques developed out of oscilloscope design have made possible new instruments to measure voltage and phase in high-speed circuits with unprecedented accuracy and ease. The 8405A Vector Voltmeter simultaneously measures amplitude (voltage) *and* phase relationships between signals, instantly giving the design engineer circuit information previously unavailable, all the way to 1 GHz, for $2500. Another sampling instrument, the HP 3406A RF Voltmeter, provides good sensitivity to 1.5 GHz. It is priced at $650.

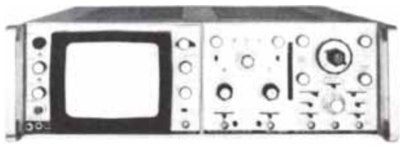


What's the newest, most practical high-performance oscilloscope available?

Possibly the most broadly significant new HP measuring instrument is the 180A Oscilloscope. It's the *only* truly portable scope with the high resolution of "big picture" display (8 x 10 cm). Its bandwidth, in real time, is 50 MHz (50 million cycles per second), and it achieves a new high in sensitivity (5 millivolts/cm) in this broad band. As a plug-in scope, it is versatile, and a hedge against obsolescence.

The 180A offers this unmatched performance in a compact package that weighs only 30 pounds.





It can be used on the bench in any position or mounted on a mobile tripod. As a rack-mounted instrument it is only 5¼ inches high.

1500 standards of measurement...

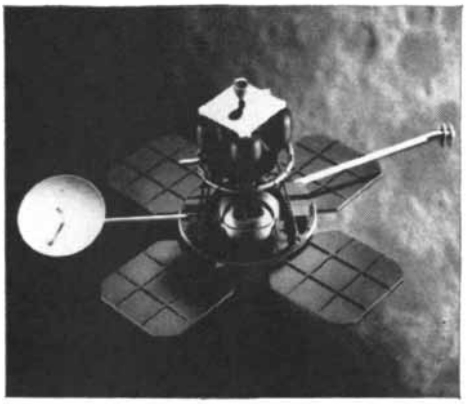
Hewlett-Packard makes more than 1500 directly compatible measuring instruments: scopes; voltmeters; current, resistance and impedance meters; signal sources, signal and pulse generators; electronic counters; frequency and time standards; microwave instrumentation; amplifiers; power supplies; spectrum analyzers; electronic thermometers; nuclear instruments; diagnostic, patient monitoring and research instruments for medicine; instrumentation for chemical analysis; and instrumentation recorders—strip-chart, oscillographic, X-Y plotters, digital printers, and analog and digital magnetic tape recorders. These instruments interface easily and effectively into unlimited measuring and data acquisition system configurations, without complicated external circuitry or instrument modification.

Consider instrument soft-ware...

From instrument design through packaging for shipment, excellence is built in. Nothing is marginal. This is also true of HP's customer support organization. *No customer is marginal.* Throughout the technical world, factory-trained engineers speak all the dialects of measurement: electronic, chemical, medical and nuclear. They provide application assistance, measurement demonstrations, quick delivery, calibration and maintenance service, and a continuing flow of helpful technical information... all on a local basis. Each marketing engineer focuses total HP capability on your measurement needs. This extra measure of quality is built into each of the more than 1500 value-priced HP instruments. HP growth comes through working for you.

For new standards in measurement...think HP

HEWLETT hp PACKARD
measuring instruments for science and industry



Lunar Orbiter

On its initial space mission, NASA's Boeing-built Lunar Orbiter scored a number of historic firsts. It was the first U.S. spacecraft to orbit the moon, to photograph the earth from the moon, and to photograph the far side of the moon.

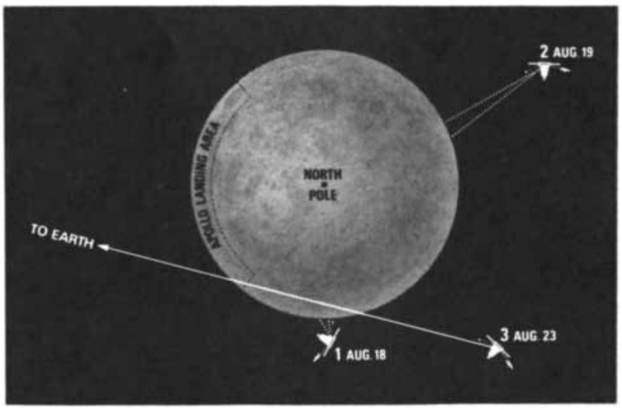
Orbiter flew and maneuvered flawlessly throughout its mission. And while its high-resolution camera performed below planned standards, its medium-resolution camera work exceeded expectations. Orbiter photographed thousands of square miles along the moon's equator, taking stereo-pairs of pictures, which NASA is viewing three-dimensionally to help select level, safe landing sites for America's Apollo astronauts.

Astronomers report that Orbiter has already sent back more information about the moon than had been learned in the past 50 years. Besides pictures of the lunar surface, Orbiter sent back data revealing that the moon, like earth, bulges upward at the North Pole, and is flattened at the South. It has helped determine the exact gravitational characteristics of the moon, an important aid in future manned missions. It has measured radiation near the moon, and is instrumented to detect and report the presence of micrometeoroids.

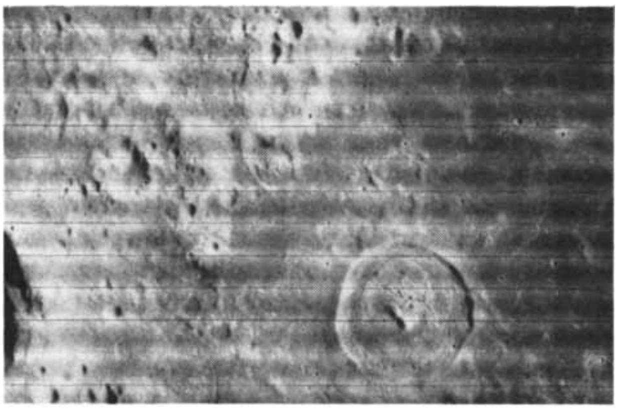
Boeing scientists and engineers, working with NASA personnel, controlled Lunar Orbiter's flight from Jet Propulsion Laboratory facilities. NASA's Langley Research Center is Orbiter's systems manager.

Launching of Lunar Orbiter I—the first of five to be flown—took place 28 months, 15 days after contract signing, the shortest span ever for a major U.S. spacecraft.

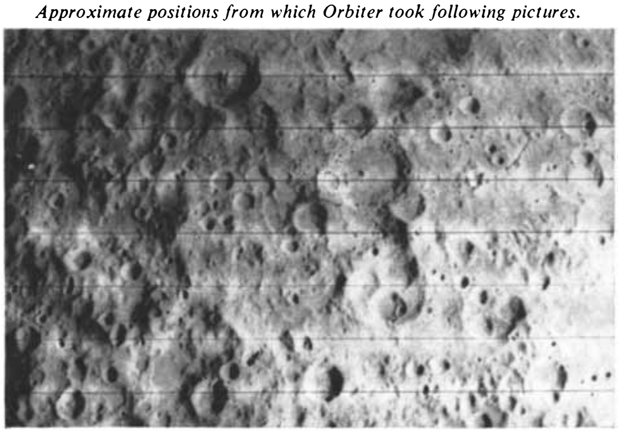
SPACE DIVISION **BOEING**



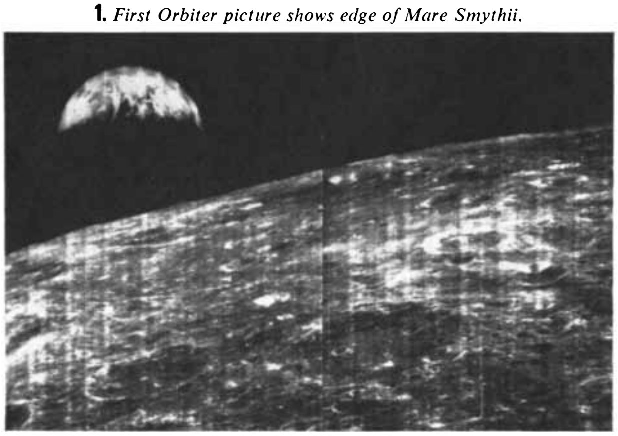
Approximate positions from which Orbiter took following pictures.



1. *First Orbiter picture shows edge of Mare Smythii.*



2. *First U.S. picture of backside of moon.*



3. *First picture of earth, from moon.*

Designed and built by Boeing for NASA

THE AUTHORS

GENKO UCHIDA ("Technology in China") is international economic secretary in the Ministry of International Trade and Industry of Japan. He has been with the ministry since his graduation from the mechanical engineering department of the University of Tokyo in 1951. Three years ago he initiated in the ministry a study of science and technology in China; he is a member of the ministry's China Study Group. He writes: "I also have many informal study groups, inside and outside of our ministry, organized around me. Most of them concern computer 'software.'" Uchida was in London during the academic year 1954–1955 as a British Council Scholar at the Imperial College of Science and Technology. In 1958 he visited the U.S. with a Japanese group studying automation.

WILLIAM W. HOWELLS ("Homo Erectus") is professor of anthropology at Harvard University. He received undergraduate and graduate degrees at Harvard, taking a Ph.D. in anthropology in 1934. Twenty years later, after working at the American Museum of Natural History in New York and teaching at the University of Wisconsin, he returned to Harvard as a member of the faculty. Grandson of the author and editor William Dean Howells, he has himself written several books, including *Mankind So Far* and *Mankind in the Making*. A revised edition of the latter work will be published in January. Howells wishes to acknowledge assistance in the preparation of his article from Andor Thoma, F. Fülep and L. Vértes of Hungary, who supplied him with information, a cast and a photograph of the Vértesszöllös find.

WILLIAM C. LIVINGSTON ("Magnetic Fields on the Quiet Sun") is associate astronomer at the Kitt Peak National Observatory in Tucson, Ariz. As a high school graduate in Los Angeles in 1945 he applied for work at the Mount Wilson Observatory, thinking that astronomy would be an attractive vocation. To his delight he was hired as a junior draftsman with some janitorial duties on the side. In time he became an observing assistant. "Around the dinner table on the mountain," he writes, "conversation often turned to the 'good old days' with George Ellery Hale. I became envious of the chances and fun of those early days." Livingston was graduated from the University of California at Los Angeles in 1953 and obtained a Ph.D. from the University of California at Berkeley in 1958. Of his work at Kitt Peak he writes: "Times change but new opportunities take the place of old. Here I have been helping to develop electronic instruments for the new McMath telescope, and I am certain that the present pioneering atmosphere must be every bit as exciting as it was in Hale's era."

DAVID C. PHILLIPS ("The Three-dimensional Structure of an Enzyme Molecule") is professor of molecular biophysics at the University of Oxford. After taking bachelor's and doctor's degrees at the University of Wales, he worked at the National Research Laboratories in Ottawa for four years, investigating with X rays the structure of small organic molecules. From 1956 until this year he was at the Royal Institution in London, working with Sir Lawrence Bragg, J. C. Kendrew, M. F. Perutz and others on X-ray analysis of protein structures. Phillips writes that his nonprofessional interests include "reading (mainly history), growing vegetables and talking with children."

CHARLES F. POWERS and ANDREW ROBERTSON ("The Aging Great Lakes") are respectively associate research oceanographer and assistant research limnologist with the Great Lakes Research Division of the University of Michigan. Powers received a bachelor's degree in zoology at the University of North Carolina in 1950; while there he developed an interest in water environments. As a graduate student at Cornell University, where he obtained a Ph.D. in 1955, he concentrated on oceanography but also gave attention to limnology and ichthyology. His primary interest is the Great Lakes, but he has also worked on the ecological aspects of small marshes and on coastal oceanography and estuarine processes. Robertson, who majored in chemistry at the University of Toledo, received master's and doctor's degrees in zoology from the University of Michigan.

GERARD K. O'NEILL ("Particle Storage Rings") is professor of physics at Princeton University. As a young man not yet 20 he served in the U.S. Navy from 1944 to 1946. Thereafter he entered Swarthmore College, from which he was graduated in 1950. Since 1954, when he obtained a Ph.D. in physics from Cornell University, he has taught at Princeton. From 1954 to 1959 O'Neill was a member of a group that designed the three-billion-volt proton synchrotron now being operated jointly by Princeton and the University of Pennsylvania. In 1956 he began designing storage rings; since 1959 he has concentrated on storage ring development and on experiments in high-energy physics.

AHARON GIBOR ("Acetabularia: A Useful Giant Cell") is assistant professor of biochemistry and cell physiology at Rockefeller University. A native of Israel, he studied at an agricultural high school and engaged in farming until the age of 21, when he decided to continue his education. He came to the U.S. in 1947 to study agriculture at the University of California at Berkeley, but he soon shifted to biochemistry. With work on algae he received a Ph.D. from Stanford University in 1955. After a few years as a biologist with the Department of Fish and Game in Alaska he went to Rockefeller University, where his work was concerned with fundamental relations between the components of living cells. "For my studies I prefer to draw from the rich variety of algal forms available in nature," he writes, "since finding the right organism for tackling a biological problem is probably the most important step toward the solution of the problem." Gibor adds that when he has the time he likes to "read novels, particularly science fiction novels."

MARSHALL GATES ("Analgesic Drugs") is professor of chemistry at the University of Rochester. After obtaining bachelor's and master's degrees at Rice Institute in 1936 and 1938 respectively he received a doctorate from Harvard University in 1941 and began teaching chemistry at Bryn Mawr College. He has been at the University of Rochester since 1949. Since 1963 he has served as editor of the *Journal of the American Chemical Society*. Gates, whose interests are synthetic organic chemistry and the chemistry of natural products and organic medicinals, achieved the first synthesis of morphine in 1952. He writes that aside from his professional interests he is "a keen sailor in the summer and skier in the winter, not very proficient at either."

HARLOW SHAPLEY, who in this issue reviews *Explorer of the Universe: A Biography of George Ellery Hale*, by Helen Wright, is Paine Professor of Astronomy emeritus at Harvard University.


V I D A R

We made a raincoat
for a bee.

Not just an ordinary raincoat either.

It's a skintight plastic coat so thin you would never know it's there. Yet it covers the bee completely, right down to the individual hairs on the bee's knees. It was done to protect specimens in a natural history museum.

But we didn't spend 12 years on a new plastic just to protect bees. We developed parylene to protect things *like* bees—fragile, complex things so intricate in shape they are next to impossible to coat.

For instance. Each tiny grain of a highly reactive chemical can be protected to provide stability in the presence of gases or moisture. Tiny electronic capacitors, just one-fifth the size of previous types, can be insulated with a coating as thin as eighty-millionths of an inch.

Union Carbide finished the initial development work on parylene in February 1965. Until then, there was no comparable way to encapsulate delicate objects.

Parylene is one of the latest, most sophisticated new plastics to result from the exploring, researching and discovering that is always going on at Union Carbide. The same scientific inventiveness that has put Union Carbide into a greater variety of plastic products than anyone else. Ever.

UNION CARBIDE

THE DISCOVERY COMPANY

Home-freezer to table in minutes... using an RCA-powered microwave oven! A frozen turkey can be thawed and roasted to perfection in less than an hour using RF heat—the "4th dimension" in heat transfer. By comparison, today's standard methods of cooking—using convection, radiation or conduction heating—take hours even after thawing.

Heat is simply the vibration of molecules in a substance. The faster they vibrate, the hotter the substance. The slower they vibrate, the colder the substance. Throughout time, man has applied heat by three classic methods—convection, conduction, radiation. But all three of these more-usual methods require that surface heat work its way from the outside to the inside—by the transfer of molecular motion.

Fig. 1

Today a "4th dimension" in heat transfer has emerged that is faster and more effective than the classic methods. It is being used for drying, heating and cooking both perishable and imperishable products. The system relies on heat transfer by RF energy—using powerful RCA electron tubes such as shown in Figures 1, 2 and 3 to develop the RF energy. It imparts molecular motion uniformly throughout the product. It eliminates the delay of heat transfer from the surface to the center.

Fig. 2

Fig. 3

Interested in Continuous Accelerated Freeze-Drying?

This is how it's done.

The product which is to be preserved—usually a foodstuff—is frozen instantly in a cryogenic liquified gas such as nitrogen (77.3°K). Then it is heated by RF energy in a vacuum of 20 to 60 Torr. The ice crystals in the product pass directly from a solid to a vapor and are removed—they sublimate! Result: The product is completely dried; weighs only about 10 percent of its original weight, and it can be preserved indefinitely. *No refrigeration is needed!*

Fig. 4

The photograph in Figure 4 is a freeze-drying installation in operation at North Carolina State University Department of Food Science. Inside this unit a microwave cavity functions as the RF oven. Out of view in this illustration is the generator that delivers up to 5000 watts of RF power at 915 MHz. RCA designed and built this energy oven which uses an RCA-8501 beam power tube to develop the RF energy.

Figure 5 shows a comparison of drying curves for radiant and UHF freeze-drying of 1-inch-thick chopped beef from an initial moisture content of about 60% to approximately 2% moisture. *The moisture removal that required over 15 hours by radiant heating was accomplished in less than 3 hours by RCA's UHF heating process—an improvement in drying time of over 5 to 1.*

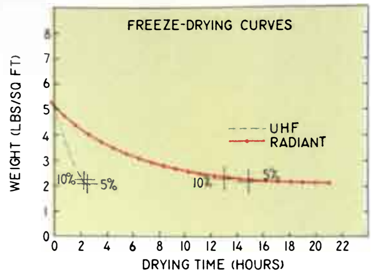


Fig. 5

But more important still is this: *Drying time with RCA UHF heating is virtually independent of product thickness.* That means, for example, you can dry beef 1-inch thick just as quickly as you can dry beef only ¼-inch thick (see Figure 6).

Heating with RF energy has likewise been successfully applied to the quick thawing of frozen foods as well as to the cooking of foods both fresh and frozen. Also, it is now conceivable that bread could be baked at point of sale in minutes, with frozen dough immune to deterioration. And, of immediate impact, RF-energy ovens are already on the way to household kitchens.

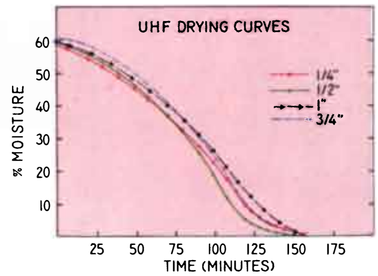


Fig. 6

Interested in Non-Food Applications?

The "4th dimension" in heat transfer is already successfully at work in industry.

In textile drying, fabric backed with heavy glue runs through a gas-fired oven. But because drying is only superficial, the fabric must be "aged" before shipping. By comparison, RF heating provides high-speed, thorough, uniform drying to save time, inventory storage space and handling.

Other industrial applications include heating of large bulky masses such as bales of rubber...certain fusion and bonding operations...and drying products such as plywood...all through the use of RF heating.

RCA has pioneered and developed both the high power electron tubes and much of the supporting apparatus and processes that are putting the "4th dimension" in heat transfer to practical use today.

Undoubtedly RCA—based on our experience gained in this remarkable new "4th dimension" of heat application—can help you. If you have a product or process that requires rapid, economical, uniform heat transfer, describe it to your RCA Field Representative. Or, contact RCA Industrial Market Development, Lancaster, Pennsylvania—(717) 397-7661.

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Established 1845 SCIENTIFIC AMERICAN November 1966 Volume 215 Number 5

Technology in China

A Japanese analyst reports on a study of China's struggle to become an industrial power. He estimates that a breakthrough to economic growth driven by industrial investment may be five to 10 years off

by Genko Uchida

What progress are the Chinese making in technology and industrialization? The fact that mainland China accounts for a fifth of the world's population is sufficient reason for worldwide interest in this question. As next-door neighbors of China we in Japan of course are more interested than most people. Three years ago I began a systematic study with the object of obtaining a detailed estimate of China's technical development. Measuring a nation's technical progress is at best a difficult problem. In China's case the immensity of the country and the secretiveness of her government magnify the difficulty; the task seems comparable to trying to guess the number of beans in an opaque bottle. The problem is not, however, completely unsolvable. China's own statements and her intercourse with the industrial world outside provide enough clues to allow a well-based appraisal of the state of her technology.

We Japanese are in a particularly good position to measure China's progress because in the past 20 years we traveled the road over which China is now laboring. Twenty years ago Japan was a backward country with a per capita income of less than $100; today our per capita income is well over $500—the milestone that divides the advanced countries from the backward—and Japan is recognized as one of the world's most modern industrialized nations. By comparing China's present development in various sectors with the stages in our own history we can estimate how far China has come along the road.

I shall present here a brief review of China's stated technical goals and policies, her problems and the extent of her advancement in key industries. I must emphasize that my conclusions are only estimates derived from fragmentary information, not the kind of precise evaluation that is possible in countries where the essential technological and economic facts are fully known.

One should understand at the outset that, although the most conspicuous aspect of modern China is her system of communistic control, in a fundamental sense she is more a "developing" country than a communistic one. That is to say, her economic policies are rooted primarily in her needs as a still poor, backward nation. This may help to explain why her views on Marxism and communism differ in some respects from those of the more advanced U.S.S.R. It also accounts for the extremely aggressive, evangelistic role adopted by the Chinese central government in directing the development of the national economy. In a country seeking to transform itself rapidly from the primitive, impoverished state to a modern industrial power, patriotic zeal and strong central control over the economy are indispensable.

Naturally zeal has tended to run far ahead of capability. Under the lash of experience the overall approach of China's leaders toward industrialization has undergone an evolution that is subtly reflected in the changing slogans they have used to exhort the people. They began with a simple appeal: "Catch up and overtake." They believed that by heroic efforts their immense, determined country could soon establish a modern industrial economy and outdo the advanced nations of the West. To that end they threw all the capital and labor they could command into the industrialization sector. They soon learned that this was a self-defeating policy. It took too much labor and capital from the agricultural sector and thus left the population intolerably short of food. Furthermore, the Chinese leaders (like the politically oriented leaders in most developing countries) had underestimated the importance of technical know-how. They had failed to realize that industrialization requires not only capital and a work force but also an adequate staff of technically trained personnel who understand the machines. Without this third essential element much of the capital and labor was wasted.

The agricultural problem was compounded by three years of bad weather (between 1959 and 1962) that ruined crops. The Chinese government shifted to greater emphasis on the agricultural sector and introduced a new slogan:

INDUSTRIALIZATION of China is being carried out primarily at the sites shown on this map of the central and eastern parts of the country. The locations of major coal and iron-ore fields are shown along with 20 large iron and steel "combines" (those with an annual capacity of a million tons of pig iron) and 18 chemical-industry bases. There are also 74 smaller iron and steel centers.

"Stable production and more crops." Meanwhile China had been hit by another unexpected setback. As a result of the Chinese criticisms of Russian leaders, the U.S.S.R. suddenly withdrew its technical advisers and workers from China in August, 1960. The factories under construction and those already in operation were left without skilled personnel. Faced with the necessity of training her own people to complete the construction projects and run the factories, the Chinese government issued a new slogan: "Self-development." From 1960 on China depended largely on her own resources for training engineers, technicians and researchers.

She became timid and notably suspicious in her dealings with other countries, Communist or non-Communist, friendly or unfriendly. Her feeling was that those with whom she could trade were out to "pick her clean." For this feeling there was some justification, as some of the equipment China had bought from Communist countries turned out to be obsolescent. The Chinese government in recent years has insisted on buying only the latest models of equipment, often overlooking the fact that the newest models are not necessarily the best for China's own needs. The Chinese also ask for a two-year or three-year supply of spare parts for the equipment, fearing that in the event of an increase in international tension the suppliers might refuse to deliver parts. All in all, the Chinese suspicion of foreigners is so strong and the drive for self-reliance so determined that there is a general reluctance to use foreign machinery at all.

China today has a well-organized establishment for the direction of science and technology. At the policy level it is headed by a Science and Technology Commission in the Chinese Department of State. Under this commission are many bureaus, bearing names such as the General Agency, the International Cooperation Bureau, the Standards Bureau and the Fourth Bureau, whose responsibility is the needs of the manufacturing industries. The control of research work itself is centered in the National Science Department, the Chinese version of the U.S.S.R.'s Academy of Sciences. This department maintains about 100 research institutes, employing a total of about 7,000 investigators who work on research projects assigned by the government. The department's head is Kuo Mo-jo; he is also president of the National Institute of Science and Technology, which was established for the education of engineers, particularly in the fields of atomic research and electronics.

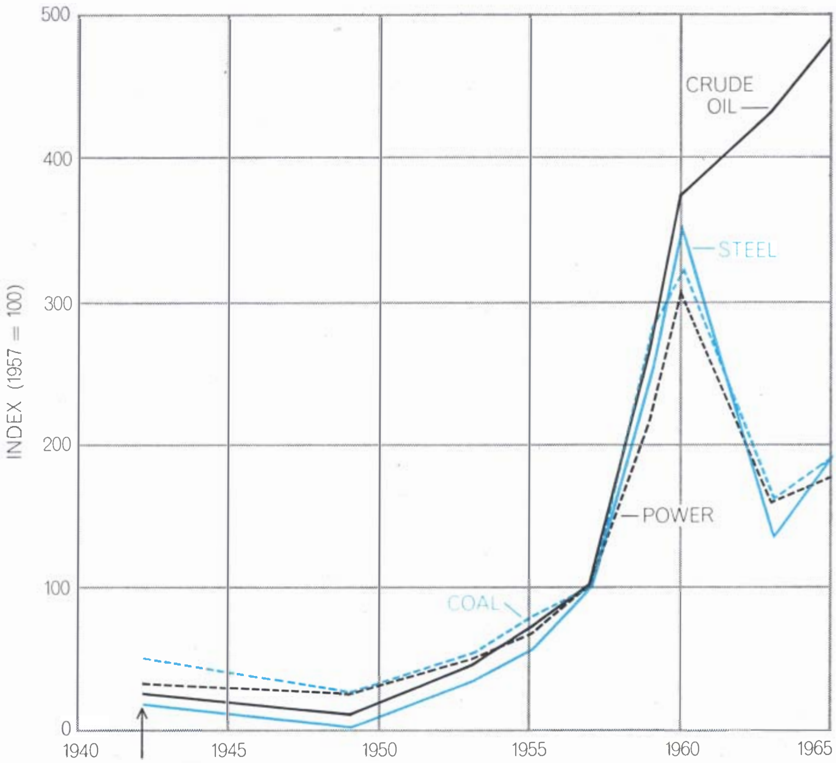
The new generation of engineers that China is producing is an impressive national asset. The profession is not limited to men; it is attracting increasing numbers of women. China's young engineers are confident, ambitious, eager to learn. They are acquiring, mainly from foreign publications, a detailed theoretical knowledge of the latest advances in technology. The Chinese engineering establishment is still weak, however, in two crucial requirements: seasoned leadership and the resourcefulness that can come only from practical experience. In an industrialized country the engineers are imbued by education and job experience with a generalized expertise that enables them to cope with a wide range of tasks and with new problems as they arise. In addition to their specific training they have automatically absorbed a fund of basic knowledge and skills—one may call it a common sense—that is the heritage of the nation's industrial traditions. China of course lacks such traditions or such a "common sense." Her engineers' knowledge is largely theoretical; the questions they ask of foreign engineers often betray a naïveté that shows lack of experience in applying the theories. The lack of practical experience has led China's leaders into some serious errors in industrial policy.

Let me cite a few errors that we Japanese can appreciate because they repeat lessons we learned ourselves on the road to industrialization. One lesson has to do with imitation. It is natural, and indeed inevitable, for a developing country to begin by copying the products of advanced industrial countries. Unfortunately there are grave pitfalls in such a policy. First of all, one had better be careful about what one selects for copying. A case in point is an agricultural machine China began to produce a few years ago. It was copied from a machine that had been designed and produced by a small manufacturer in Japan. After a year or so the Chinese found that the machine was poorly designed—and that the Japanese manufacturer who had produced it had gone into bankruptcy. China lacked this automatic corrective; once the model was put on the production line, politics and bureaucracy made it very difficult to stop. Other instances of unwise imitation can be cited. A Chinese instrument-producing plant lavished great care on the production of a laboratory oscillograph it had copied from a foreign make, but all efforts to get the instrument to work well failed because it was badly designed. At a trade show in Tokyo the Chinese displayed an automobile they had copied from a 20-year-old model of a Western car; by loading it with air conditioning and other new equipment, they had made the sedan as heavy as a small dump truck!

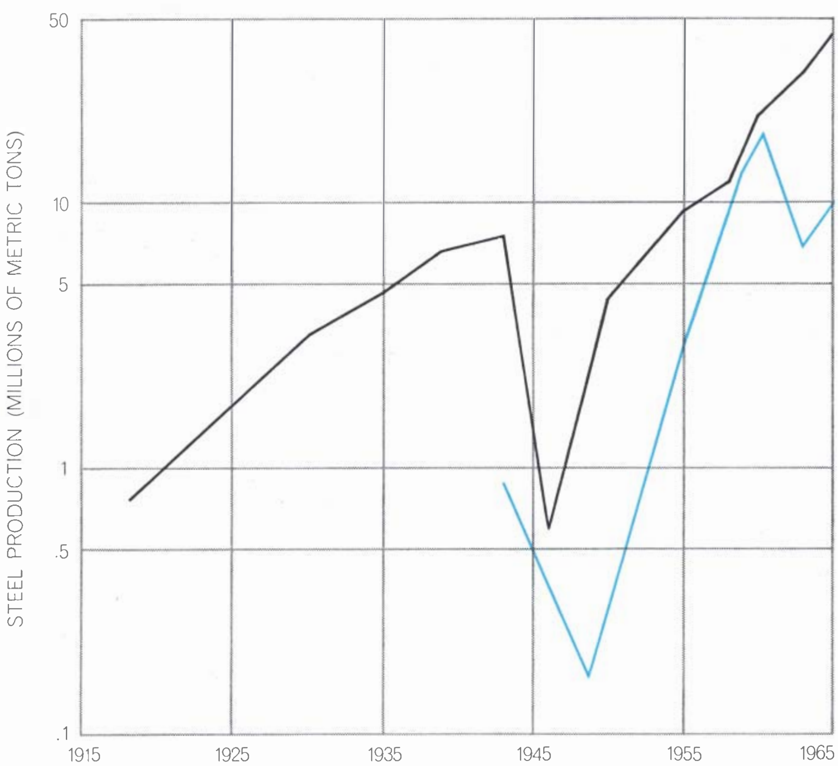
Another pitfall inherent in imitation is that it retards the development of a capability for design. China requires detailed designs to accompany all the equipment she buys from foreign countries so that she can copy the equipment in her own factories. She has succeeded in copying many sophisticated machine tools of the U.S.S.R., Germany, the U.S., Switzerland and Japan. This itself is no small achievement. Yet although China has developed high skill in copying designs, she has not developed much ability to improve on them or to design new machinery of her own. Indeed, I have seen no evidence that any factory in China has a research and development division for the design of new products.

Japan herself went through a period of industrial copying that gave her the reputation of being an "imitator." She soon recognized, however, that the development of a technology of design was itself an essential step toward full industrialization, and she hastened this stage by purchasing expertise from abroad. China now seems to be coming to the same realization; she has begun to seek technical assistance and knowledge from non-Communist countries.

A second mistake in policy that has victimized China is the "production first" slogan, or what is called in the U.S. the "crash program." This is the policy of putting all the available resources to work at any cost to turn out some article for which there is an urgent need. For example, the Chinese at one point found there was an acute shortage of steel angle irons for agricultural development, and all the steel factories were therefore ordered to make angle irons, whether or not they had efficient equipment for doing so. The result was a deluge of angle irons and a sharp reduction in the country's total industrial output. This lack of balance or planned programming has been characteristic of Chinese factories and of the overall economy. Japan learned the necessity of harmonizing production in the various



OUTPUT of coal, steel, crude oil and electric power in China is charted in terms of 1957 production. The peak production attained in the pre-Communist era is shown at the left (*arrow*). After the revolution production rose steadily until 1960, when farm trouble and the withdrawal of Russian aid caused a sharp drop. The index is based on statistics from United Nations surveys and a study by Robert F. Emery of the Federal Reserve System.



STEEL PRODUCTION growth rates in Japan and China are compared. Because of the logarithmic scale, any parallel segments of the curves represent similar rates of growth.

sectors of the economy 20 years ago. It appears that the leaders of China have now learned the same lesson and are beginning to apply it.

Chinese technology shows many signs of severe imbalance. For example, the country is mass-producing agricultural machinery but has not yet persuaded the farmers to make full use of it. China is building many dams and hydroelectric plants; however, because she has not mastered the technology of control of river systems, there are often harmful repercussions upstream from the dams. China's factories are producing machine tools of excellent design but so poor in the quality of the materials that their reliability is far below standard.

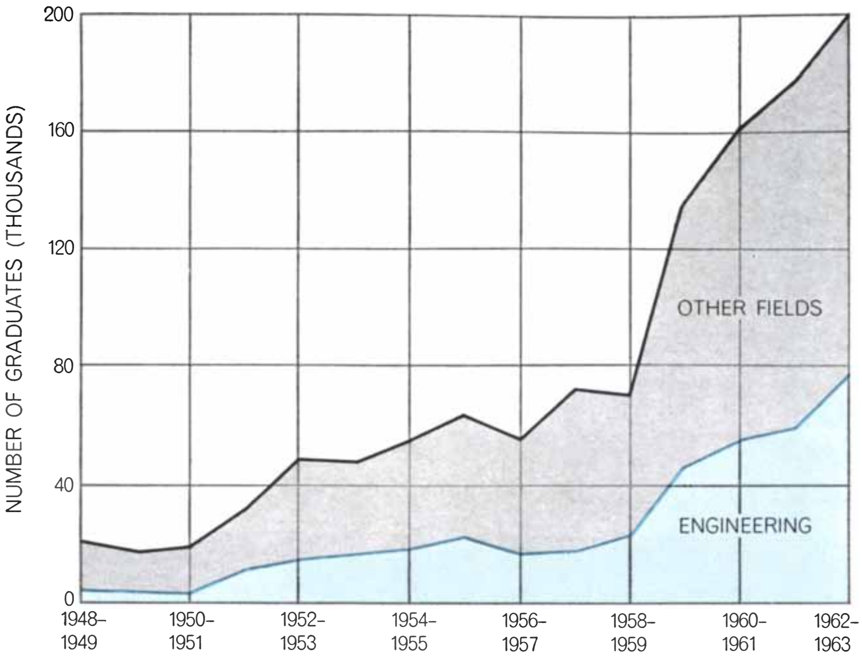
The manufacturing industry as a whole is backward in the sense that it lacks the base of feeder industries for making parts and components. The plants producing final products (for instance the leading factory for building trucks) must make their own nuts and bolts. A factory that makes electrical measuring instruments assigns a considerable proportion of its 4,000 workers to turning out precision screws on bench lathes and to die-casting metal parts. A plant that produces testing machines must build its own oil pumps. In short, the unorganized structure of China's industry and technology is a severe obstacle to the development of high special skills and efficient production. Chinese industrial leaders are now taking steps toward establishment of a parts industry: they have built a pilot project in the Shenyang area of Manchuria around heavy-machinery and machine-tool factories. From Japan's experience it must be said that the full integration of satellite parts plants into the industrial system as a whole will take a long time.

To round off this discussion of general approach and policies, I shall merely mention one other simple but fundamental lesson that Japan learned some time ago and that China's leaders now begin to show signs of appreciating. A populous country is tempted to believe any project, however formidable, can be accomplished if one only puts enough people to work on it—the "human sea" idea. This method has been demonstrated as working wonders in circumstances such as the restoration of a bombed road in wartime with only human hands as tools, but it is certainly an unsound one for building an industrial system or a modern civilized society. Man is not an ant. China, with all her hundreds of millions of people, is now turning to emphasis on modern tools—mechanization and automation—for building her society.

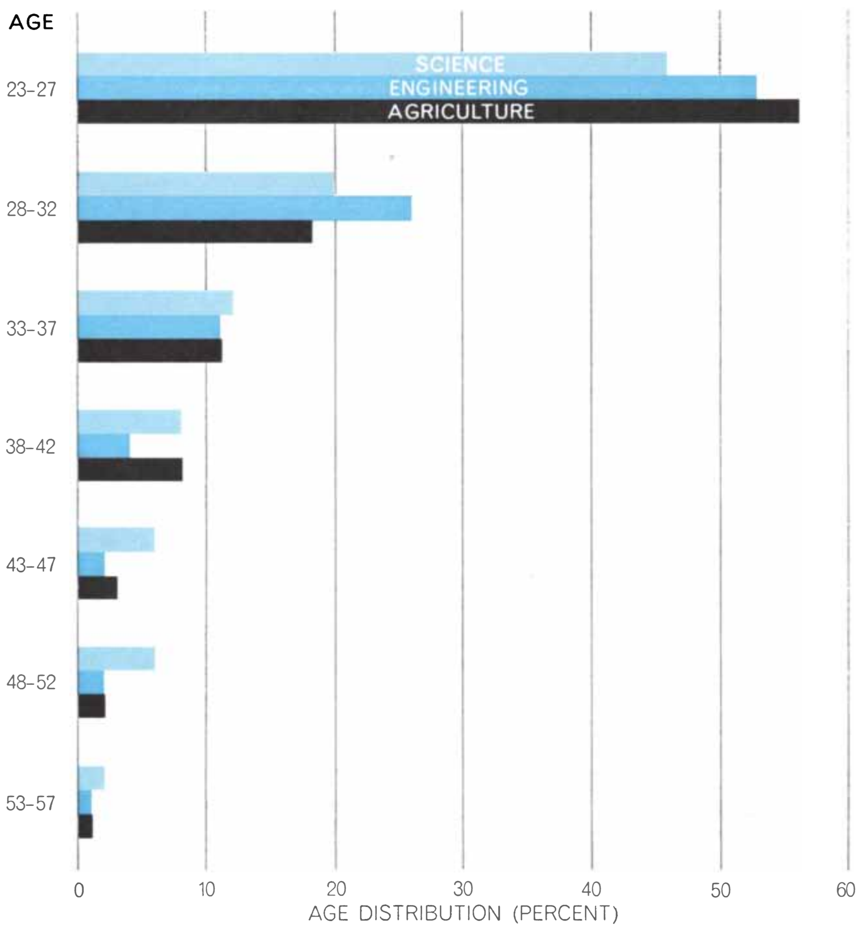
For the specific measurement of China's technical progress so far, let us look at three basic industries: (1) iron and steel, (2) chemicals and (3) machinery, including consumer machines such as automobiles and electronic devices. I wish to remark here that in this evaluation we cannot take production figures alone as our guide. In China the rate of industrial production is heavily conditioned by the structure and quality of management and by the prevailing attitude toward productivity, which are still in a highly primitive stage. Each factory is more or less autonomous, and the plant is run by a quadrumvirate consisting of the manager, the chief engineer, the workers' labor union and a Communist party representative who is responsible for education of the workers. Thus the plant management is democratic but not particularly conducive to rapid decisions, flexibility in innovation or efficiency of operation. The manager usually has little training in the special techniques of management. Moreover, Chinese policies have given scant regard to production efficiency. The net result is that the productivity of labor in China's industries is very low: it averages only about a tenth to a fifth of the productivity of workers in Japan. Presumably the skill of management and production efficiency in China will grow as her industries advance in size and sophistication. In any case, what we are concerned with here is not the question of efficiency but the state of China's industrial techniques, or engineering, as the measure of her technological progress.

China's iron and steel industry is a mixture of large-scale and small-scale operations, of modern methods and primitive ones. In her hurry to industrialize, the new Chinese nation urged the farmers to turn to making iron and steel in their spare time. Some 400,000 small shops, hardly more than smelting sheds, sprouted all over the country. This effort proved to be so inefficient and so injurious to agriculture that only about 300 of the small mills are still operating. They supply, however, about a third of China's pig iron and steel, and they remain politically important because they enable farmers to contribute to the nation's industrialization.

Before World War II China had five



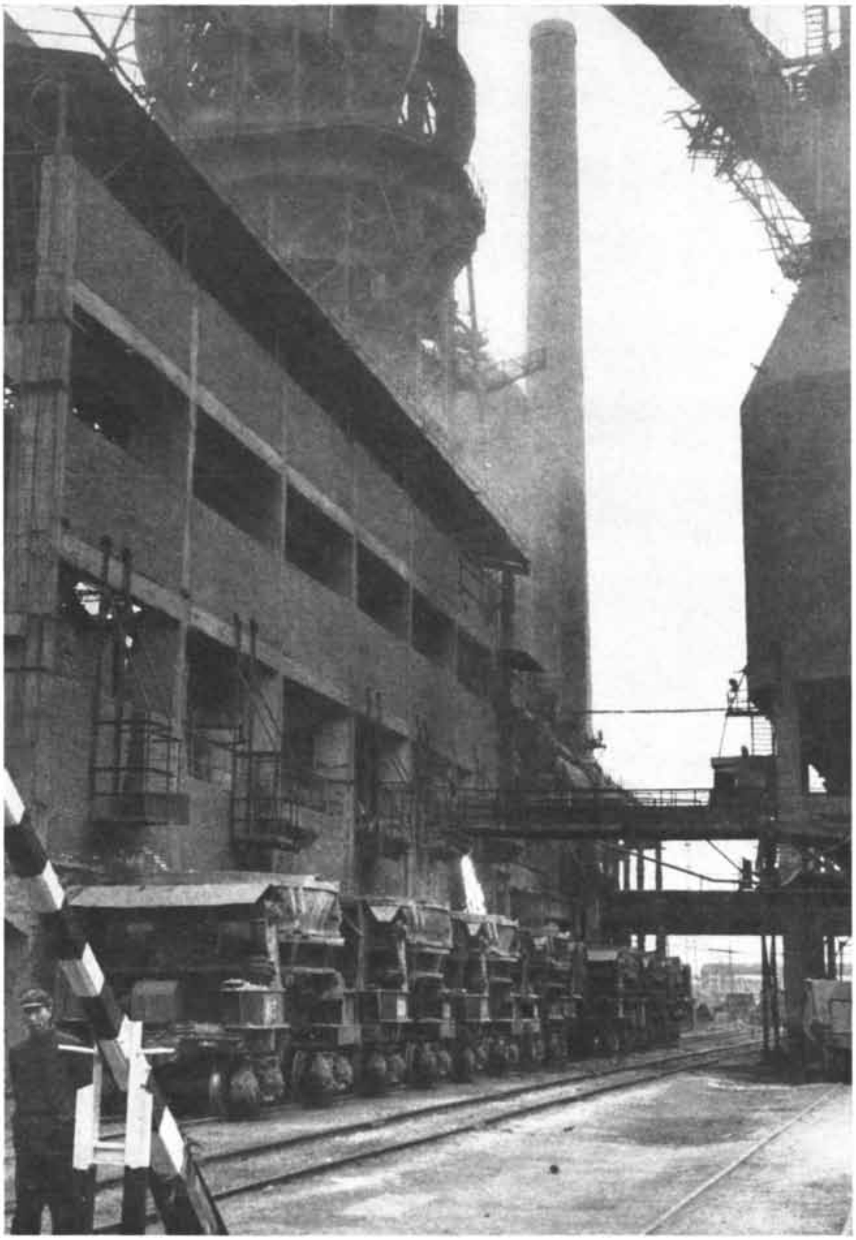
NUMBER OF GRADUATES of institutions of higher learning has soared in China as the country seeks to build an educational base for technical progress. The proportion of the graduates who are in engineering has been rising. Data are from a National Science Foundation study of technical manpower in China by Chu-yuan Cheng of Seton Hall University.



SHARP RISE in number of graduates in recent years is reflected in the predominance of young men and women among natural scientists, engineers and agricultural scientists.

large steel plants, located in Shanghai, Tientsin, Dairen and two other cities in Manchuria near Dairen. These five accounted for nearly 90 percent of the country's iron and steel production. Today there are 20 large iron and steel combines, or producing centers, distributed in central and southern China as well as in the northeast. Their blast furnaces for iron production are large, but they do not employ the high-pressure oxygen technique of the most modern furnaces. In the production of steel the Chinese mills are limited to the open-hearth-furnace technique without oxygen; they have not yet come to the liquid-oxygen converters or the large electric furnaces that are now being installed in advanced countries. China's rolling mills for processing steel are mostly imports from the U.S.S.R. and East Germany that are not up to date and are operated by control instruments that had to be improvised by Chinese engineers, since the Russian technicians left in the midst of the installation of the mill machinery. The Chinese plants have no strip-milling equipment. Nor are they yet able to produce or process high-grade special steels (such as stainless steel) in any substantial quantity.

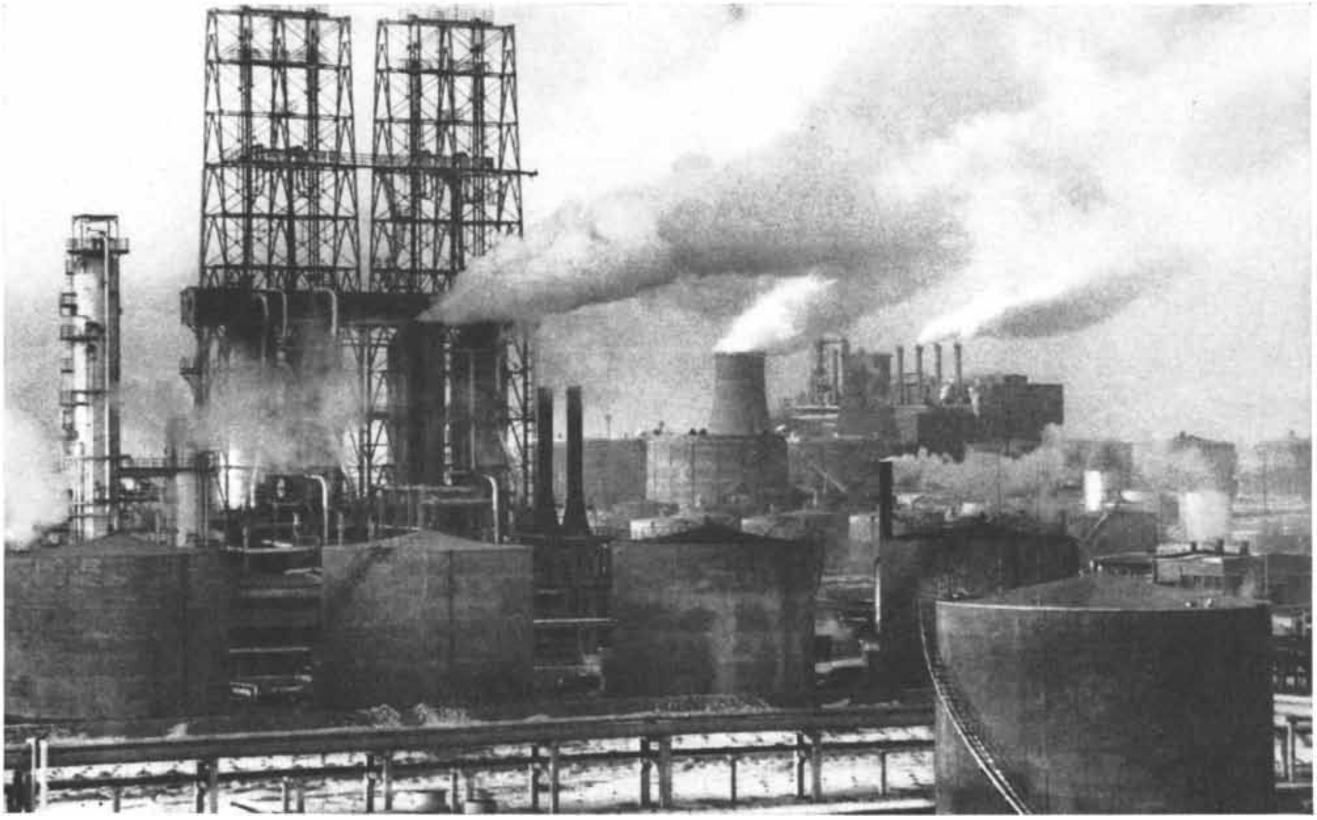
On the whole I estimate that in steel technology China today is about 15 years behind Japan (which is the world's third-largest producer of iron and steel, behind the U.S. and the U.S.S.R.). It is quite possible that China, as a larger country, will achieve her goal of passing Japan and becoming third in total steel production by 1973, but that does not mean she will have caught up in technology. If she depends only on her own resources, it will take her considerably more than six years to develop her own strip mills and reach the present world standards in modernization of steelmaking. In this connection it should be remarked that China has recently signed a contract with several companies in West Germany to obtain a complete rolling mill for the production of thick steel plates.



BLAST FURNACES (such as this one at the Shihkingshan Iron and Steel Works near Peking) and open-hearth furnaces are not technologically advanced. Nevertheless, China may overtake Japan and become the world's third-largest producer of steel as early as 1973.

In chemical technology also China is about 15 years behind. There too her development is repeating Japan's history. In a developing country the first chemical industries to receive attention are those required for the production of fertilizers, acids (principally sulfuric acid for fertilizers) and alkalis (comprising two main industries: soap and detergents and soda, which supplies raw materials for glass). China's fertilizer industry is already sizable: she produces some 7.5 million tons of chemical fertilizer a year. This is still far short of her needs, however. Although she adds to her own production by importing upward of four million tons a year (which makes her the world's largest importer of fertilizer), her total supply amounts to only 12 pounds per acre of cultivated land—about a tenth of the amount used per acre in Japan. Moreover, her production consists mostly of ammonium sulfate and includes only negligible amounts of urea and high-grade compound fertilizers that are now in common use in Western countries. It appears that unless China obtains substantial help from outside it will take at least five to 10 years to raise her agricultural productivity to a level at which it can provide her with sufficient capital for a major breakthrough in industrialization.

From Japan's experience it can be predicted that China's next stage in the development of chemical industries will be based principally on the extraction of products from coal tar. Like prewar Japan, China still depends on coal as her main fuel (although large oil fields are reported to have been discovered recently in Manchuria). From coal tar the principal products one can obtain are dyestuffs, drugs and gunpowder. There is evidence that China is already launched on the "tar age" in chemical



OIL REFINERY in the newly developed Taching oil field is said to have been built by Chinese technicians and workers without foreign assistance. In order to modernize its oil refinery technology, however, China has been contracting to buy equipment in Europe.

production. She has begun to produce pesticides in substantial quantities for her agriculture, and we can reasonably guess, even without specific information, that she is not neglecting explosives production.

After the tar age comes the age of synthesis, meaning the production of new chemicals from basic raw materials. Japan entered this stage only 20 years ago, after World War II. China, although still in the early phases of the tar age, has made a beginning in the establishment of synthetics industries. She has been able to do this by importing complete plants from abroad. The Chinese chemical industry is now producing perhaps 60,000 to 70,000 tons of plastics a year, including some 25,000 tons of vinyl chloride and small amounts of synthetic fibers such as rayon and nylon. China does not have a synthetic rubber industry of any consequence, partly because she readily obtains natural rubber from Indonesia and Malaysia and partly because her total use of rubber (about 1.5 million tons a year) is still relatively small, only about half the amount used in Japan.

In oil refining and the production of petrochemicals China is held back, as are all but the most advanced countries, by the fact that modern, large-scale operation in this field depends entirely on automation. Like some other developing countries, however, China has recently made a beginning by entering into contracts to buy oil refining plants (from Italy, West Germany and France in her case).

China is making an effort to speed up development of a wide spectrum of chemical industries by buying plants of various types from Japan, Italy, the United Kingdom, France, the Netherlands and West Germany. Experience has shown, however, that a country cannot make great progress in industrialization until it has acquired the ability to build its own equipment. Japan reached that stage a decade ago and has since become the world's third-largest producer of synthetic fibers, oil refinery products and petrochemicals. China is now taking the first steps toward such self-reliance in chemical technology. For a vinyl chloride factory in Peking the Chinese constructed the carbide electric furnaces, electrolytic chlorine cells, equipment for the synthesis of chloric acid and equipment for the synthesis and refining of the monomers that are linked to make vinyl chloride. They had to import from West Germany, however, the polymerization equipment that joins the monomers into the final product. The polymerization division has 2,700 employees, which seems a very large number, but the management explains that most of them are trainees who will staff new plants to be built soon.

Obviously the clearest index to a nation's industrial development is the state of its machinery industry, because this must supply the tools for all other industries. In the production of machines China presents a mixed picture: she is well advanced in some fields, far behind in others.

As in the chemical industry, in launching a machinery industry a developing country's first concern must be the needs of agriculture. The Chinese have put great emphasis on the production of farm tractors. A single large factory in Loyang is turning out 300 to 400 45-horsepower tractors a month, plus some power shovels and graders. The production cost of the tractors is reported to be about $10,000 apiece—30 to 40 percent higher than the standard in industrialized countries. To Japan, which produces tractors mainly for construction jobs rather than for agriculture, China's investment in tractor production seems disproportionately large, since labor-saving in farming is less urgent than increasing the productivity of the soil.

In addition to her tractor factories China has a great number of small factories throughout the country producing other agricultural machines and implements. She has also developed a substantial industry in the manufacture of pumps, which are used to a large extent for agriculture. A pump factory in Shanghai is mass-producing about 2,000 rotary pumps a month. In size (up to 1,600 millimeters in diameter) and design (applying the latest hydrodynamic theories) the pumps are quite modern, and so is the equipment employed in producing them, except for the final testing instruments.

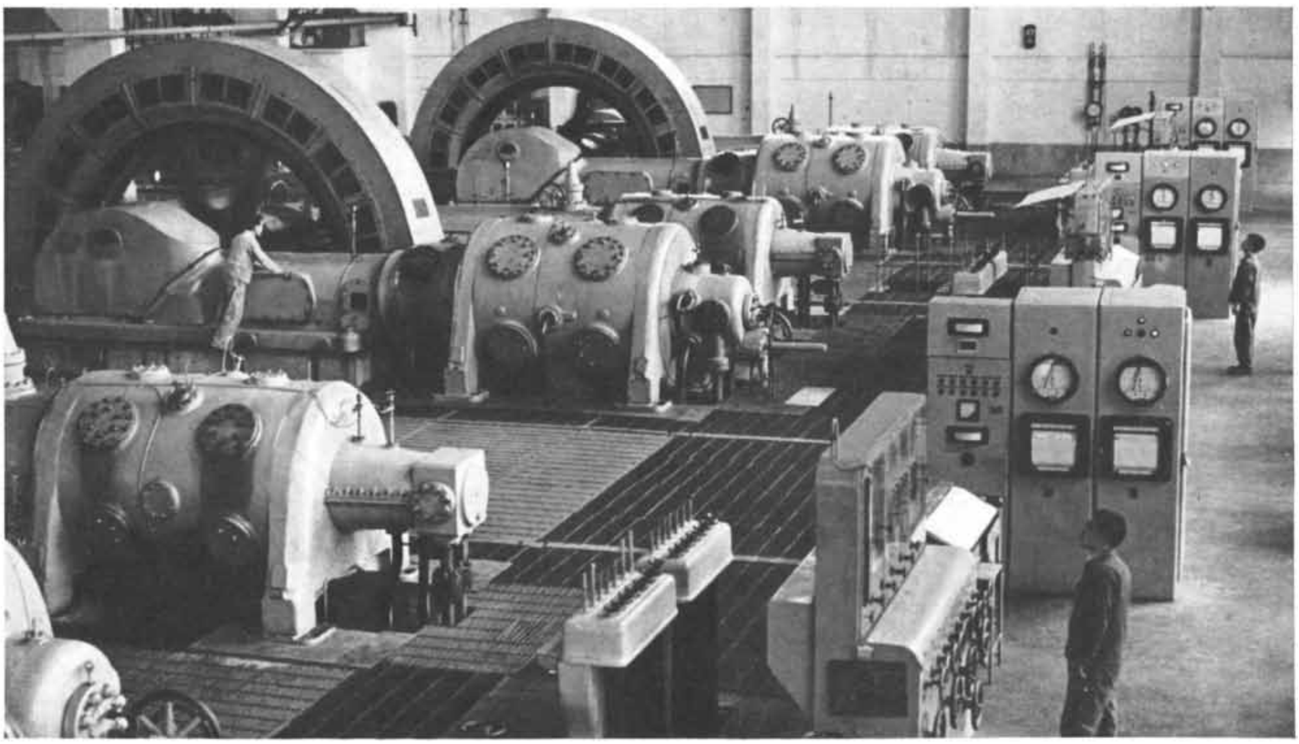
One of the early requirements for an industrializing country is the production of machinery for transportation—a vital necessity for the exchange of products between the agricultural and industrial sectors. When Japan started to produce railroad rolling stock some 90 years ago, it took her nearly 20 years to reach the industrial nations' technical level in this field at the time. China began to build locomotives 15 years ago and is now reported to be producing almost all her supply of these machines in her own shops. In shipbuilding, an industry Japan developed within 20 years in the 19th century, China lags, primarily because she has relatively little foreign trade and depends mainly on overland and inland-waterway transport within her own country. She has no facilities yet for building a ship of more than 12,000 tons and lacks modern techniques such as the block-building system or construction of giant tankers.

Transport machinery in a modern industrial system also includes trucks and automobiles, but this industry requires a higher level of development. China does not yet have an automotive industry in the modern sense.

After the initial development of elementary machines for agriculture and transport, the next stage for an industrializing country is the production of machine tools and major power sources, which entails the making of boilers, turbines and heavy electrical machinery. China has entered this second stage. As I have mentioned, many of her factories are equipped with modern machine tools that were imported from various countries: East Germany, Czechoslovakia, Switzerland, West Germany, the United Kingdom, France and Japan. China herself is only beginning, however, to produce machine tools of her own, and her progress so far is very uneven. Her output of tools of the grinding class, for example, is good, but her boring tools are far below standard. We can estimate the level of the Chinese machine-tool industry by noting that it does not produce transfer machines, roll grinders or jig borers and it cannot turn out really large machines; the boring machines are limited to 150 millimeters (about six inches), hobbing machines to 2,500 millimeters, vertical boring and turning lathes to 6,000 millimeters and planomillers to 3,000 millimeters.

China's dependence on foreign machine tools has held back her own education and practice in the design of such tools, but on the other hand it bestows the advantage that her engineers are not inhibited by experience. They can boldly explore unorthodox approaches. For example, in a machine-tool factory in Shanghai they have put all the operations, from machining of the various parts to final assembly, in one huge, temperature-controlled room —perhaps the largest room in the world for making machine tools. With increasing sophistication in the techniques and synthesis of the various operations, this room might eventually turn out the world's best machine tools.

Judging from the history of our own machine-tool industry in Japan, we can estimate that China is about 15 years behind in this field, but with the importation of foreign know-how she might easily catch up in a decade. Much the same conclusion applies to her production of heavy electrical machinery. China has built a turbogen-



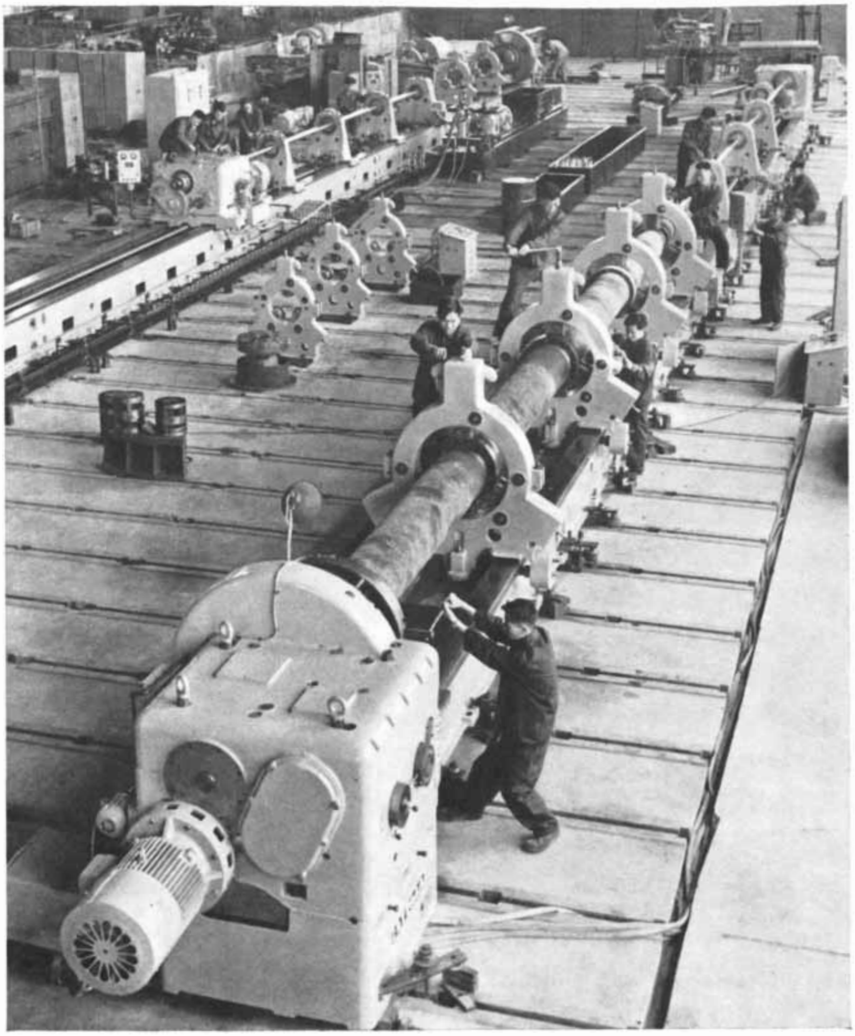
FERTILIZER PLANT at Kwangchow (Canton) went into operation in 1964, producing such nitrogenous fertilizers as ammonium sulfate. The photograph shows the ammonia-production facility. China still imports a large proportion of her chemical fertilizer.

erator of the high-temperature, high-pressure type with a capacity of 30,000 kilowatts—a position Japan reached 15 years ago. We are now building 500,000-kilowatt generators; presumably it will take China a similar period to reach that level.

The production of automobiles requires not only a high level of specific techniques for their fabrication but also a highly integrated industrial structure bringing together a diversity of industries. Many different enterprises contribute to the making and running of an automobile: a wide variety of materials (including fuel) and of parts (including many specialized instruments). All of these must be supplied in reliable quantity and quality. Presumably the lack of such diversity and industrial organization is the main reason China has not yet even attempted to create an automotive industry. She has only one mass-production plant in this field: a factory in Changchun that turns out 2,000 trucks a month. It can be estimated that from this infant stage it will take China more than 20 years to develop an industry capable of producing automobiles comparable to those of the advanced countries. The same is true of her production of aircraft. She has begun to produce small planes by herself, but almost all are complete copies of Russian models.

In electronics, a field in which Chinese leaders are now showing keen interest, China has not yet gone much further than investigations in the laboratory. About the only device she has put into production is a transistor radio incorporating low-grade germanium transistors. She is not far advanced in research on the technology of digital computers, but it is reported that her laboratories have recently built some analogue computers. No doubt China will give increasing attention to electronics in the coming years, because of its great importance from the standpoint of automating her industries and developing communications over her large territory.

If we take Japan to be typical of the modern industrialized country, then by nearly all the indexes China is 10 to 15 years behind in technology. It is a striking fact that the Japanese engineers who have visited China recently have in almost every case found Chinese engineers today confronted by the same problems Japan attacked about 15 years ago. Since China seems to be repeating our history technologically, we can perhaps also make a forecast of her likely development in economic terms.



MACHINE TOOLS are beginning to be made domestically. The photograph shows a special "deep hole" drilling machine that was produced at the Shanghai Heavy Machine Tool Plant.

In 1950 Japan's income as a nation was $9.3 billion, amounting to $93 per capita. She soon passed the level of $100 per capita, and thereafter she was able to devote an average of about 30 percent of her annual gross national product to capital investment; in 1961 she actually allocated 43 percent of her G.N.P. to expanding her productive capacity. This high rate of investment enabled the nation to generate a growth rate of 10 to 20 percent a year in G.N.P. By 1965 her national income had risen to $62 billion, or $620 per capita. In 15 years it had multiplied sevenfold.

China's present national income is estimated to be about $100 per capita, or $60 billion in total for her estimated 600 million population. Most of that income of course comes from agriculture. She has emerged from the "takeoff" stage (to borrow a term from the U.S. economist W. W. Rostow) and entered the industrialization stage. If she follows the experience of Japan, she will soon accumulate enough technical knowledge and capital to make a breakthrough into a period of rapid economic growth, a growth that is driven by industrial investment. In 10 to 15 years she might attain a per capita income equal to Japan's present figure ($620). In that case China's gross national income would be about 70 percent as large as that of the U.S.

How far off is the impending breakthrough for China? My own estimate is five to 10 years. One may wonder, of course, whether recent political events in China, apparent to the outside world largely in the activities of the so-called "Red Guards," will affect this timetable. In this connection I shall observe that Japan suffered from similar political instability in the years before World War II. Thereafter the pace of her progress toward industrialization was quicker.

HOMO ERECTUS

This species, until recently known by a multiplicity of other names, was probably the immediate predecessor of modern man. It now seems possible that the transition took place some 500,000 years ago

by William W. Howells

In 1891 Eugène Dubois, a young Dutch anatomist bent on discovering early man, was examining a fossil-rich layer of gravels beside the Solo River in Java. He found what he was after: an ancient human skull. The next year he discovered in the same formation a human thighbone. These two fossils, now known to be more than 700,000 years old, were the first remains to be found of the prehistoric human species known today as *Homo erectus*. It is appropriate on the 75th anniversary of Dubois's discovery to review how our understanding of this early man has been broadened and clarified by more recent discoveries of fossil men of similar antiquity and the same general characteristics, so that *Homo erectus* is now viewed as representing a major stage in the evolution of man. Also of interest, although of less consequence, is the way in which the name *Homo erectus*, now accepted by many scholars, has been chosen after a long period during which "scientific" names for human fossils were bestowed rather capriciously.

Man first received his formal name in 1758, when Carolus Linnaeus called him *Homo sapiens*. Linnaeus was trying simply to bring order to the world of living things by distinguishing each species of plant and animal from every other and by arranging them all in a hierarchical system. Considering living men, he recognized them quite correctly as one species in the system. The two centuries that followed Linnaeus saw first the establishment of evolutionary theory and then the realization of its genetic foundations; as a result ideas on the relations of species as units of plant and animal life have become considerably more complex. For example, a species can form two or more new species, which Linnaeus originally thought was impossible. By today's definition a species typically consists of a series of local or regional populations that may exhibit minor differences of form or color but that otherwise share a common genetic structure and pool of genes and are thus able to interbreed across population lines. Only when two such populations have gradually undergone so many different changes in their genetic makeup that the likelihood of their interbreeding falls below a critical point are they genetically cut off from each other and do they become separate species. Alternatively, over a great many generations an equivalent amount of change will take place in the same population, so that its later form will be recognized as a species different from the earlier. This kind of difference, of course, cannot be put to the test of interbreeding and can only be judged by the physical form of the fossils involved.

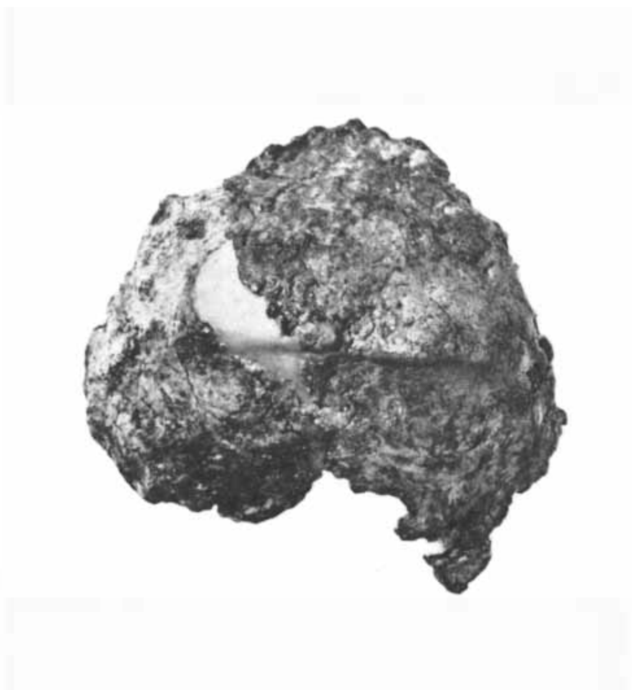
In the case of living man there is no reason to revise Linnaeus' assignment: *Homo sapiens* is a good, typical species. Evolution, however, was not in Linnaeus' ken. He never saw a human fossil, much less conceived of men different from living men. Between his time and ours the use of the Linnaean system of classification as applied to man and his relatives past and present became almost a game. On grasping the concept of evolution, scholars saw that modern man must have had ancestors. They were prepared to anticipate the actual discovery of these ancestral forms, and perhaps the greatest anticipator was the German biologist Ernst Haeckel. Working on the basis of fragmentary information in 1889, when the only well-known fossil human remains were the comparatively recent bones discovered 25 years earlier in the Neander Valley of Germany, Haeckel drew up a theoretical ancestral line for man. The line began among some postulated extinct apes of the Miocene epoch and reached *Homo sapiens* by way of an imagined group of "ape-men" (Pithecanthropi) and a group of more advanced but still speechless early men (Alali) whom he visualized as the worldwide stock from which modern men had evolved [*see illustration on page 48*]. A creature combining these various presapient attributes took form in the pooled imagination of Haeckel and his compatriots August Schleicher and Gabriel Max. Max produced a family portrait, and the still-to-be-discovered ancestor was given the respectable Linnaean name *Pithecanthropus alalus*.

Were he living today Haeckel would never do such a thing. It is now the requirement of the International Code of Zoological Nomenclature that the naming of any new genus or species be supported by publication of the specimen's particulars together with a description showing it to be recognizably different from any genus or species previously known. Haeckel was rescued from retroactive embarrassment, however, by Dubois, who gave Haeckel's genus name to Java man. The skull was too large to be an ape's and apparently too small to be a man's; the name *Pithecanthropus* seemed perfectly appropriate. On the other hand, the thighbone from the same formation was essentially modern; its possessor had evidently walked upright. Dubois therefore gave his discovery the species name *erectus*. Since Dubois's time the legitimacy of his finds has been confirmed by the discovery in Java (by G. H. R. von Koenigswald between 1936 and 1939 and by Indonesian workers within the past three years) of equally old and older fossils of the same population.

In the 50 years between Dubois's discovery and the beginning of World

JAVA MAN, whose 700,000-year-old remains were unearthed in 1891 by Eugène Dubois, is representative of the earliest *Homo erectus* population so far discovered. This reconstruction was made recently by G. H. R. von Koenigswald and combines the features of the more primitive members of this species of man that he found in the lowest (Djetis) fossil strata at Sangiran in central Java during the 1930's. The characteristics that are typical of *Homo erectus* include the smallness and flatness of the cranium, the heavy browridge and both the sharp bend and the ridge for muscle attachment at the rear of the skull. The robustness of the jaws adds to the species' primitive appearance. In most respects except size, however, the teeth of *Homo erectus* resemble those of modern man.

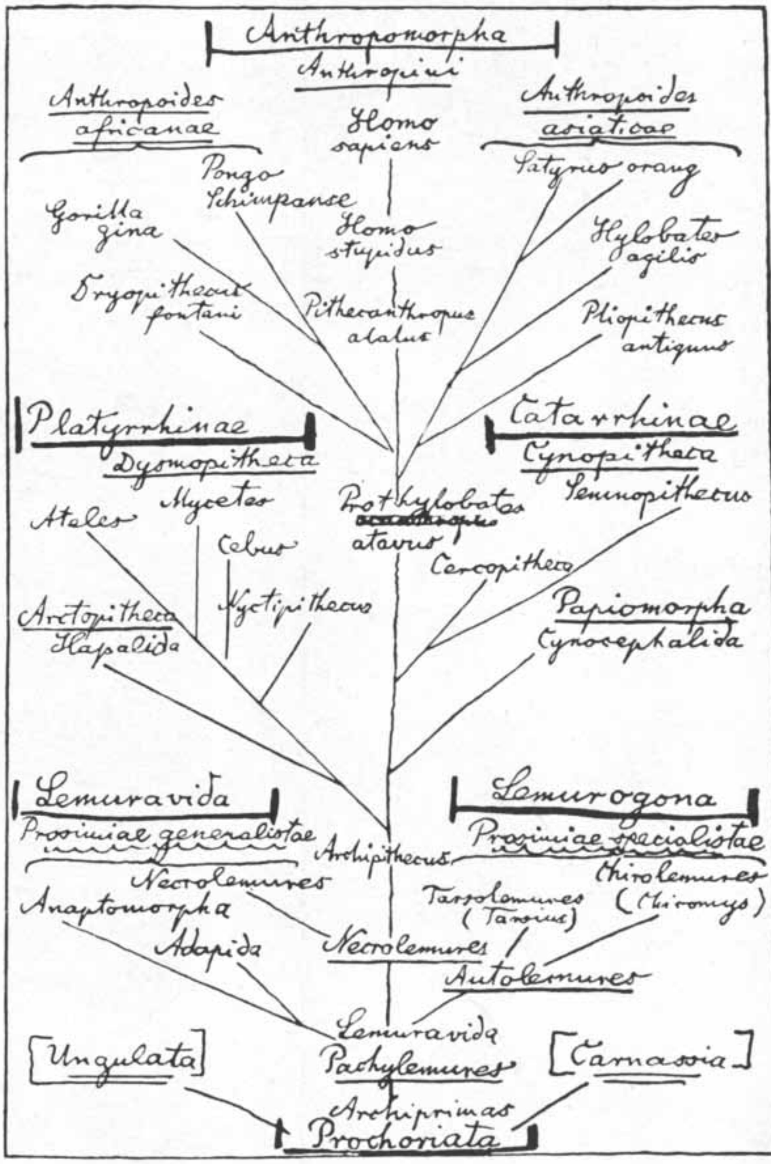
LANTIAN MAN is the most recently found *Homo erectus* fossil. The discovery consists of a jawbone and this skullcap (*top view, browridge at bottom*) from which the occipital bone (*top*) is partially detached. Woo Ju-kang of the Chinese Academy of Sciences in Peking provided the photograph; this fossil man from Shensi may be as old as the earliest specimens of *Homo erectus* from Java.



OCCIPITAL BONE found at Vértesszöllös in Hungary in 1965 is 500,000 or more years old. The only older human fossil in Europe is the Heidelberg jaw. The bone forms the rear of a skull; the ridge for muscle attachment (*horizontal line*) is readily apparent. In spite of this primitive feature and its great age, the skull fragment from Vértesszöllös has been assigned to the species *Homo sapiens*.

War II various other important new kinds of human fossil came into view. For our purposes the principal ones (with some of the Linnaean names thrust on them) were (1) the lower jaw found at Mauer in Germany in 1907 (*Homo heidelbergensis* or *Palaeanthropus*), (2) the nearly complete skull found at Broken Hill in Rhodesia in 1921 (*Homo rhodesiensis* or *Cyphanthropus*), (3) various remains uncovered near Peking in China, beginning with one tooth in 1923 and finally comprising a collection representing more than 40 men, women and children by the end of 1937 (*Sinanthropus pekinensis*), and (4) several skulls found in 1931 and 1932 near Ngandong on the Solo River not far from where Dubois had worked (*Homo soloensis* or *Javanthropus*). This is a fair number of fossils, but they were threatened with being outnumbered by the names assigned to them. The British student of early man Bernard G. Campbell has recorded the following variants in the case of the Mauer jawbone alone: *Palaeanthropus heidelbergensis, Pseudhomo heidelbergensis, Protanthropus heidelbergensis, Praehomo heidelbergensis, Praehomo europaeus, Anthropus heidelbergensis, Maueranthropus heidelbergensis, Europanthropus heidelbergensis* and *Euranthropus.*

Often the men responsible for these redundant christenings were guilty merely of innocent grandiloquence. They were not formally declaring their conviction that each fossil hominid belonged to a separate genus, distinct from *Homo,* which would imply an enormous diversity in the human stock. Nonetheless, the multiplicity of names has interfered with an understanding of the evolutionary significance of the fossils that bore them. Moreover, the human family trees drawn during this period showed a fundamental resemblance to Haeckel's original venture; the rather isolated specimens of early man were stuck on here and there like Christmas-tree ornaments. Although the arrangements evinced a vague consciousness of evolution, no scheme was presented that intelligibly interpreted the fossil record.



THE NAME "PITHECANTHROPUS," or ape-man, was coined by the German biologist Ernst Haeckel in 1889 for a postulated precursor of *Homo sapiens.* Haeckel placed the ape-man genus two steps below modern man on his "tree" of primate evolution, adding the species name *alalus,* or "speechless," because he deemed speech an exclusively human trait.

At last two questions came to the fore. First, to what degree did the fossils really differ? Second, what was the difference among them over a period of time? The fossil men of the most recent period—those who had lived between roughly 100,000 and 30,000 years ago—were Neanderthal man, Rhodesian man and Solo man. They have been known traditionally as *Homo neanderthalensis, Homo rhodesiensis* and *Homo soloensis,* names that declare each of the three to be a separate species, distinct from one another and from *Homo sapiens.* This in turn suggests that if Neanderthal and Rhodesian populations had come in contact, they would probably not have interbred. Such a conclusion is difficult to establish on the basis of fossils, particularly when they are few and tell very little about the geographical range of the species. Today's general view is a contrary one. These comparatively recent fossil men, it is now believed, did not constitute separate species. They were at most incipient species, that is, subspecies or variant populations that had developed in widely separated parts of the world but were still probably able to breed with one another or with *Homo sapiens.*

It was also soon recognized that the older Java and Peking fossils were not very different from one another. The suggestion followed that both populations be placed in a single genus (*Pithecanthropus*) and that the junior name (*Sinanthropus*) be dropped. Even this, however, was one genus too many for Ernst Mayr of Harvard University. Mayr, whose specialty is the evolutionary basis of biological classification, declared that ordinary zoological standards would not permit Java and Peking man to occupy

GRADE	EUROPE	NORTH AFRICA	EAST AFRICA	SOUTH AFRICA	EAST ASIA	SOUTHEAST ASIA
(5)	HOMO SAPIENS (VÉRTESSZÖLLÖS)					
(4)						(HOMO ERECTUS SOLOENSIS)
3	HOMO ERECTUS HEIDELBERGENSIS	HOMO ERECTUS MAURITANICUS	HOMO ERECTUS LEAKEYI		HOMO ERECTUS PEKINENSIS	
2						HOMO ERECTUS ERECTUS
1			HOMO ERECTUS HABILIS	HOMO ERECTUS CAPENSIS	(HOMO ERECTUS LANTIANENSIS)	HOMO ERECTUS MODJOKERTENSIS

EIGHT SUBSPECIES of *Homo erectus* that are generally accepted today have been given appropriate names and ranked in order of evolutionary progress by the British scholar Bernard G. Campbell. The author has added Lantian man to Campbell's lowest *Homo erectus* grade and provided a fourth grade to accommodate Solo man, a late but primitive survival. The author has also added a fifth grade for the *Homo sapiens* fossil from Vértesszöllös (*color*). Colored area suggests that Heidelberg man is its possible forebear.

a genus separate from modern man. In his opinion the amount of evolutionary progress that separates *Pithecanthropus* from ourselves is a step that allows the recognition only of a different species. After all, Java and Peking man apparently had bodies just like our own; that is to say, they were attacking the problem of survival with exactly the same adaptations, although with smaller brains. On this view Java man is placed in the genus *Homo* but according to the rules retains his original species name and so becomes *Homo erectus*. Under the circumstances Peking man can be distinguished from him only as a subspecies: *Homo erectus pekinensis*.

The simplification is something more than sweeping out a clutter of old names to please the International Commission on Zoological Nomenclature. The reduction of fossil hominids to not more than two species and the recognition of *Homo erectus* has become increasingly useful as a way of looking at a stage of human evolution. This has been increasingly evident in recent years, as human fossils have continued to come to light and as new and improved methods of dating them have been developed. It is now possible to place both the old discoveries and the new ones much more precisely in time, and that is basic to establishing the entire pattern of human evolution in the past few million years.

To consider dating first, the period during which *Homo erectus* flourished occupies the early middle part of the Pleistocene epoch. The evidence that now enables us to subdivide the Pleistocene with some degree of confidence is of several kinds. For example, the fossil animals found in association with fossil men often indicate whether the climate of the time was cold or warm. The comparison of animal communities is also helpful in correlating intervals of time on one continent with intervals on another. The ability to determine absolute dates, which makes possible the correlation of the relative dates derived from sequences of strata in widely separated localities, is another significant development. Foremost among the methods of absolute dating at the moment is one based on the rate of decay of radioactive potassium into argon. A second method showing much promise is the analysis of deep-sea sediments; changes in the forms of planktonic life embedded in samples of the bottom reflect worldwide temperature changes. When the absolute ages of key points in sediment sequences are determined by physical or chemical methods, it ought to be possible to assign dates to all the major events of the Pleistocene. Such methods have already suggested that the epoch began more than three million years ago and that its first major cold phase (corresponding to the Günz glaciation of the Alps) may date back to as much as 1.5 million years ago. The period of time occupied by *Homo erectus* now appears to extend from about a million years ago to 500,000 years ago in terms of absolute dates, or from some time during the first interglacial period in the Northern Hemisphere to about the end of the second major cold phase (corresponding to the Mindel glaciation of the Alps).

On the basis of the fossils found before World War II, with the exception of the isolated and somewhat peculiar Heidelberg jaw, *Homo erectus* would have appeared to be a human population of the Far East. The Java skulls, particularly those that come from the lowest fossil strata (known as the Djetis beds), are unsurpassed within the entire group in primitiveness. Even the skulls from the strata above them (the Trinil beds), in which Dubois made his original discovery, have very thick walls and room for only a small brain. Their cranial capacity probably averages less than 900 cubic centimeters, compared with an average of 500 c.c. for gorillas and about 1,400 c.c. for modern man. The later representatives of Java man must be more than 710,000 years old, because potassium-argon analysis has shown that tektites (glassy stones formed by or from meteorites) in higher strata of the same formation are of that age.

The Peking fossils are younger, probably dating to the middle of the second Pleistocene cold phase, and are physically somewhat less crude than the Java ones. The braincase is higher, the face shorter and the cranial capacity approaches 1,100 c.c., but the general construction of skull and jaw is similar. The teeth of both Java man and Peking man are somewhat larger than modern man's and are distinguished by traces of an enamel collar, called a cingulum, around some of the crowns. The latter is an ancient and primitive trait in man and apes.

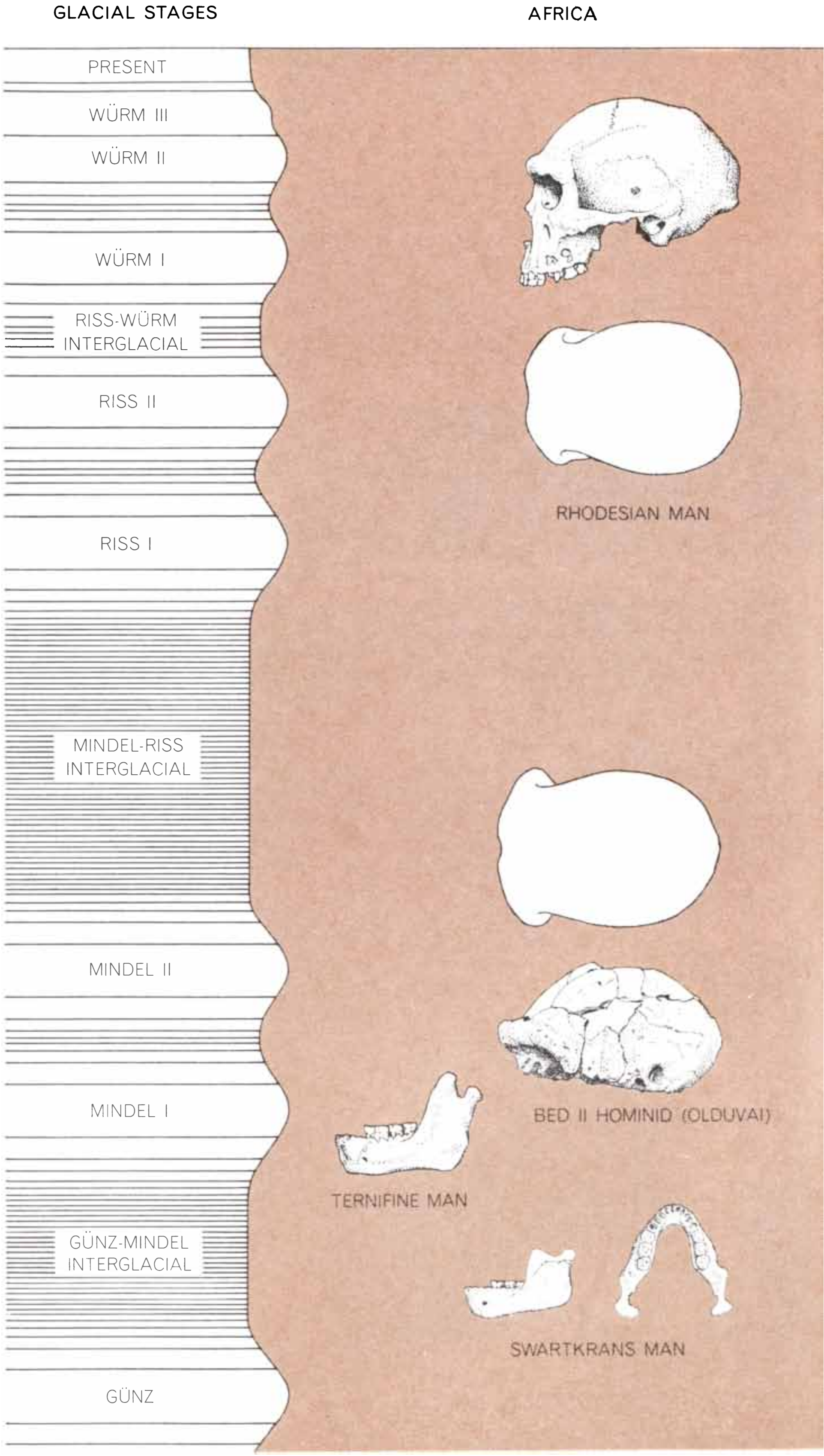
Discoveries of human fossils after World War II have added significantly to the picture of man's distribution at this period. The pertinent finds are the following:

1949: Swartkrans, South Africa. Jaw and facial fragments, originally given the name *Telanthropus capensis*. These were found among the copious remains at this site of the primitive subhumans known as australopithecines. The fossils were recognized at once by the late Robert Broom and his colleague John T. Robinson as more advanced than the australopithecines both in size and in traits of jaw and teeth. Robinson has now assigned *Telanthropus* to *Homo erectus*, since that is where he evidently belongs.

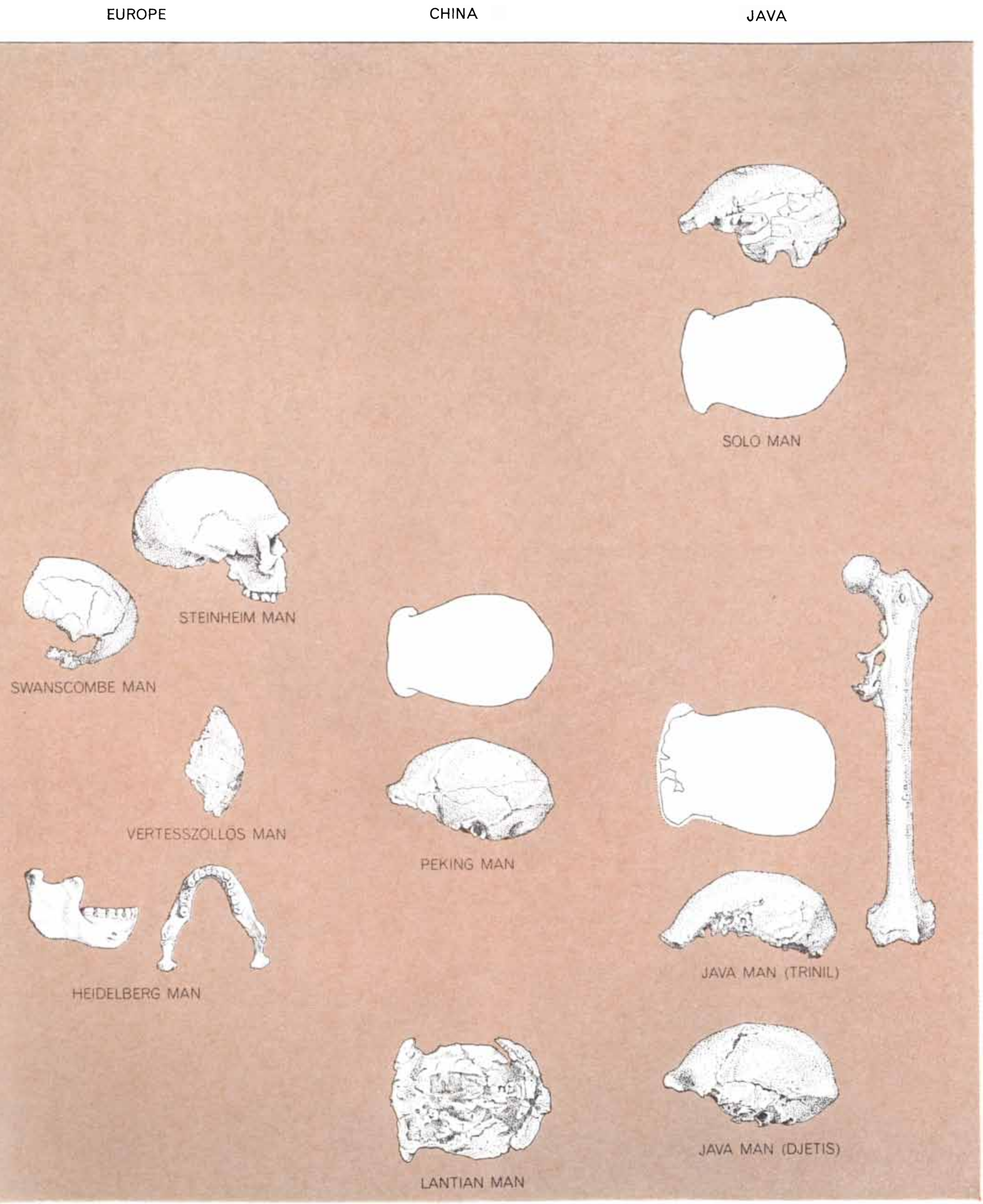
1955: Ternifine, Algeria. Three jaws and a parietal bone, given the name *Atlanthropus mauritanicus*, were found under a deep covering of sand on the clay floor of an ancient pond by Camille Arambourg. The teeth and jaws show a strong likeness to the Peking remains.

1961: Olduvai Gorge, Tanzania. A skullcap, not formally named but identified as the Bed II Hominid, was discovered by L. S. B. Leakey. Found in a context with a provisional potassium-argon date of 500,000 years ago, the skull's estimated cranial capacity is 1,000 c.c. Although differing somewhat in detail, it has the general characteristics of the two Far Eastern subspecies of *Homo erectus*. At lower levels in this same important site were found the remains of a number of individuals with small skulls, now collectively referred to as "Homo habilis."

1963–1964: Lantian district, Shensi, China. A lower jaw and a skullcap were found by Chinese workers at two separate localities in the district and given the name *Sinanthropus lantianensis*. Animal fossils indicate that the Lantian sites are older than the one that yielded Peking man and roughly as old as the lowest formation in Java. The form of the skull and jaw accords well with this



FOSSIL EVIDENCE for the existence of a single species of early man instead of several species and genera of forerunners of *Homo sapiens* is presented in this array of individual remains whose age places them in the interval of approximately 500,000 years that separates the first Pleistocene interglacial period from the end of the second glacial period (*see scale at left*). The earliest *Homo erectus* fossils known, from Java and China, belong to the first interglacial period; the earliest *Homo erectus* remains from South Africa may be equally



old. Half a million years later *Homo erectus* continued to be represented in China by the remains of Peking man and in Africa by the skull from Olduvai Gorge. In the intervening period this small-brained precursor of modern man was not the only human species inhabiting the earth, nor did *Homo erectus* become extinct when the 500,000-year period ended. One kind of man who had apparently reached the grade of *Homo sapiens* in Europe by the middle or later part of the second Pleistocene glacial period was unearthed recently at Vértesszöllös in Hungary. In the following interglacial period *Homo sapiens* is represented by the Steinheim and Swanscombe females. Solo man's remains indicate that *Homo erectus* survived for several hundred thousand years after that.

dating; both are distinctly more primitive than the Peking fossils. Both differ somewhat in detail from the Java subspecies of *Homo erectus,* but the estimated capacity of this otherwise large skull (780 c.c.) is small and close to that of the earliest fossil cranium unearthed in Java.

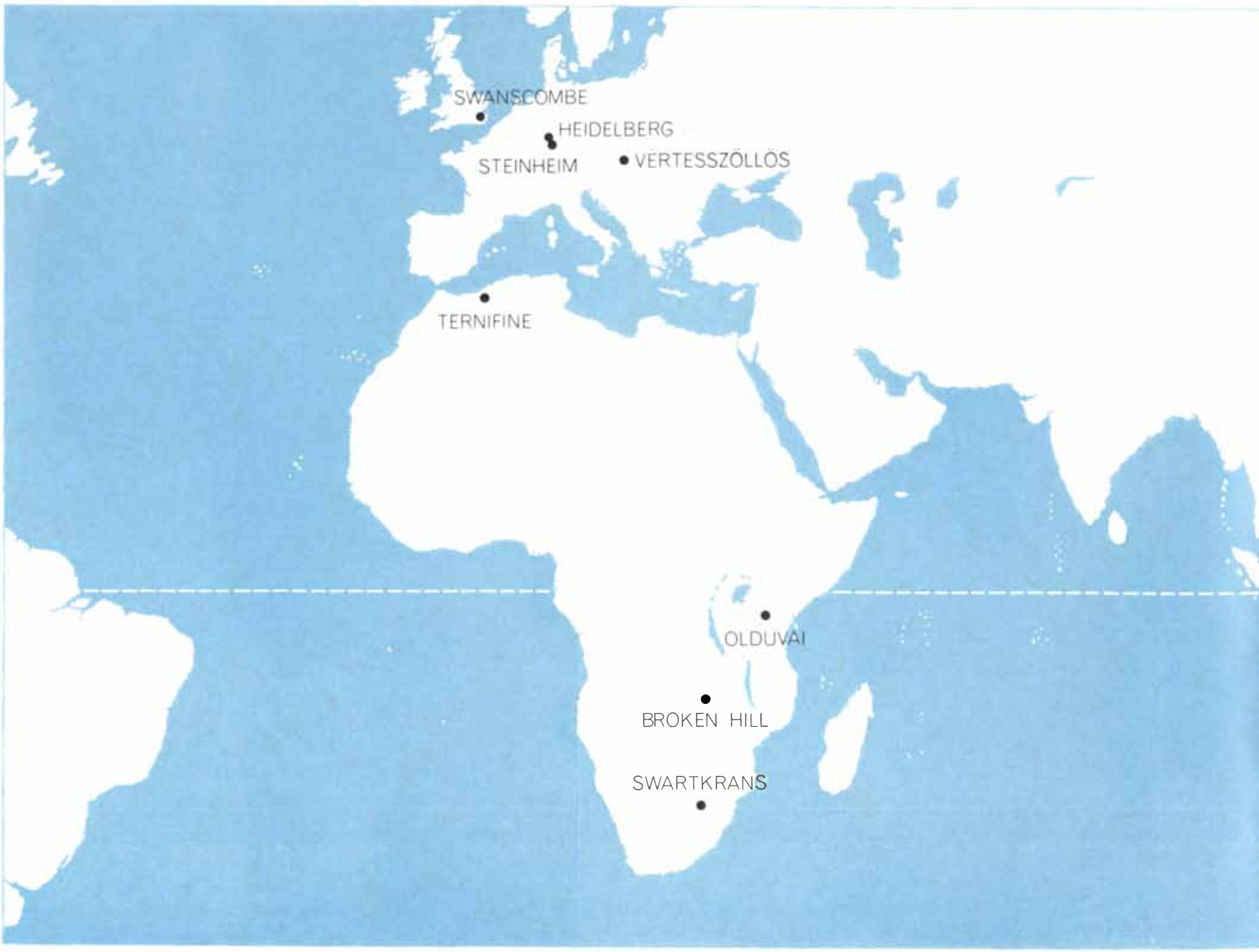
1965: Vértesszöllös, Hungary. An isolated occipital bone (in the back of the skull) was found by L. Vértes. This skull fragment is the first human fossil from the early middle Pleistocene to be unearthed in Europe since the Heidelberg jaw. It evidently dates to the middle or later part of the Mindel glaciation and thus falls clearly within the *Homo erectus* time zone as defined here. The bone is moderately thick and shows a well-defined ridge for the attachment of neck muscles such as is seen in all the *erectus* skulls. It is unlike *erectus* occipital bones, however, in that it is both large and definitely less angled; these features indicate a more advanced skull.

In addition to these five discoveries, something else of considerable importance happened during this period. The Piltdown fraud, perpetrated sometime before 1912, was finally exposed in 1953. The detective work of J. S. Weiner, Sir Wilfrid Le Gros Clark and Kenneth Oakley removed from the fossil record a supposed hominid with a fully apelike jaw and manlike skull that could scarcely be fitted into any sensible evolutionary scheme.

From this accumulation of finds, many of them made so recently, there emerges a picture of men with skeletons like ours but with brains much smaller, skulls much thicker and flatter and furnished with protruding brows in front and a marked angle in the rear, and with teeth somewhat larger and exhibiting a few slightly more primitive traits. This picture suggests an evolutionary level, or grade, occupying half a million years of human history and now seen to prevail all over the inhabited Old World. This is the meaning of *Homo erectus.* It gives us a new foundation for ideas as to the pace and the pattern of human evolution over a critical span of time.

Quite possibly this summary is too tidy; before the 100th anniversary of the resurrection of *Homo erectus* is celebrated complications may appear that we cannot perceive at present. Even today there are a number of fringe problems we cannot neglect. Here are some of them.

What was the amount of evolution taking place within the *erectus* grade? There is probably a good deal of accident of discovery involved in defining *Homo erectus.* Chance, in other words, may have isolated a segment of a continuum, since finds from the time immediately following this 500,000-year period are almost lacking. It seems likely, in fact practically certain, that real evolutionary progress was taking place,



DISTRIBUTION of *Homo erectus* seemed to be confined mainly to the Far East and Southeast Asia on the basis of fossils unearthed before World War II; the sole exception was the Heidelberg jaw. Postwar findings in South, East and North Africa, as well as dis-

but the tools made by man during this period reveal little of it. As for the fossils themselves, the oldest skulls—from Java and Lantian—are the crudest and have the smallest brains. In Java, one region with some discernible stratigraphy, the later skulls show signs of evolutionary advance compared with the earlier ones. The Peking skulls, which are almost certainly later still, are even more progressive. Bernard Campbell, who has recently suggested that all the known forms of *Homo erectus* be formally recognized as named subspecies, has arranged the names in the order of their relative progressiveness. I have added some names to Campbell's list; they appear in parentheses in the illustration on page 49. As the illustration indicates, the advances in grade seem indeed to correspond fairly well with the passage of time.

What are the relations of *Homo erectus* to Rhodesian and Solo man? This is a point of particular importance, because both the African and the Javanese fossils are much younger than the date we have set as the general upward boundary for *Homo erectus*. Rhodesian man may have been alive as recently as 30,000 years ago and may have actually overlapped with modern man. Solo man probably existed during the last Pleistocene cold phase; this is still very recent compared with the time zone of the other *erectus* fossils described here. Carleton S. Coon of the University of Pennsylvania deems both late fossil men to be *Homo erectus* on the basis of tooth size and skull flatness. His placing of Rhodesian man is arguable, but Solo man is so primitive, so like Java man in many aspects of his skull form and so close to Peking man in brain size that his classification as *Homo erectus* seems almost inevitable. The meaning of his survival hundreds of thousands of years after the period I have suggested, and his relation to the modern men who succeeded him in Southeast Asia in recent times, are unanswered questions of considerable importance.

covery of a new *Homo erectus* site in northern China, have extended the species' range.

Where did *Homo erectus* come from? The Swartkrans discovery makes it clear that he arose before the last representatives of the australopithecines had died out at that site. The best present evidence of his origin is also from Africa; it consists of the series of fossils unearthed at Olduvai Gorge by Leakey and his wife and called Homo habilis. These remains seem to reflect a transition from an australopithecine level to an *erectus* level about a million years ago. This date seems almost too late, however, when one considers the age of *Homo erectus* finds elsewhere in the world, particularly in Java.

Where did *Homo erectus* go? The paths are simply untraced, both those that presumably lead to the Swanscombe and Steinheim people of Europe during the Pleistocene's second interglacial period and those leading to the much later Rhodesian and Neanderthal men. This is a period lacking useful evidence. Above all, the nature of the line leading to living man—*Homo sapiens* in the Linnaean sense—remains a matter of pure theory.

We may, however, have a clue. Here it is necessary to face a final problem. What was the real variation in physical type during the time period of *Homo erectus*? On the whole, considering the time and space involved, it does not appear to be very large; the similarity of the North African jaws to those of Peking man, for example, is striking in spite of the thousands of miles that separated the two populations. The Heidelberg jaw, however, has always seemed to be somewhat different from all the others and a little closer to modern man in the nature of its teeth. The only other European fossil approaching the Heidelberg jaw in antiquity is the occipital bone recently found at Vértesszöllös. This piece of skull likewise appears to be progressive in form and may have belonged to the same general kind of man as the Heidelberg jaw, although it is somewhat more recent in date.

Andor Thoma of Hungary's Kossuth University at Debrecen in Hungary, who has kindly given me information concerning the Vértesszöllös fossil, will publish a formal description soon in the French journal *L'Anthropologie*. He estimates that the cranial capacity was about 1,400 c.c., close to the average for modern man and well above that of the known specimens of *Homo erectus*. Although the occipital bone is thick, it is larger and less sharply angled than the matching skull area of Rhodesian man. It is certainly more modern-looking than the Solo skulls. I see no reason at this point to dispute Thoma's estimate of brain volume. He concludes that Vértesszöllös man had in fact reached the *sapiens* grade in skull form and brain size and accordingly has named him a subspecies of *Homo sapiens*.

Thoma's finding therefore places a population of more progressive, *sapiens* humanity contemporary with the populations of *Homo erectus* 500,000 years ago or more. From the succeeding interglacial period in Europe have come the Swanscombe and Steinheim skulls, generally recognized as *sapiens* in grade. They are less heavy than the Hungarian fossil, more curved in occipital profile and smaller in size; they are also apparently both female, which would account for part of these differences.

The trail of evidence is of course faint, but there are no present signs of contradiction; what we may be seeing is a line that follows *Homo sapiens* back from Swanscombe and Steinheim to Vértesszöllös and finally to Heidelberg man at the root. This is something like the Solo case in reverse, a *Homo sapiens* population surprisingly early in time, in contrast to a possible *Homo erectus* population surprisingly late. In fact, we are seeing only the outlines of what we must still discover. It is easy to perceive how badly we need more fossils; for example, we cannot relate Heidelberg man to any later Europeans until we find some skull parts to add to his solitary jaw.

Magnetic Fields on the Quiet Sun

Solar activity is essentially an expression of changing magnetic fields in the sun's atmosphere. Recent observations substantiate a comprehensive theory that explains the 11-year magnetic cycle

by William C. Livingston

Under ordinary circumstances the sun seems to be a changeless celestial object. So it is in comparison with some other stars, but when it is observed with astronomical instruments it is seen to be quite active. The most striking feature of this activity is its cyclic nature. At the beginning of each cycle the surface of the sun is quiet, disturbed only by the "granulation" effect of convection cells rising from its hot interior. Then sunspots begin to appear in the sun's higher latitudes; over a period of years their number and intensity increase and their points of origin migrate toward the solar equator. When, after three or four years, the sunspots are at their height, numerous other signs of solar activity are most apparent: bright flares, prominences and surges, and their associated radio emissions. Then the activity tapers off, and about 11 years after the first sunspots appeared the sun is quiet again.

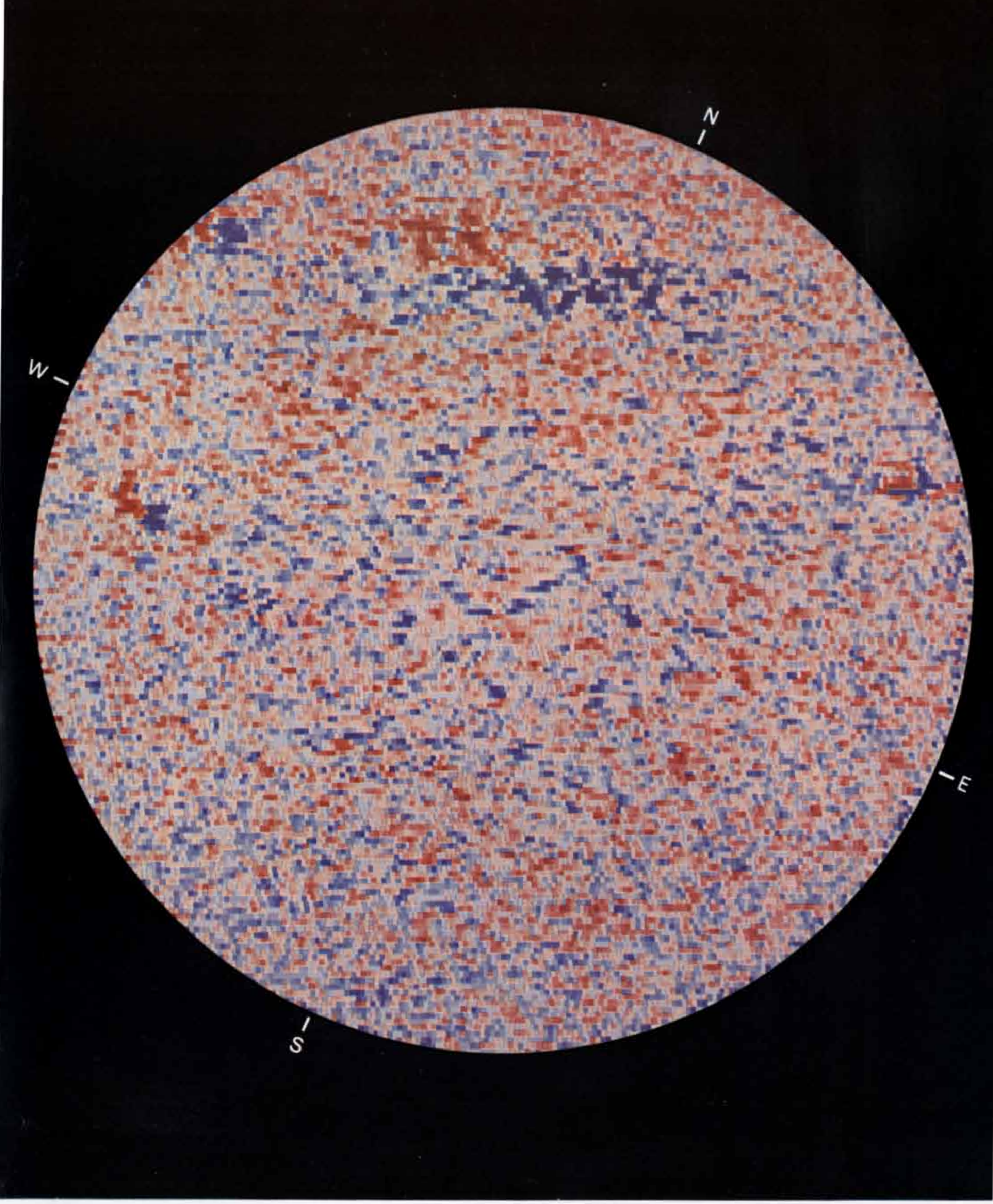
In recent years it has become clear that most solar activity is an expression of changes in the magnetism of the sun. Five years ago Horace W. Babcock of the Mount Wilson and Palomar Observatories proposed a theory explaining the cyclic evolution of solar magnetic fields. The theory could not well be tested until the sun had moved through a period of minimum activity, during which the magnetic fields could be measured at what might be called their resting level, and had then begun to move into a new cycle. The opportunity came in 1964–1965, the "International Quiet Sun Year." Observations at the Kitt Peak National Observatory in Arizona substantiate Babcock's theory in detail and make it clear that magnetic events on the quiet sun set the stage for the complex, interwoven phenomena that characterize the active sun.

Solar magnetism can be investigated through its effect on the light absorbed by atoms in the photosphere, the luminous surface layer of the sun. The spectral lines of the light emitted or absorbed by atoms in a magnetic field are split and the light is polarized; the extent of the splitting varies with the strength of the field, and the direction of polarization depends on the magnetic polarity, or the direction of the field. In 1908 George Ellery Hale of the Mount Wilson Observatory demonstrated this "Zeeman effect" (named for Pieter Zeeman, the Dutch physicist who discovered it) in the spectral absorption lines originating in sunspots. It developed that all sunspots have strong magnetic fields, that the "preceding" and "following" elements of typical sunspot pairs (as they are seen as the sun rotates from east to west) have opposite polarity and that this polarity reverses in successive 11-year cycles.

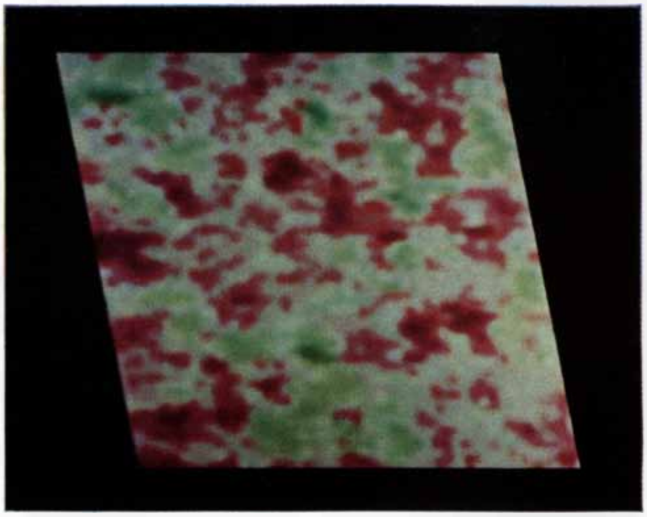
Hale and his successors proceeded to look for evidence of other magnetic fields weaker than those of the sunspots and perhaps indicative of a general field of the sun comparable to that of the earth. Spectral lines from atoms in a weak field are barely broadened, however, and the Zeeman effect is hard to detect. It was only in the 1950's that Babcock and his father, Harold D. Babcock, were able to develop an exquisitely sensitive "magnetograph," by which the broadening and polarization could be measured and the direction and strength of the field recorded and displayed in various ways. Studies with the new instrument revealed scattered regions with magnetic intensities ranging from less than a gauss to tens of gauss, compared with the hundreds or thousands of gauss in sunspot fields and the .6 gauss of the earth's average field. Most of these fields were "bipolar," with contiguous parts opposite in polarity as they are in the strong sunspot fields. In the high latitudes, however, there was evidence of the general field Hale had sought: widespread areas of weak magnetism that were predominantly of one polarity. In 1953 the polarity was generally positive in the north and negative in the south; by 1958 these directions were reversed [see "The Magnetism of the Sun," by Horace W. Babcock; Scientific American, February, 1960].

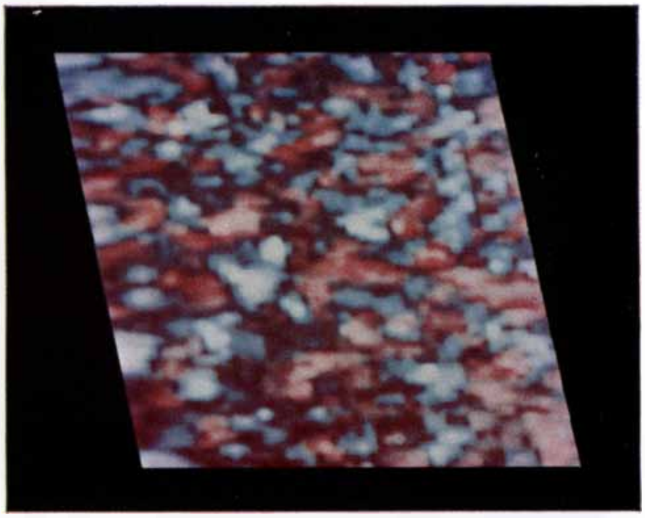
A magnetic pattern characteristic of the quiet sun is shown in the color illustration on the opposite page, a map of the magnetic fields on the sun's surface on November 5, 1964, a day when no sunspots were visible. To make the map the image of the sun 33.5 inches in diameter formed at the focus of the McMath solar telescope at Kitt Peak was scanned back and forth across the entrance aperture of a large spectrograph. The aperture—and therefore the resolution of the instrument—was a square about 10 seconds of arc on a side, corresponding to an area some 7,300 kilometers square on the surface of the sun. The spectrograph selected a single absorption line (the line of iron at a wavelength of 5,250 angstrom units) and separated its split components on the basis of their different polarization. Photomultiplier tubes converted the light from each component into electric currents that provided a record of the direction and intensity of the magnetic field in each 10-by-10-second square.

It was from this record that we built up the map, representing fields of positive polarity in blue and negative fields in red and letting the intensity of the color indicate the strength of the field,

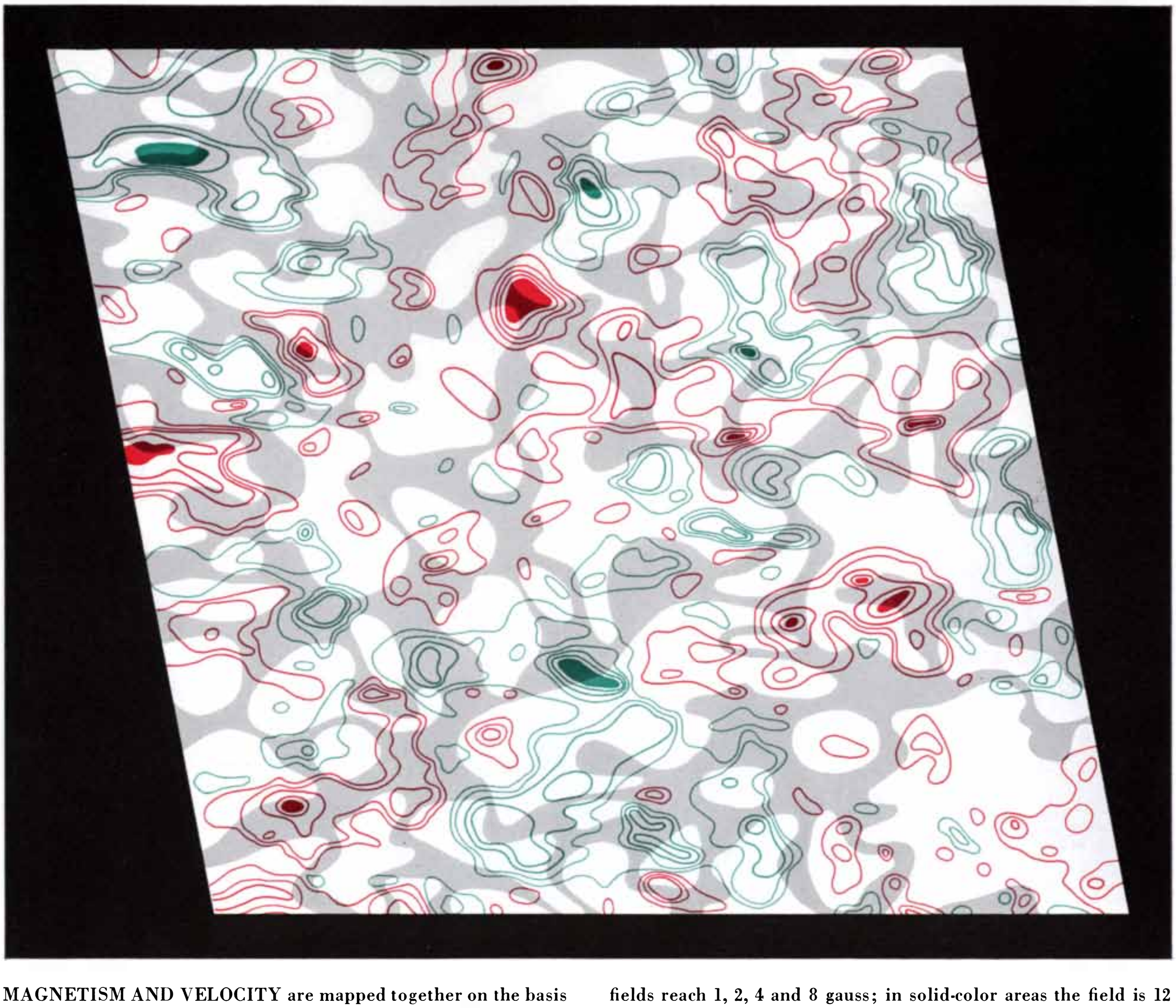


MAGNETIC FIELDS on the quiet sun on November 5, 1964, are mapped here on the basis of measurements made with a magnetograph attached to the McMath solar telescope at the Kitt Peak National Observatory in Arizona. The map was built up with colored chips, each representing the magnetic field in an area some 7,300 kilometers on a side. Blue indicates positive polarity and red negative; intensity of color indicates the strength of the field from .8 to about 27 gauss. The map shows several bipolar magnetic regions (*dark red and blue groups*) and the general field: negative (*red*) in the north, positive (*blue*) in the south. There were no sunspots.





HIGH-RESOLUTION MAPS show the magnetic (*left*) and velocity (*right*) fields in a quiet region of the sun. The area of the sun covered by each map is about 80,000 kilometers wide and is skewed because of instrument drift. The magnetic map is like the one on the preceding page but was photographed out of focus to soften construction detail. Positive fields are red, negative green; field strength varies with color from 0 to 12 gauss. The velocity map is based on Doppler shifting of light from atoms moving up out of the sun (*blue*) or down into the sun (*red*). Velocities, shown by color intensity, range from 0 to more than 375 meters per second.



MAGNETISM AND VELOCITY are mapped together on the basis of data in the maps at the top of this page. The contour-like "isogauss" lines show where the positive (*red*) or negative (*green*) fields reach 1, 2, 4 and 8 gauss; in solid-color areas the field is 12 gauss or more. The gray areas are those in which the velocity map shows little or no vertical velocity at the surface of the sun.

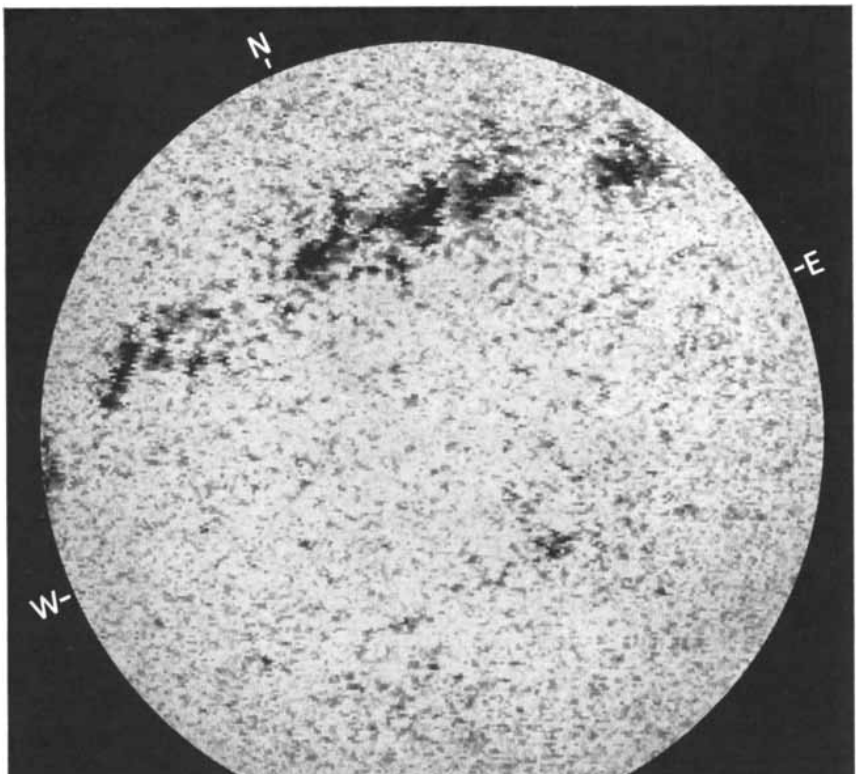
which varied from about .8 to 27 gauss. The map shows that the sun's surface is completely covered by magnetic fields, with several bipolar regions visible in the solar northern hemisphere and one in the southern. There is also a predominance of negative fields (red) in the north and of positive fields (blue) in the south.

Let us analyze the November 5 magnetogram in terms of present theory, first considering two conceptual tools that will be basic to this discussion. One is the idea of magnetic lines of force. Magnetic fields can best be dealt with in terms of these imaginary constructs: endless loops along which a compass needle would be aligned. The strength of the field in a given volume of space is considered to depend simply on the number of lines that cut through the volume; if any physical process causes a compression or rarefaction of the lines of force, the magnetic intensity is increased or decreased in proportion to the density of the lines.

The other concept is that of "frozen in" lines of force. There is a close—almost an inseparable—coupling between magnetic lines of force and the material of the sun. This is a consequence of the rather high electrical conductivity of the solar atmosphere, which is somewhat greater than that of seawater. Any movement of a line of force through this conductive gaseous medium induces an electric current that tends to oppose the motion exactly, so that the line of force carries the surrounding gas along with it. By the same token any forced motion of the solar atmosphere tends to carry the frozen-in line of force along with the gas.

Now to develop Babcock's theory, taking the November 5 map as a starting point. Consider the sun as a dipole magnet, with lines of force emerging from the south polar region, presumably looping through the corona, or outer atmosphere of the sun, and reentering near the north pole [*see "1" in illustration on next two pages*]. Old textbooks would have these lines converging to a hypothetical bar magnet at the center of the sun; present models of the interior of the sun suggest, however, that the lines actually penetrate no more than a tenth of the distance to the center. In other words, the general field is mainly a surface phenomenon. This is a result of the lines' becoming frozen in and of differential rotation: the fact that the sun does not rotate as a solid body but rather as a fluid one, with a period ranging from about 27 days at the equator to 32 days in the upper latitudes. Now consider a single line of force, one that enters and leaves the sun at a latitude of about 60 degrees [2]. As the entry and exit points make successive rotations, the points nearer the equator begin to pull ahead, with the result that the frozen-in line becomes drawn out along the equator [3].

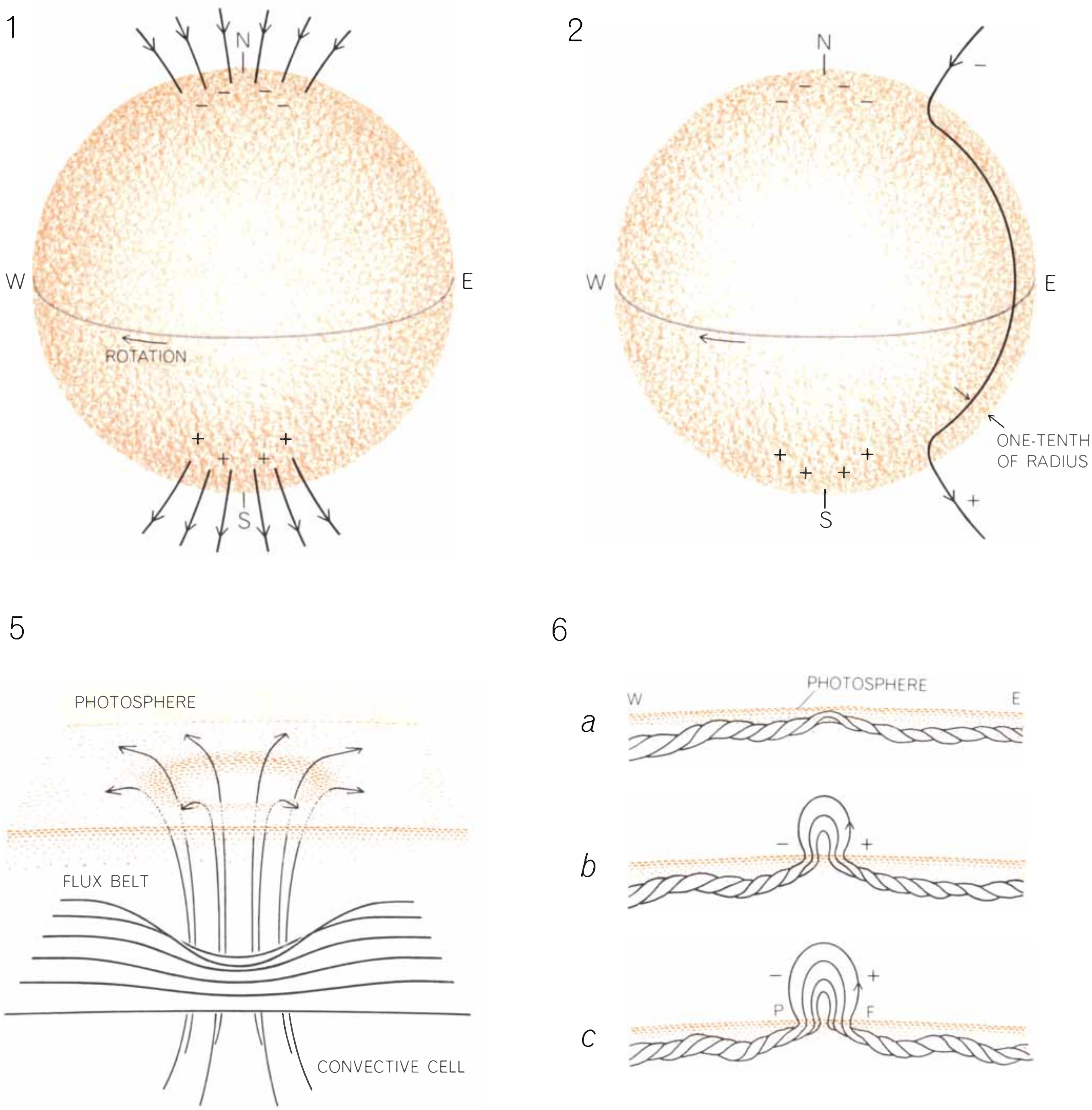
Each successive rotation draws the line out more, until the point at which it crosses the equator "laps" the entry and exit points like a runner lapping the field on a closed track. The process continues; after three years the line is wrapped completely around the interior of the sun six times [*"4" in illustration*]. Babcock calculated, on the basis of the variation of rotation period with latitude, that the resulting spiral becomes tighter and the lines of force become correspondingly closer with increasing latitude. This crowding of the lines of force is equivalent to a local increase in field strength at higher latitudes. In addition to the one line we have been considering there are of course innumerable other lines originating in the polar regions, and the entire set will form a spherical shell of lines of force. This shell is affected by the convective currents moving outward from the deep interior of the sun; a rising convective cell tends to curl up the edge of a "belt" of lines of force [5]; together with differential rotation, this rolls the belt into irregularly twisted tubes or ropes. If at this point chance convection currents cause a kink at some place along such a rope, the lines of force become further constricted; the density of the magnetic flux increases and a kind of magnetic buoyancy causes the rope to rise to the surface of the sun. Breaking free of the solar matter, the lines of force fan out in a typical loop configuration, thereby forming a bipolar magnetic region and, if the region is of sufficiently high intensity, a sunspot group [6]. Clearly the critical flux density that will drive the rope to the surface is most likely to be attained, early in the solar cycle, at the high latitudes where the lines are most closely wrapped. The polarity of the preceding (or westerly) and following (or easterly) fields of a bipolar re-



MAGNETIC MAP of the sun made this past April 29 shows a later stage of the solar cycle than the map on page 55. The southern hemisphere was still quiet but the northern hemisphere had more active regions and greater field strengths than in 1964; the strongest (*solid black*) were 500 to 1,000 gauss and there were several sunspots. Black-and-white reproduction does not distinguish positive and negative polarities, which were oriented as in 1964.

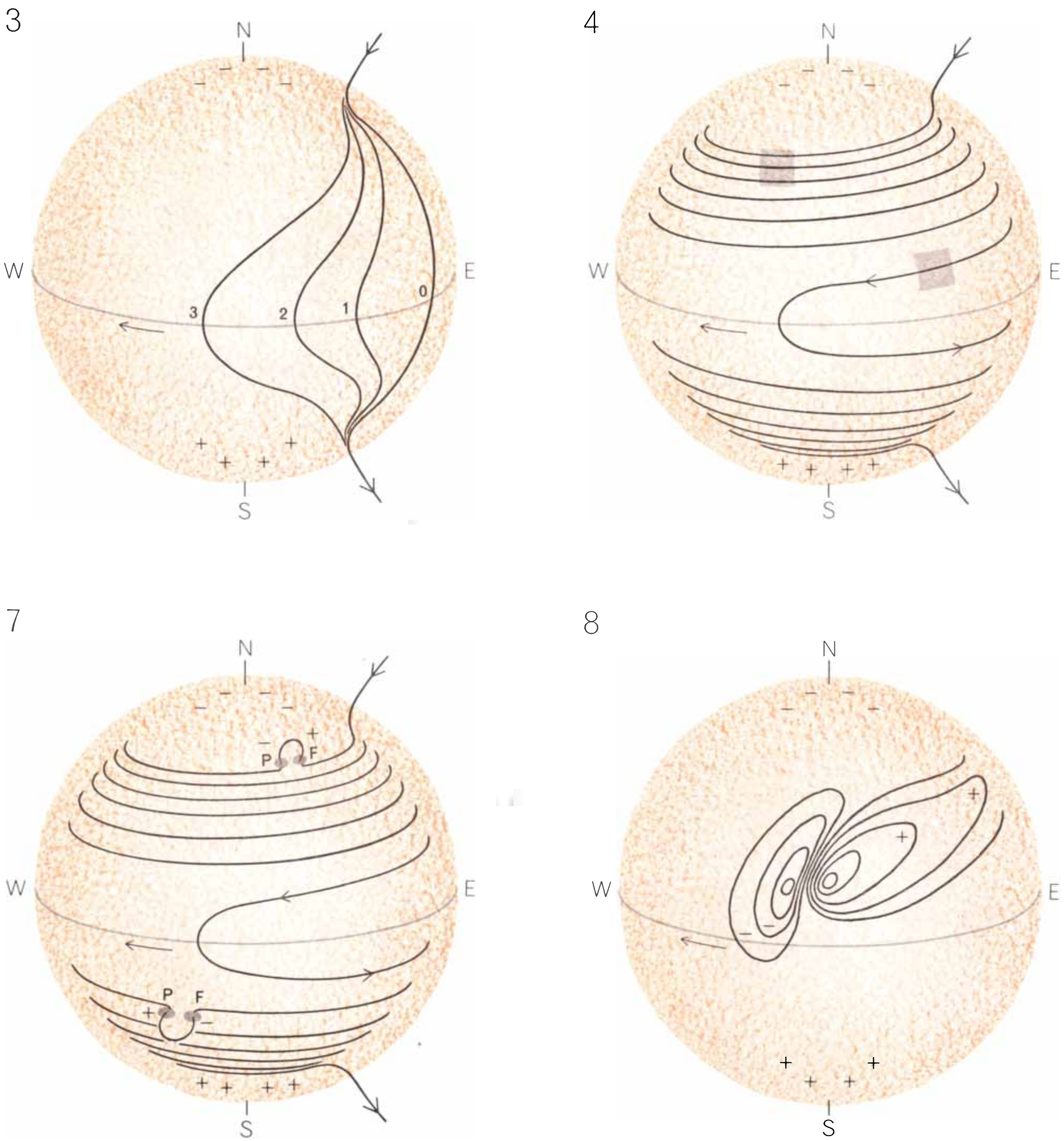
gion is logically related to the orientation of the general polar field that gave birth to it [7].

The Babcock theory accounts for the rather rapid formation of compact bipolar magnetic regions. What explains their slower dissipation, apparently by gradual expansion and weakening? In 1964 Robert B. Leighton of the California Institute of Technology and his colleagues discovered at Mount Wilson systematic horizontal currents on the surface of the sun and showed that these currents must serve to disperse the compact magnetic regions. Leighton called this horizontal motion "supergranulation." He thus compared it to the "white-light granulation" that forms the base of the photosphere. This granulation, which presents the rice-grain pattern visible in the best photographs of the sun in white light, is derived from the cells of hot gas that rise from the interior. These convection cells appear to be about 1,000 kilometers in diameter and to have an individual lifetime of about six minutes. Leighton considers that supergranulation is a large-scale counterpart, with cells that are some 15,000 kilometers in diameter and last about a day. These cells are not visible in white light; supergranulation reveals

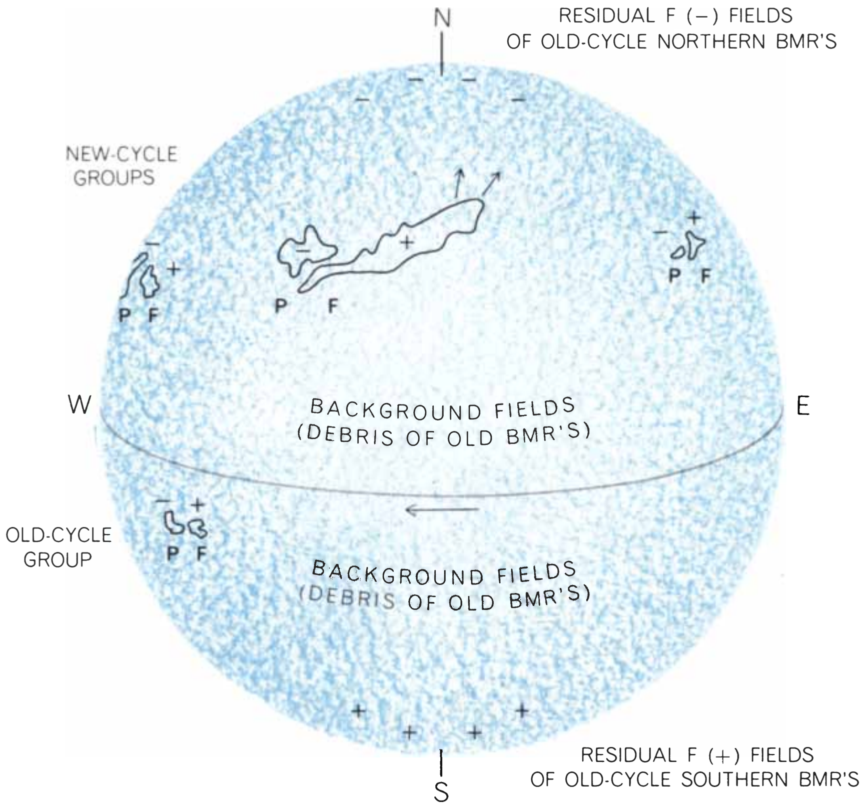


BABCOCK THEORY of the magnetic cycle considers the sun as a dipole magnet (*1*). A typical magnetic line of force entering and leaving the sun at a latitude of 60 degrees penetrates about a tenth of the way to the center (*2*). As the sun rotates the line of force becomes drawn out along the equator because the period of rotation is shorter there than nearer the poles (*3*). This process in time creitself only as a pattern of horizontal motion across the surface of the sun that can be detected spectroscopically.

Leighton suggests that a given supergranulation cell moves an element of gas, along with its magnetic field, in some direction for about a day. Then a new cell gives the same element a new direction completely independent of its earlier motion. In this way an element of solar material is moved over the surface in a "random walk." Thus supergranulation nibbles at the boundaries of a compact field, moving parts of the field this way and that until eventually, with the aid of differential rotation, the field becomes greatly extended. Young bipolar regions lie approximately along parallels of latitude, but with a tilt that puts the following component nearer the pole than the preceding component. Leighton's calculations show that the following component expands preferentially toward the polar region ["8" *in illustration below*]. As the solar cycle advances, this preferential movement slowly populates the polar regions with remnant following fields. Since in any given generation of bipolar regions these following fields are always opposite in sign to the pole adjacent to them, their migration explains the periodic reversal of the sun's magnetic dipole and



ates a shell of lines of force (*4*), their density varying with latitude (*gray areas*). Convection cells rising to the surface curl lines into a rope (*5*). If a kink develops, the rope may be forced to the surface (*6*), forming a bipolar magnetic region (*BMR*) with "preceding" (*P*) and "following" (*F*) fields (*7*). The *F* fields expand toward the poles (*8*), thus eventually reversing the sun's magnetic polarity.



MAJOR FEATURES of the map on page 55 are diagrammed in terms of the magnetic-cycle theory. The polar fields are derived from the "following" fields of the previous cycle, from which one bipolar region still remains in the southern hemisphere. The relative polarity of the bipolar regions in the northern hemisphere shows them to be of the current cycle.

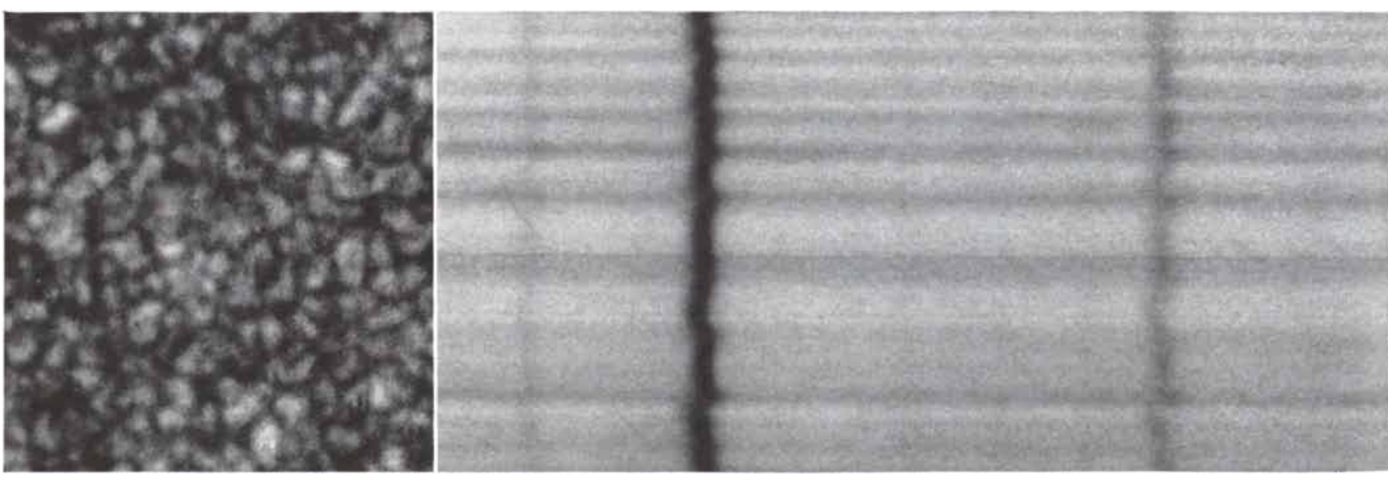
sets the stage for successive solar cycles.

Recent studies at Mount Wilson by Robert Howard and the Czechoslovakian astronomer V. Bumba support the Babcock-Leighton view by providing some details of the gradual weakening and breaking up of the bipolar regions. Examining magnetic records from over a period of years, Howard and Bumba noted what happens when two randomly moving fields approach each other. Contrary to expectation, two fields of opposite polarity seem to repel each other; fields of the same polarity seem to coalesce, adding their strengths. What probably actually happens is that convection, random walk and differential rotation mix the converging fields thoroughly. In the case of fields of opposite polarity the structure becomes so fine that to the magnetograph, with its finite resolution, the net field is zero and the "empty" region simulates repulsion. Fields of the same polarity, on the other hand, cause the magnetograph to register a definite intensity over the area it resolves. The background fields that cover most of the sun with a random magnetic pattern can thus be considered the ground-up remnants of bipolar magnetic regions—the debris of past stages in the solar cycle.

Let us turn back to the November 5 map [*page 55*] and see how it conforms with the theoretical picture [*see illustration at left*]. Random, ground-up fields cover most of the surface. The three bipolar regions in the northern hemisphere are recognizable as being of the current cycle because of their position high in the hemisphere and their relative polarity with respect to the polar, or parent, field. The single bipolar region in the southern hemisphere, on the other hand, is near the equator; the polarity of its two components is not what one would expect of a region spawned by the current cycle. It is, in fact, a remnant field from the last cycle, when the polarity of the polar fields was the opposite of what it is now.

This past April 29 we made another magnetic map of the sun that showed a later stage in the solar cycle [*see illustration on page 57*]. Although the southern hemisphere was still characteristic of the quiet sun, the northern hemisphere had developed a number of more active magnetic regions, some of which appeared as sunspots on a white-light photograph of the sun.

So far I have discussed magnetic pictures of the sun made through rather coarse "eyes." There are interesting questions that call for substantially higher resolving power, close to the limit

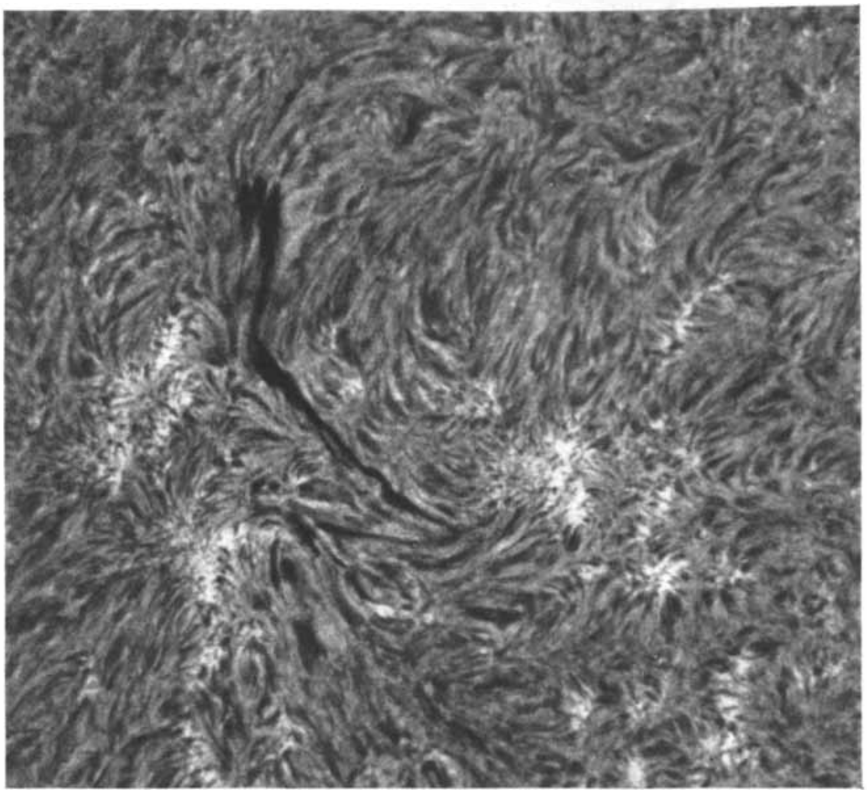


WHITE-LIGHT GRANULATION, shown in a photograph (*left*) made at the Aerospace Corporation observatory in California, consists of rising cells of hot gas separated by dark lanes of descending gas. The spectrograph (*right*), made with the McMath telescope at (about one second of arc) set by the blurring effect of the earth's atmosphere. One question is whether or not the quiet sun is covered by minute but very strong fields that have not yet been resolved. Beyond this there is the broader question of the relation of magnetic fields and the white-light granulation.

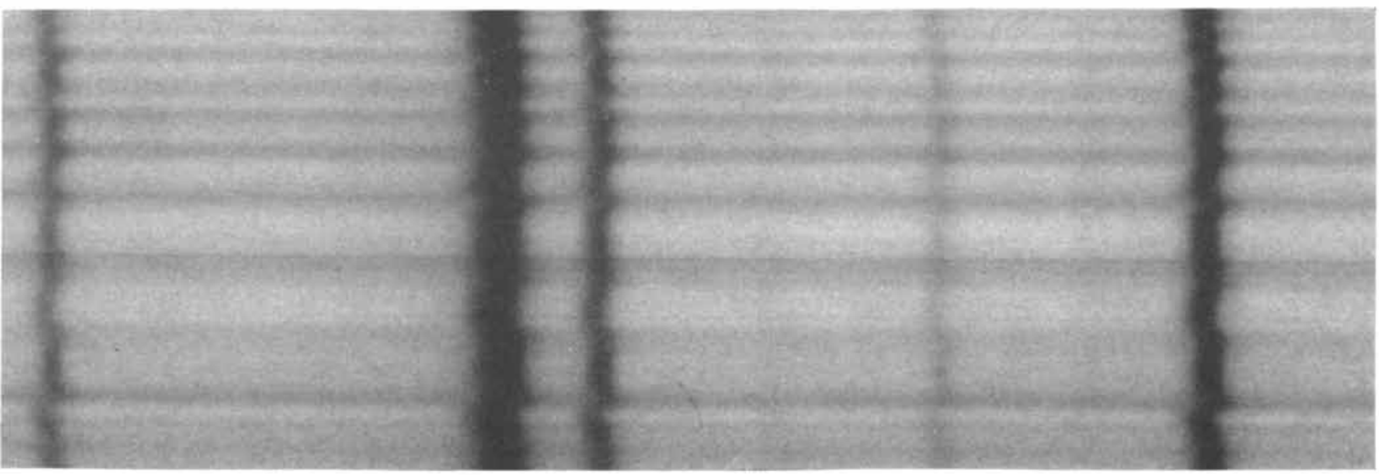
The Swedish physicist Hannes Alfvén has often questioned the validity of magnetograph results because each measurement necessarily averages the field over a large area. The 10-second aperture, for example, encompasses perhaps a dozen granulation cells. If field lines are twisted and distorted by turbulent gas motions in the granules, the overall field might seem to be weak or nonexistent even if small peak fields of hundreds of gauss are present in individual granules. If this is the case, high-resolution measurements should detect higher peak fields.

Solar granulation is difficult to observe by any means. It can be photographed from the ground only with a near-perfect telescope and under the best "seeing" conditions—when the atmosphere of the earth is exceptionally steady. The clearest photographs of granulation available were made with a balloon-borne telescope at an altitude of 80,000 feet [see "Balloon Astronomy," by Martin and Barbara Schwarzschild; SCIENTIFIC AMERICAN, May, 1959]. Since then ground-based astronomers have made pictures almost as good [*see photograph at left in illustration at bottom of these two pages*].

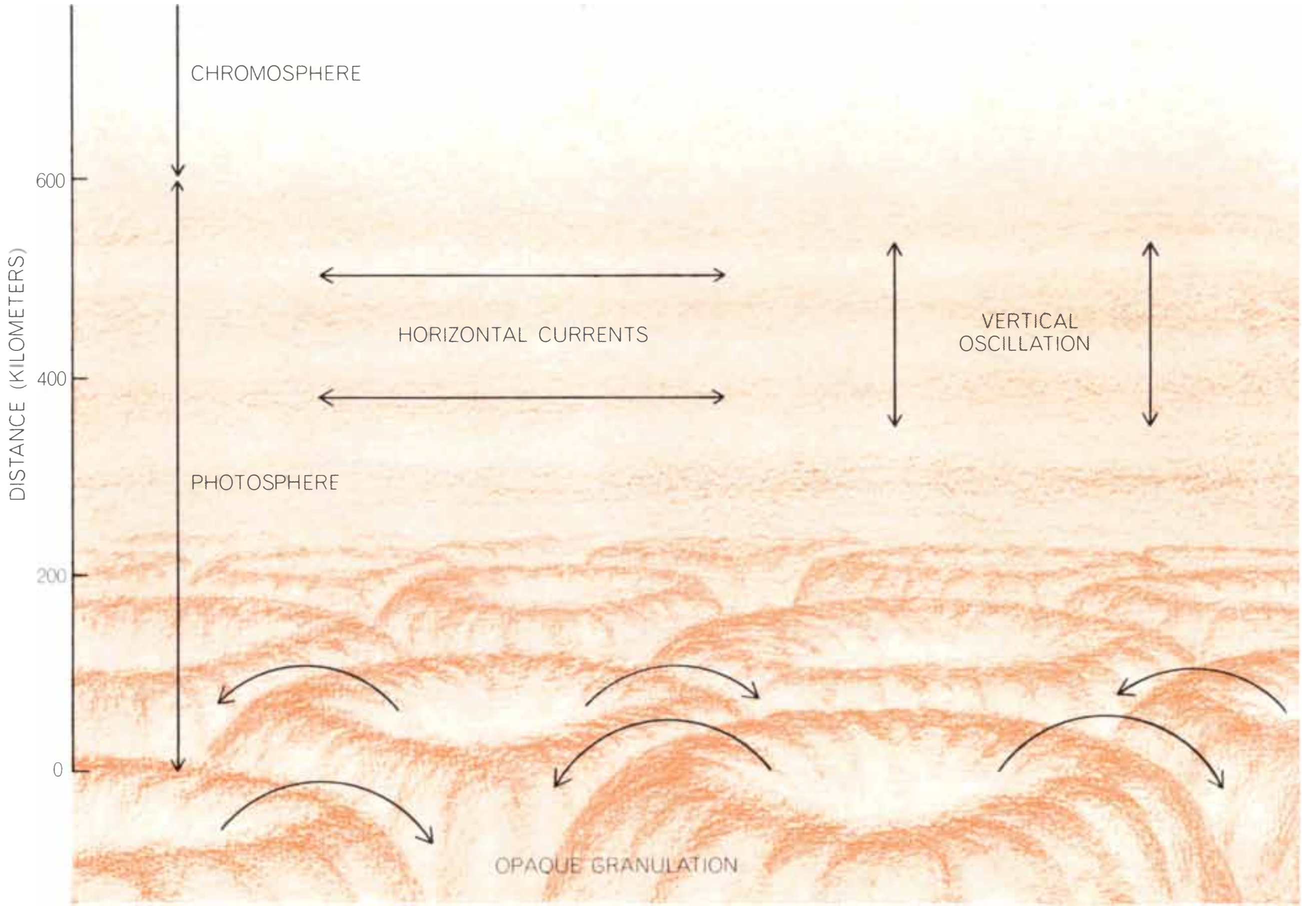
It has been assumed that the bright polygonal shapes seen in granulation pictures are convection cells of hot gases moving up with respect to the darker intergranule lanes. This is confirmed by spectroscopic studies. When the granulation image is focused on the slit of a spectrograph, the absorption lines are seen to take on a wavy appearance [*see photograph at right in illustration at bottom of these two pages*]; there is a Doppler shift to the right (to a longer wavelength) that coincides with the intergranule regions, where cooler gases are presumably moving downward. The spectral lines originate in the photosphere, above the granulation. It appears that there is an "overshoot" from the granulation cells up into the more tenuous photosphere. In addition to this motion, which is suggestive of systematic convective currents, time studies show that the solar atmosphere is oscillating vertically with a well-defined period of about five minutes; gravity waves and sound waves driven by disturbances moving vertically out



CHROMOSPHERE, the atmospheric layer above the photosphere, or luminous surface of the sun, is sharply resolved in this "filtergram" made in the red hydrogen-alpha spectral line at the Lockheed Solar Observatory in California. The orientation of the fibrils of gas suggests that the sun's magnetic fields exert influence on this layer of its atmosphere.



Kitt Peak, shows the "overshoot" effect that granulation has on the photosphere. The dark horizontal streaks are from the lanes of descending gas. At each streak the vertical absorption lines shift to the right, showing that the absorbing atoms are moving down.



PHOTOSPHERE, **the layer in which absorption lines used in magnetic measurements originate, is the scene of converging motions, among them overshoot from granulation cells (*curved arrows*), vertical oscillation and the horizontal flow of supergranulation.**

of the granules have been suggested as sources of this oscillation. When one adds to these vertical motions the horizontal movement of supergranulation, it is clear that a number of energetic driving forces must converge in the photosphere [*see illustration above*]. We are trying to learn the role of magnetic forces in the dynamics of the situation.

Under good seeing conditions we obtained a high-resolution magnetogram covering a small area at the center of the solar disk. The aperture of the spectrograph was a square 1.8 seconds of arc on a side [*see photograph at left in top illustration on page 56*]. Although this aperture is some 30 times smaller than the one used for the full-disk record of 1964, the field intensities are in the same range as those recorded with the coarse scan. Therefore, in reply to Alfvén's question, if there are localized strong fields their size must be much less than a second of arc. Moreover, the fields depicted by the high-resolution magnetogram do not resemble a granulation pattern. Although it is tempting to conclude that the granulation has no specific magnetic character, it may be that the resolution is still inadequate; it is always difficult to judge the full effect of telescope imperfections and seeing conditions on such observations.

If there is a relation between magnetic field and granulation, it should be reflected in the pattern of vertical velocities in the area covered by the magnetogram. Along with the high-resolution magnetic data we recorded the Doppler shift of the absorption lines [*see photograph at right in top illustration on page 56*]. There seems to be little correlation between velocity and magnetic fields except that maximum field strength tends to occur along lines of minimum velocity [*see bottom illustration on page 56*]. Why this should be so is not understood. Improvements in technique may yet establish a direct tie between the white-light granulation and magnetic fields.

One other problem of solar physics on which magnetic studies should provide evidence is the origin and mechanism of solar flares, the sudden bright flashes in the sun's upper atmosphere, usually above sunspots, that emit radiation and particles that disturb the earth's ionosphere and also cause geomagnetic storms. During the last solar maximum, between 1957 and 1961, A. B. Severny of the Crimean Astrophysical Observatory in the U.S.S.R. found that flares occur in regions where there is a steep gradient in the magnetic field, and that the stronger the gradient, the greater the flare's terrestrial effects.

Flares are difficult to observe because they begin abruptly and without warning. With the passing of solar minimum a number of observatories are getting ready to follow magnetic developments on the sun closely, with the emphasis on preparing high-resolution maps of areas likely to produce flares. The knowledge that has been gained about the magnetic structure of the quiet sun should provide the necessary foundation for this work. Whereas during the last approach to maximum activity on the sun only two observatories were equipped for magnetic measurements, now worldwide observations are to be made at more than a dozen installations. The next decade should see important advances in the observation and interpretation of solar magnetic fields.

Hardly worth mentioning

Osmium has many distinctions. Long considered the heaviest substance known, it has had a metallurgical career in which it has written billions of words on the tips of pens and has done duty in lamp filaments and in standards of weight and measure. OsO_4, its most prominent compound, surprises by being quite volatile and smelling bad, a fact which gave the element its name. Through this highly toxic compound, osmium has had a second and perhaps more important role as a stain and hardening agent in microscopy. The light microscopists had familiarized themselves with OsO_4 so that it was ready for the electron microscopists, who need it worse for its electron-stopping power.

Now (*Biochemistry*, 5:2283) there is news about it that ties it into the fashionable subject of genetic code-reading and the possibility of doing so by the electron microscope. OsO_4, which reacts with denatured DNA but not with double-stranded DNA, can differentiate between nucleotides. It attacks desoxythymidine quantitatively. Investigating this reaction, the authors turned to thin-layer chromatography on flexible, scissorable EASTMAN CHROMAGRAM Sheet. What pleases us is that they don't say why they chose to do their TLC on our product. Obviously they did not consider the point pertinent but only a matter of laboratory efficiency, as compared with coating one's own plates uniformly by hand.*

We observe this more and more, as at a mycological meeting where neither of two independent investigators of fungal pigments saw any point in mentioning until asked that they were doing their separations on CHROMAGRAM Sheet.

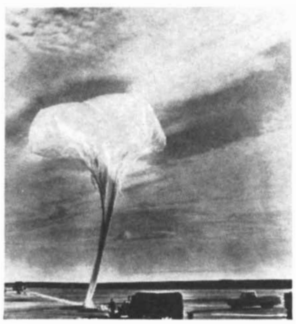
Whether for reaction-following or analytical separations, twenty 8″ x 8″ sheets of EASTMAN CHROMAGRAM *Sheet (silica gel or alumina, please specify) for $17.60 and the* EASTMAN CHROMAGRAM *Developing Apparatus for $35.50 can be ordered (f.o.b. Rochester, N. Y.) from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). Or ask one of the lab supply houses that stocks* EASTMAN *Organic Chemicals.*

* They do mention both ultraviolet and visible-light photography of their chromatograms. This subject draws us many questions, most of which we have tried to answer in Data Release No. M-23, available free from Eastman Kodak Company, Special Applications, Rochester, N. Y. 14650.

Prices subject to change without notice.

Higher than a kite, cheaper than a satellite

We smile at the number of tons of a certain polyolefin formulation which Winzen Research, Inc. of Minneapolis has just ordered from us. The size of the order, considered in relation to the frequency of UFO reports and the unit weight and nature of Winzen's products (*one of which is seen here being launched from Fort Churchill in Canada with a 292-pound payload for a university physics department*), may make others smile, too.



Physicists, geophysicists, environmental scientists—Winzen's customers all—enjoy their objectivity as buyers even more than do the squeezers of bread offered on food market shelves in extruded polyolefin also. It is not necessarily the same formulation, however. Winzen and we have invested considerable effort together to find a formulation which, when extruded ½-mil thick by Winzen's own processes, can withstand such solar UV and cracking cold at 148,000 feet as need never worry bakers. The effort has succeeded.

If a little altitude can gain you desired access to the cheap fluxes of space, talk to Winzen at 401 West 84th Street, Minneapolis, Minn. 55420. Material bearing their trademark "Strato-Film" bears our trademark "Tenite" before Winzen works it over. If it's advice you need on specialized plastic formulations for purposes other than altitude, write Eastman Chemical Products, Inc., Plastics Division, Kingsport, Tenn. 37662 (Subsidiary of Eastman Kodak Company).

Range with x-rays

Politics may be too important a subject to be left to politicians, but radiography, while also of some importance, had better be left to the radiographers. Except that, busy minding their own business, they might overlook slipping you an item of technological news you might find useful: that the new importance of their craft in reliability control of modern micron-scale circuitry has led us to make them an x-ray film capable of 35× useful enlargement.

If you want some, order it from a dealer in x-ray supplies and equipment as KODAK *Industrial X-ray Film, Type R (Single-Coated).*

Don't write to ask about the resolving power of this film. Radiography is three-dimensional and doesn't lend itself to clear-cut two-dimensional answers. We'll hem and haw and tell you that some electronics people are using this product routinely to check on the integrity of buried wires only .0005″ thick. We'll inform you that this is one-third the thickness of a human hair and conclude by magnanimously brushing aside whatever shyness you may feel about calling on us if we can be of any further service. It's the slowest x-ray film we make and the one to choose for fighting off insomnia from worry about the dreadful possibility of tiny hidden solder balls.

By omitting the parenthetical "(Single-Coated)" on the order, you'll get twice the film speed at the expense of parallax that will restrict magnified viewing. From this point up the scale of speed we go on by factors of roughly two, with consequent trade-off on fineness of grain, continuing to Type M, Type T, Type AA, and Type F, which for direct Pb-screened 200-kv x-rays is 2^5 times as fast as Single-Coated Type R.* Actually Type F is usually amplified in speed by a further factor of 15 to 30 through use of intensifying screens that transduce x-rays to visible light. If you can't accept what this does to fineness of detail, you might prefer to skip the screens and use our rather coarse-grained Type KK, which is of the order of 100 times as fast as the film with which this discussion started. It has fewer fans than any other in our line.

* Some people stack four or five of these types together in a single exposure, saving time and money by extending range.

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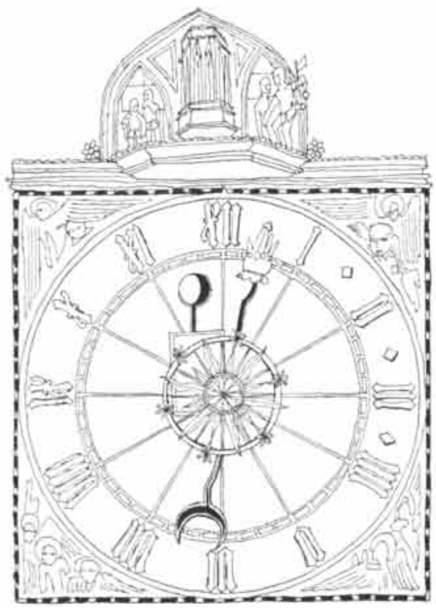
SCIENCE AND



No Bias for the Positive?

The experiment that offered the possibility of determining whether a body anywhere in the universe is composed of matter or antimatter has not passed its first test. An international group of physicists at CERN (the European Organization for Nuclear Research) has repeated the experiment and has not obtained the same result. The original experiment, which had appeared to make it possible to define what physicists know by convention as a positive charge, had been reported in June by workers who examined the decay of neutral eta mesons produced by the 31-billion-electron-volt proton synchrotron at the Brookhaven National Laboratory. Their results were taken as evidence that a basic symmetry of nature—charge-conjugation symmetry—was violated in interactions other than "weak" ones. (The violation of charge-conjugation symmetry in weak interactions had been established some 10 years ago.) They found that when the neutral eta meson decays into three pions—one positive, one negative and one neutral—the positive pion emerges with more energy than its antiparticle (the negative pion) in 7.2 percent of the decays. They computed that the odds were 1,000 to one that this result could have happened by chance.

It now appears that the Brookhaven group may have lost what appeared to be almost a sure bet in its gamble with nature. The CERN workers, who analyzed more than seven times as many eta decays as the Brookhaven workers (10,665 to 1,440), could find no difference in the energy of the positive and negative pions. There were slight differences in the design of the two experiments, but there is no reason to believe this could account for the difference in results. The CERN findings were reported in *Physics Letters* by nine investigators, five from CERN (A. M. Cnops, G. Finocchiaro, J. C. Lassalle, P. Mittner and P. Zanella), three from the Federal Institute of Technology in Zurich (J. P. Dufey, B. Gobbi and M. Pouchon) and one (A. Muller) from the Center for Nuclear Studies at Saclay in France.

Against Chemical Warfare

Twenty-two American scientists, seven of them winners of the Nobel prize, have asked President Johnson that the armed services stop using chemical weapons against crops and people in Vietnam. They have initiated a petition to the President that cites the dangers of chemical and biological weapons and warns that any breach in the restraints on using them—such as is represented by the employment of anticrop sprays and tear gas in Vietnam—encourages the use of other and more devastating weapons. Their letter is now being circulated to members of the Federation of American Scientists for their signature.

The initial signers issued a statement pointing out that "chemical and biological weapons could be far more dangerous as instruments of mass extermination than anything except nuclear weapons." They suggest that this country already recognizes that the explosion of even a nuclear artillery shell could lead to a nuclear war, and that the use of even a mild chemical or biological weapon involves a similar danger. The letter observes that in World War II the nation held to a policy of never initiating chemical or biological warfare, that this position has not been reiterated lately, and that now "the large-scale use of anticrop and 'nonlethal' antipersonnel chemical weapons in Vietnam . . . sets a dangerous precedent." The petition asks for a White House study of national policy on chemical and biological weapons and their control, an end to their use in Vietnam and a statement that this country will not be the first to use them.

The 22 scientists are Felix Bloch of

Stanford University, Konrad E. Bloch of Harvard University, James F. Crow of the University of Wisconsin, William V. E. Doering of Yale University, Paul Doty of Harvard, Freeman J. Dyson of the Institute for Advanced Study, John T. Edsall of Harvard, Bernard T. Feld of the Massachusetts Institute of Technology, Irwin C. Gunsalus of the University of Illinois, Robert Hofstadter of Stanford, Arthur Kornberg of the Stanford University School of Medicine, Fritz Lipmann of Rockefeller University, Robert B. Livingston of the School of Medicine of the University of California at San Diego, Matthew Meselson of Harvard, Severo Ochoa of the New York University School of Medicine, Ray D. Owen of the California Institute of Technology, Keith R. Porter of Harvard, Charles C. Price of the University of Pennsylvania, Eugene Rabinowitch of Illinois, E. L. Tatum of Rockefeller University, George Wald of Harvard and Paul Dudley White, Boston cardiologist.

Laboratory Animal Law

Congress has passed and the President has signed a law regulating the procurement and handling of laboratory animals. A number of bills designed to limit and control animal experimentation had been before Congress, where they were vigorously opposed by the National Society for Medical Research. The society was also concerned about other bills, intended to make "pet-stealing" a Federal offense, that might have interfered with legal arrangements under which animals in public pounds can be released to research institutions instead of being put to death.

The bill finally enacted into law as the result of a series of House-Senate conferences seeks to control pet-stealing without affecting public pounds and sets standards for the care of laboratory animals except during the course of an experiment. Private dealers in dogs and cats must be licensed by the Department of Agriculture, may not sell a dog or cat until five days after it has been acquired and must permit inspection by law-enforcement agencies searching for lost animals. Institutions that use dogs or cats in research must register with the Department of Agriculture. (This language limits the law's coverage to major research facilities.) The Secretary of Agriculture is to set standards for the "humane handling, care, treatment and transportation" of laboratory animals (including monkeys, guinea pigs, hamsters and rabbits as well as dogs and cats) that must be followed by all dealers and research facilities covered. Perhaps the most important provision of the law is one that specifically exempts from these standards the handling of animals "during actual research or experimentation by a research facility as determined by such research facility."

Exploration by Satellite

Project Eros, a plan to use satellites to gather a wide variety of data about the earth's natural resources, has been announced by the Department of the Interior. The name is an acronym for Earth Resources Observation Satellites and has no connection with the Greek god of procreation, although a somewhat remote analogy could be drawn from a statement of the project's purpose by William T. Pecora, director of the U.S. Geological Survey. He said the purpose is to ensure an abundant supply of the resources needed to support an industrialized society. "There is good reason to believe," Pecora said, "that the world's undeveloped resources are large enough to support a growing demand far into the future—provided, however, we aggressively and imaginatively press the search for knowledge of our resources."

The satellites, traveling in polar orbit, will carry cameras and various sensing instruments such as infrared and ultraviolet scanners, magnetometers and gravity-gradient devices. In addition to helping to locate resources, the satellites might assist mapmaking, keep track of water resources, predict volcanic eruptions (by "taking the volcano's temperature to see if it is running a fever"), detect tremors that could lead to earthquakes and check on the spread of disease in forests and crops. Pecora outlined some other work the satellites might do: "It may be entirely possible, for example, to determine rates of reservoir sedimentation, measure the movement of glaciers, measure the effluents of major rivers, monitor the levels of lakes and reservoirs and the growth of deltas and assess both air and water pollution. Photographic techniques already available should make it possible to construct maps showing land use and vegetation. Use of other remote sensors should yield measurements of ground-surface temperature and ground-moisture content useful in a variety of engineering and agricultural problems. Even population counts and measurements of daily fluctuations in the traffic flow of both people and vehicles seem to be within the capability of remote-sensing techniques."

The Electric Automobile (Cont.)

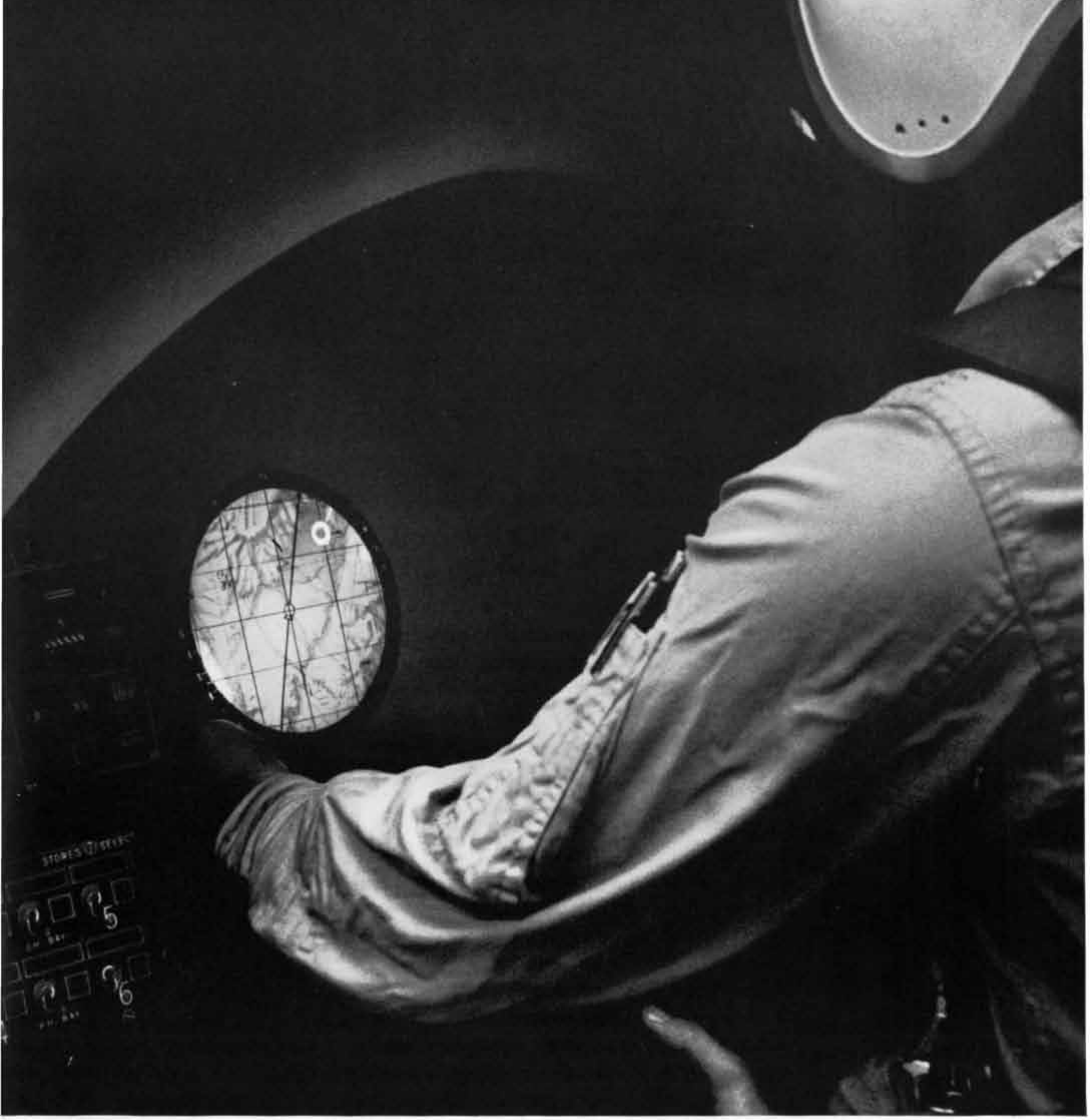
Two recent developments indicate a quickening of the technology that could lead to a modern electric automobile (see "The Electric Automobile," by George A. Hoffman; SCIENTIFIC AMERICAN, October). The Ford Motor Company announced a sodium-sulfur battery that it described as "an entirely new concept in electric-battery development." The General Atomic Division of the General Dynamics Corporation announced that 14 electric-utility companies have joined it and the Edison Electric Institute in developing a zinc-air battery. Both batteries would have a considerably higher performance than the lead-acid batteries now used to provide auxiliary power.

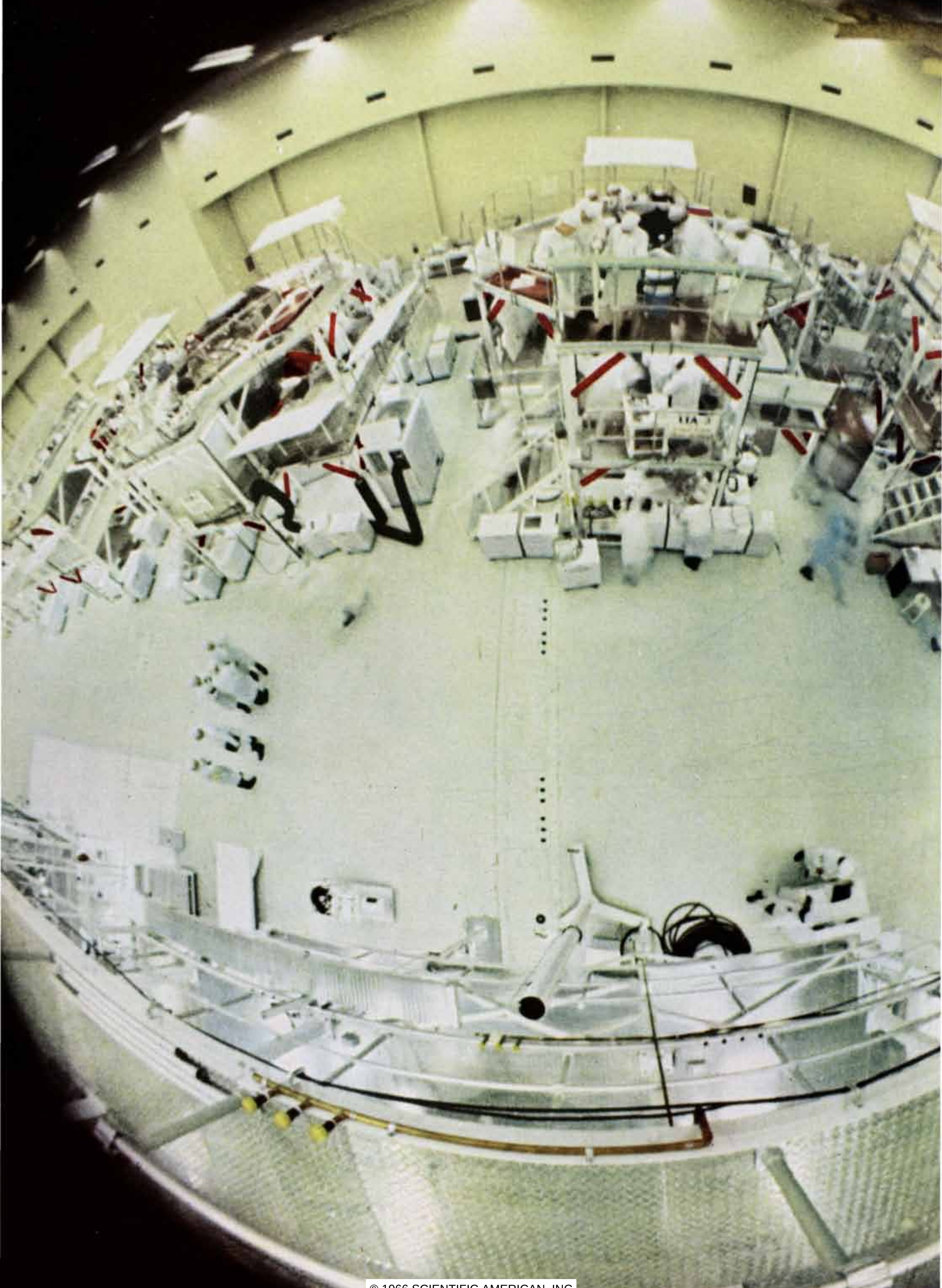
Ford's battery was described by Michael Ference, Jr., the company's vice-president for scientific research. He said the key to the battery is "a crystalline ceramic composed largely of aluminum oxide" that "selectively passes sodium ions while containing all other liquids." In the battery sodium atoms give up electrons to an external circuit, traverse the ceramic as ions and combine with sulfur. The system would be rechargeable. Ference said the battery is still in an early stage of development. At present the temperature required for its operation is between 250 and 300 degrees centigrade (about 480 to 570 degrees Fahrenheit). He also disclosed that Ford is working on motors and controls for electric cars and plans to test next year a prototype model of a "subcompact, limited-performance 'City-Car' " using conventional batteries.

General Atomic has been working on a zinc-air battery since 1960. The company said two experimental prototypes have recently been operated successfully in its laboratories. The battery produces electricity by oxidizing zinc to zinc oxide.

Rising Illiteracy

The continuing rise in world population has caused an alarming reversal of past trends favoring increased world literacy. Analyzing recent United Nations statistics that show a growth



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LASL Photograph by William H. Regan

A View of The Woods

On their frequent walks to work, Lenore and Bob Leachman pass through these woods — less than a block from the Administration Building where Lenore serves as a secretary. Dr. Leachman, an experimental physicist, walks on to the nearby Physics building where he is studying interference effects in nuclear reactions. A variety of particle accelerators are but part of the advanced equipment in use at Los Alamos, one of the great laboratories of the world.

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of 200 million in the world's population of illiterates during the past six years, the Population Reference Bureau points out that the six-year total is probably an optimistic underestimate. Half of the adult population of Africa, Latin America and non-Communist Asia, a total of almost 750 million, have received no schooling at all, and only 30 percent of these nations' 373 million school-age children are now in schools of any kind.

The Population Reference Bureau, a privately supported organization concerned with demographic forecasting, characterizes the developing countries' low per capita income, malnutrition and illiteracy as a "three-way feedback" problem. The single nation with the largest problem is India, where only 55 million out of 187 million school-age children, or less than 30 percent, go to school, and the government's expenditure per pupil per year is no more than 32 cents. In contrast, Federal, state and local government support of education in the U.S. totals some $600 per pupil per year, a figure that does not include the $11.5 billion spent by private schools and colleges.

In Latin America, although the school situation is more favorable than in Asia or Africa, dropouts increase with each grade. Among those who go to school in Brazil, for example, the average number of school years completed is 2.6, and only 10 percent of all pupils reach eighth grade. Considering the likelihood that at least a minimum of education is a prerequisite for population control, the bureau finds it significant that nearly 85 percent of the births today occur in the nations in which 70 percent of the school-age children have no schools to attend.

Direct-Current Transformer

A device that operates as a transformer of direct current has been constructed with thin films of superconductors. Historically alternating current won out over direct current in the early days of electric-power distribution because alternating current could readily be raised and lowered in voltage by means of transformers, whereas direct current could not. The new device, invented by Ivar Giaever of the General Electric Research Laboratory and described by him in the journal *Spectrum*, operates in the range of milliamperes and millivolts and therefore does not promise to revolutionize electric-power distribution.

The d.c. transformer is made by depositing a thin layer of tin a few thousand angstrom units thick on a glass slide. This serves as the primary "coil" of the transformer. A layer of tin oxide only 100 to 200 angstroms thick is deposited over the primary to insulate it. On top of this layer another tin layer slightly narrower than the first and much thinner—500 to 1,000 angstroms thick—is deposited to act as a secondary. When the device is cooled to within about 3.6 degrees centigrade of absolute zero, so that both metal films are superconducting, a current passed through the primary layer gives rise to a voltage in the secondary layer. If two secondary layers are connected in series, in imitation of a conventional transformer, the d.c. voltage is transformed. Giaever foresees that the device may find its way into electronic devices where liquid-helium temperatures are already needed for other purposes.

Scientists as Astronauts

The National Aeronautics and Space Administration is looking for scientists who want to be astronauts. In behalf of NASA the National Academy of Sciences has issued a call for experienced investigators of exceptional ability "to conduct scientific experiments in manned orbiting satellites and to observe and investigate the lunar surface and circumterrestrial space." Applicants must be U.S. citizens born after August 1, 1930, must be no taller than six feet and must have a doctorate in a natural science, medicine or engineering. Applications must be submitted to the National Academy by January 8, 1967. An academy panel will pass on the scientific qualifications of applicants who meet preliminary requirements, and NASA will then make the final selection on the basis of physical examinations and ability to function under simulated space conditions. In 1965 the academy helped to select the first group of five scientist-astronauts: three physicists, a geologist and a physician.

The Kindly Killer Whale

The killer whale (*Orcinus orca*), a species held almost in awe because of the ferocity with which it preys on whales many times its size, has recently surprised investigators by its docile behavior in captivity. Until 1964 the animal had never been observed under these circumstances. Since then three killer whales have been kept captive on the U.S. and Canadian West Coast for periods ranging from three months to

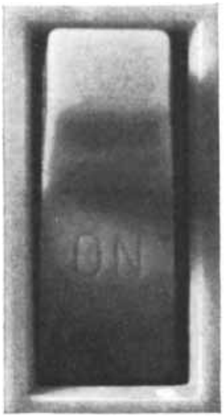
more than a year. The captive most intensively studied was a young male killer whale harpooned off British Columbia in July, 1964, by collectors for the Vancouver Public Aquarium. The animal was moved to a pen in Vancouver harbor, where it lived for 86 days.

Murray A. Newman of the aquarium and Patrick L. McGeer of the University of British Columbia report in *Zoologica* that the 15-foot, one-ton whale swam continuously in circles in its pen during its first eight weeks of captivity and refused to eat any of its captors' offerings of whale meat, fish, seals (live and dead), octopus, horse hearts and poultry. During the last four weeks the whale began to eat, consuming from 100 to 200 pounds of fish a day; it soon took most of its food from the hand of an attendant, who could summon the animal by slapping the surface of the water with a fish. The whale accepted its food slowly and deliberately; it used its formidable teeth for grasping fish but swallowed them whole rather than chewing them.

William E. Schevill and William A. Watkins of the Woods Hole Oceanographic Institution went to Vancouver and recorded the sounds made by the animal. They have now compared them with the sounds of free killer whales and of free and captive porpoises. They find that the two sounds characteristic of the porpoise—a broad-band, high-frequency click and a whistle-like squeal—are matched in the killer whale by a narrow-band, low-frequency click, which the whale often repeats at an increasing rate until it becomes a strident underwater scream that can be heard plainly by an observer on land. The killer whale used the click as "sonar" to range on obstacles when visibility was poor. The scream, however, appears to have been an attempt to communicate; it was usually stimulated by some disturbance outside the pen, such as the sound of a passing boat.

In October, 1964, after taking three fish from its attendant, the Vancouver captive exhaled while partly submerged, sank out of sight and drowned. Another male killer whale, captured in Canadian waters in June, 1965, survived on exhibit in Seattle until July of this year, when it too drowned. During its captivity the Seattle specimen showed no hostility toward swimmers who entered its tank. The third killer whale, a small female captured in Puget Sound in November, 1965, is still alive and giving piggyback rides to its keepers in San Diego.

The Rover 2000 TC's
first purpose
is to be safe?



For the same reason that a light switch, first of all, shouldn't electrocute you.

NOT to be too stuffy about it, the Rover 2000 TC Sports Sedan is generally acknowledged to be among that elite of the world's best performing cars. It is also quite likely the safest.

The two go hand-in-hand, apparently: surely safety is part of performance. What good is a car that goes the limit if it can't stop within it? And if everything else goes wrong—including driver errors*—isn't it still the car's job to protect you? We do think so.

To this end the Rover 2000 TC has two sorts of safety.

1) **So nothing will happen.** For example: the 2000 TC has disc brakes all around so it can stop as fast as it goes; radial ply tires to hold the road and a revolutionary suspension and control system to give it *immediacy*.

2) **So if something does happen it won't happen to you.** To begin with, the 2000 TC has two separate bodies. The outer you see below. The inner is of steel-cage construction to protect you even should the car roll. (Please fasten your safety harness, though.)

It follows that the 2000 TC already *has* most of the sweeping safety features that the U.S. Government demands by 1968. One notable exception: a "standard bumper height." One can't very well be standard all alone. We will be happy to cooperate on this or any other industry effort. The safer other cars are the safer ours will be.

Now you know about safety. Buy a Rover 2000 TC and stop worrying about it.

***In the recent furore over safety standards some spokesmen have pointed out that most accidents are caused by driver error. So? Is that an offense punishable by hurt or worse? And what of the innocents who aren't driving?**

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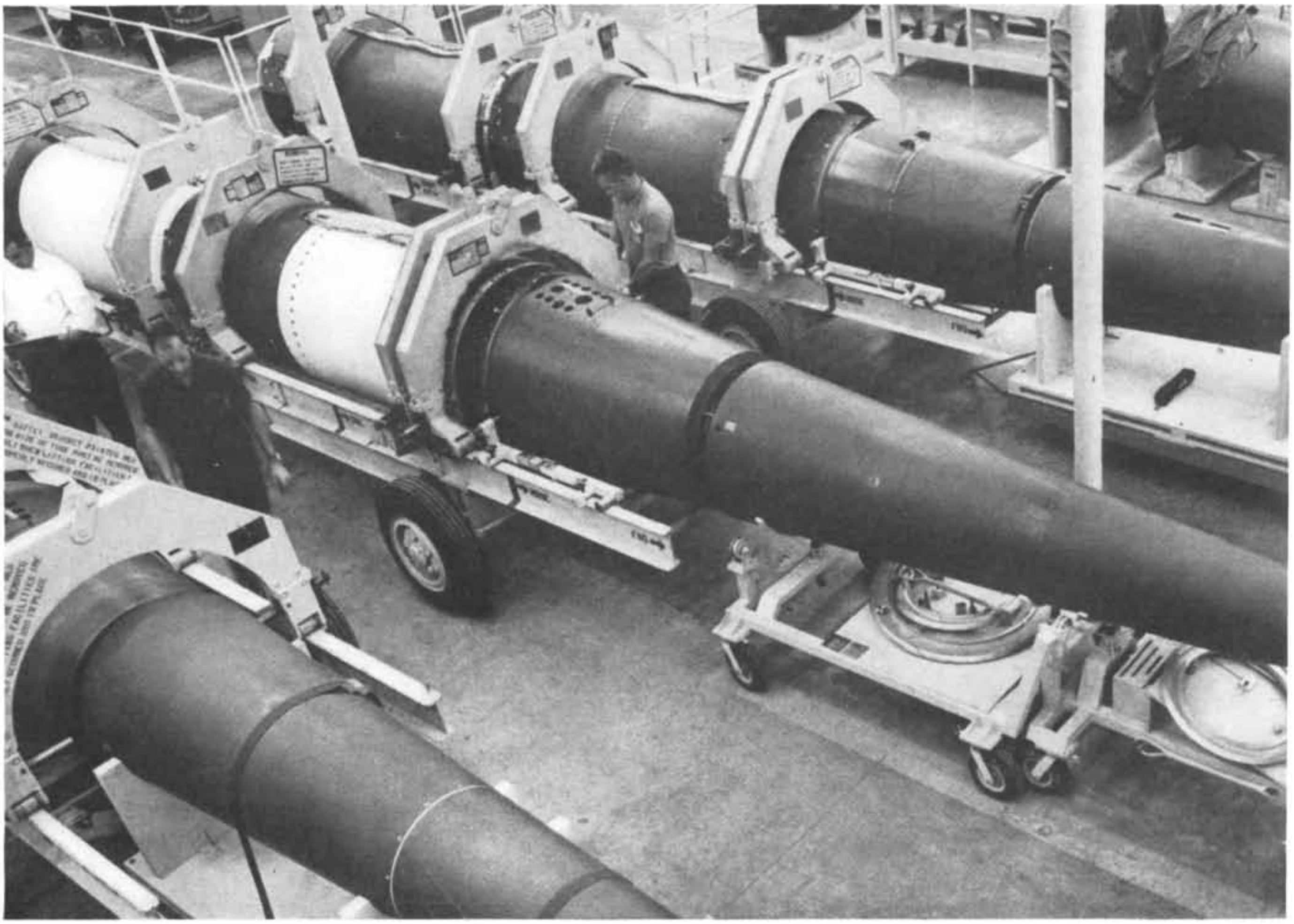
The nimble Pershing: we don't leave well enough alone.



The Three-dimensional Structure of an Enzyme Molecule

The arrangement of atoms in an enzyme molecule has been worked out for the first time. The enzyme is lysozyme, which breaks open cells of bacteria. The study has also shown how lysozyme performs its task

by David C. Phillips

One day in 1922 Alexander Fleming was suffering from a cold. This is not unusual in London, but Fleming was a most unusual man and he took advantage of the cold in a characteristic way. He allowed a few drops of his nasal mucus to fall on a culture of bacteria he was working with and then put the plate to one side to see what would happen. Imagine his excitement when he discovered some time later that the bacteria near the mucus had dissolved away. For a while he thought his ambition of finding a universal antibiotic had been realized. In a burst of activity he quickly established that the antibacterial action of the mucus was due to the presence in it of an enzyme; he called this substance lysozyme because of its capacity to lyse, or dissolve, the bacterial cells. Lysozyme was soon discovered in many tissues and secretions of the human body, in plants and most plentifully of all in the white of egg. Unfortunately Fleming found that it is not effective against the most harmful bacteria. He had to wait seven years before a strangely similar experiment revealed the existence of a genuinely effective antibiotic: penicillin.

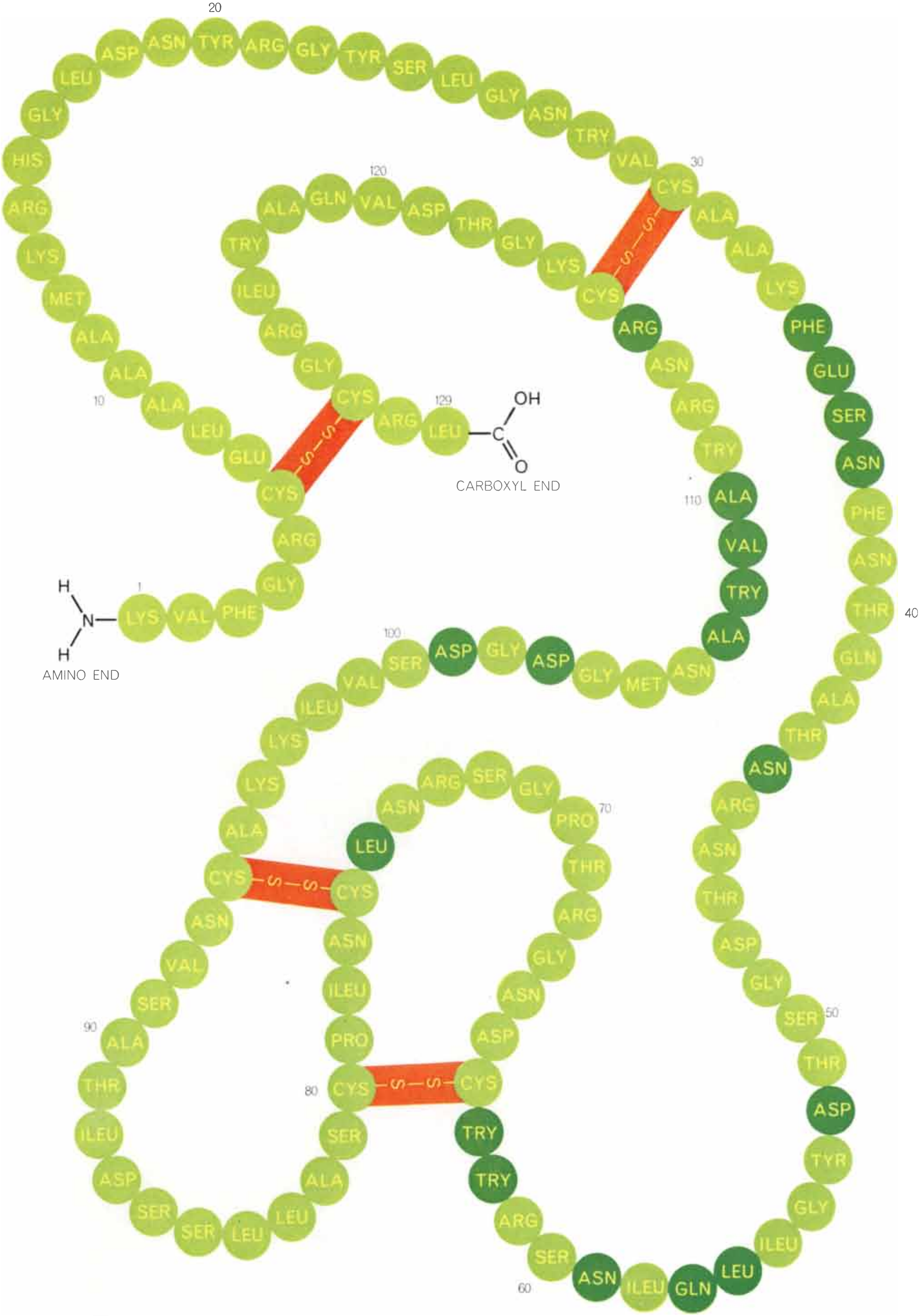
Nevertheless, Fleming's lysozyme has proved a more valuable discovery than he can have expected when its properties were first established. With it, for example, bacterial anatomists have been able to study many details of bacterial structure [see "Fleming's Lysozyme," by Robert F. Acker and S. E. Hartsell; SCIENTIFIC AMERICAN, June, 1960]. It has now turned out that lysozyme is the first enzyme whose three-dimensional structure has been determined and whose properties are understood in atomic detail. Among these properties is the way in which the enzyme combines with the substance on which it acts—a complex sugar in the wall of the bacterial cell.

Like all enzymes, lysozyme is a protein. Its chemical makeup has been established by Pierre Jollès and his colleagues at the University of Paris and by Robert E. Canfield of the Columbia University College of Physicians and Surgeons. They have found that each molecule of lysozyme obtained from egg white consists of a single polypeptide chain of 129 amino acid subunits of 20 different kinds. A peptide bond is formed when two amino acids are joined following the removal of a molecule of water. It is customary to call the portion of the amino acid incorporated into a polypeptide chain a residue, and each residue has its own characteristic side chain. The 129-residue lysozyme molecule is cross-linked in four places by disulfide bridges formed by the combination of sulfur-containing side chains in different parts of the molecule [*see illustration on opposite page*].

The properties of the molecule cannot be understood from its chemical constitution alone; they depend most critically on what parts of the molecule are brought close together in the folded three-dimensional structure. Some form of microscope is needed to examine the structure of the molecule. Fortunately one is effectively provided by the techniques of X-ray crystal-structure analysis pioneered by Sir Lawrence Bragg and his father Sir William Bragg.

ALA	ALANINE	GLY	GLYCINE	PRO	PROLINE
ARG	ARGININE	HIS	HISTIDINE	SER	SERINE
ASN	ASPARAGINE	ILEU	ISOLEUCINE	THR	THREONINE
ASP	ASPARTIC ACID	LEU	LEUCINE	TRY	TRYPTOPHAN
CYS	CYSTEINE	LYS	LYSINE	TYR	TYROSINE
GLU	GLUTAMIC ACID	MET	METHIONINE	VAL	VALINE
GLN	GLUTAMINE	PHE	PHENYLALANINE		

TWO-DIMENSIONAL MODEL of the lysozyme molecule is shown on the opposite page. Lysozyme is a protein containing 129 amino acid subunits, commonly called residues (*see key to abbreviations above*). These residues form a polypeptide chain that is cross-linked at four places by disulfide (–S–S–) bonds. The amino acid sequence of lysozyme was determined independently by Pierre Jollès and his co-workers at the University of Paris and by Robert E. Canfield of the Columbia University College of Physicians and Surgeons. The three-dimensional structure of the lysozyme molecule has now been established with the help of X-ray crystallography by the author and his colleagues at the Royal Institution in London. A painting of the molecule's three-dimensional structure appears on pages 80 and 81. The function of lysozyme is to split a particular long-chain molecule, a complex sugar, found in the outer membrane of many living cells. Molecules that are acted on by enzymes are known as substrates. The substrate of lysozyme fits into a cleft, or pocket, formed by the three-dimensional structure of the lysozyme molecule. In the two-dimensional model on the opposite page the amino acid residues that line the pocket are shown in dark green.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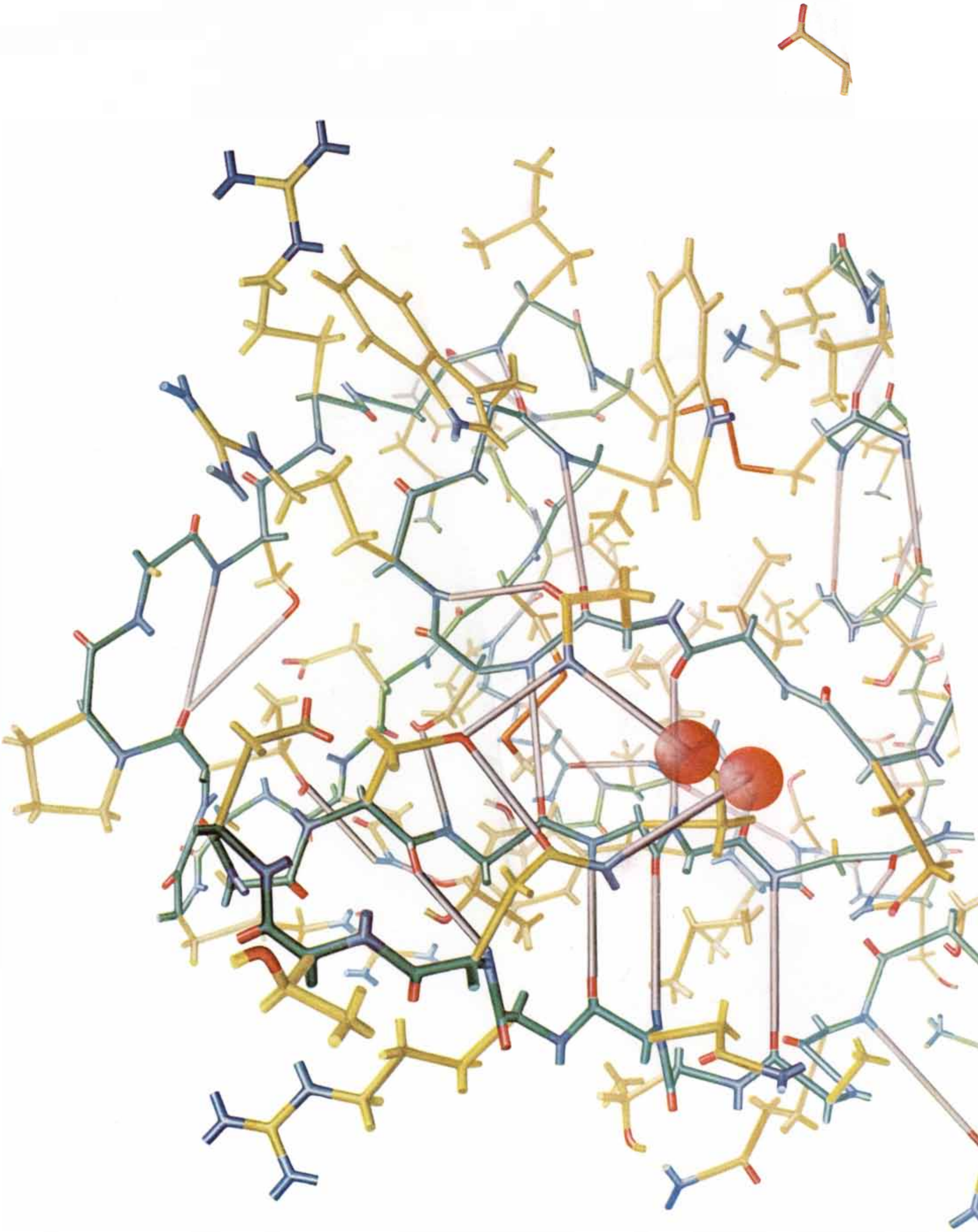
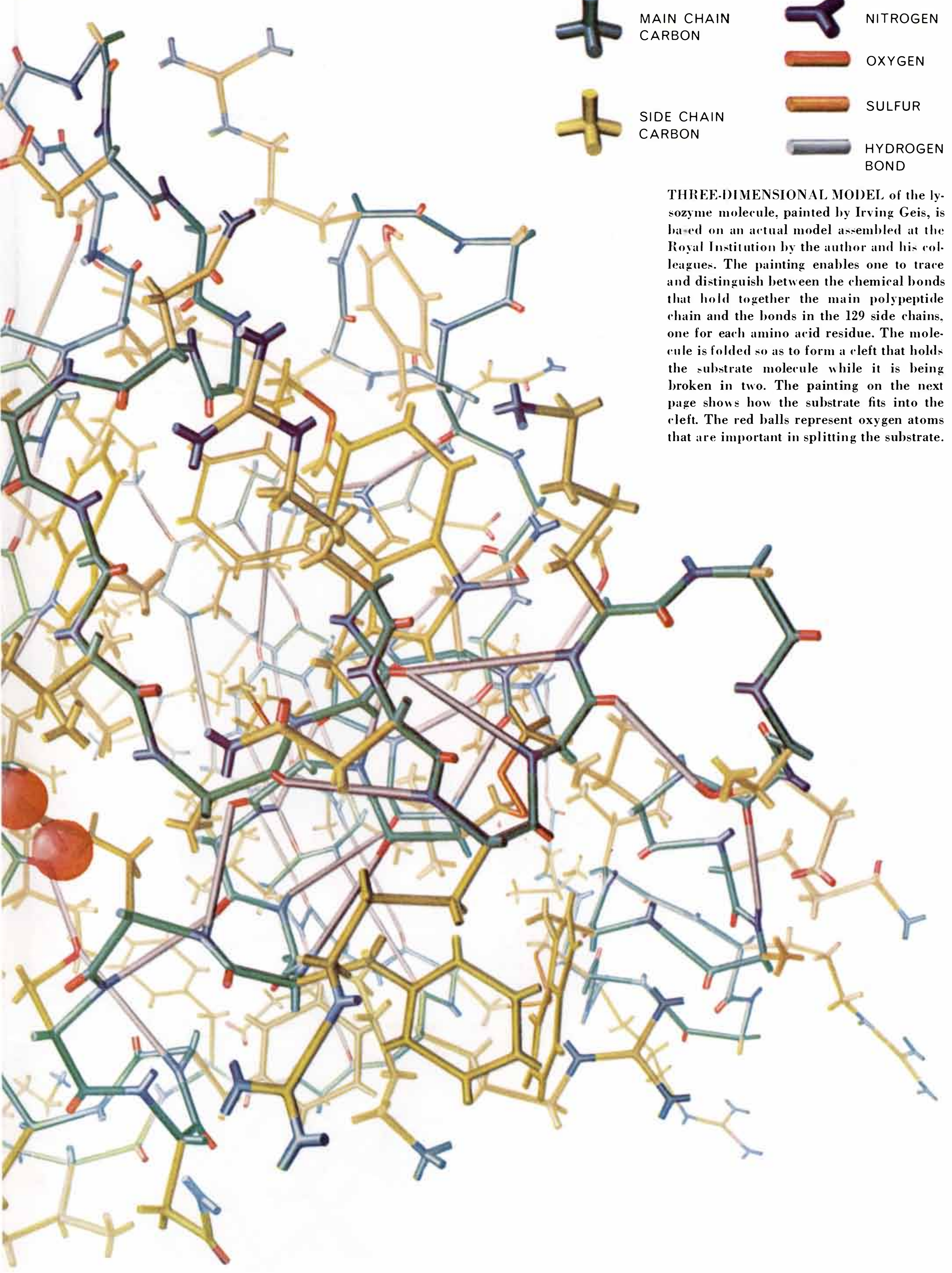
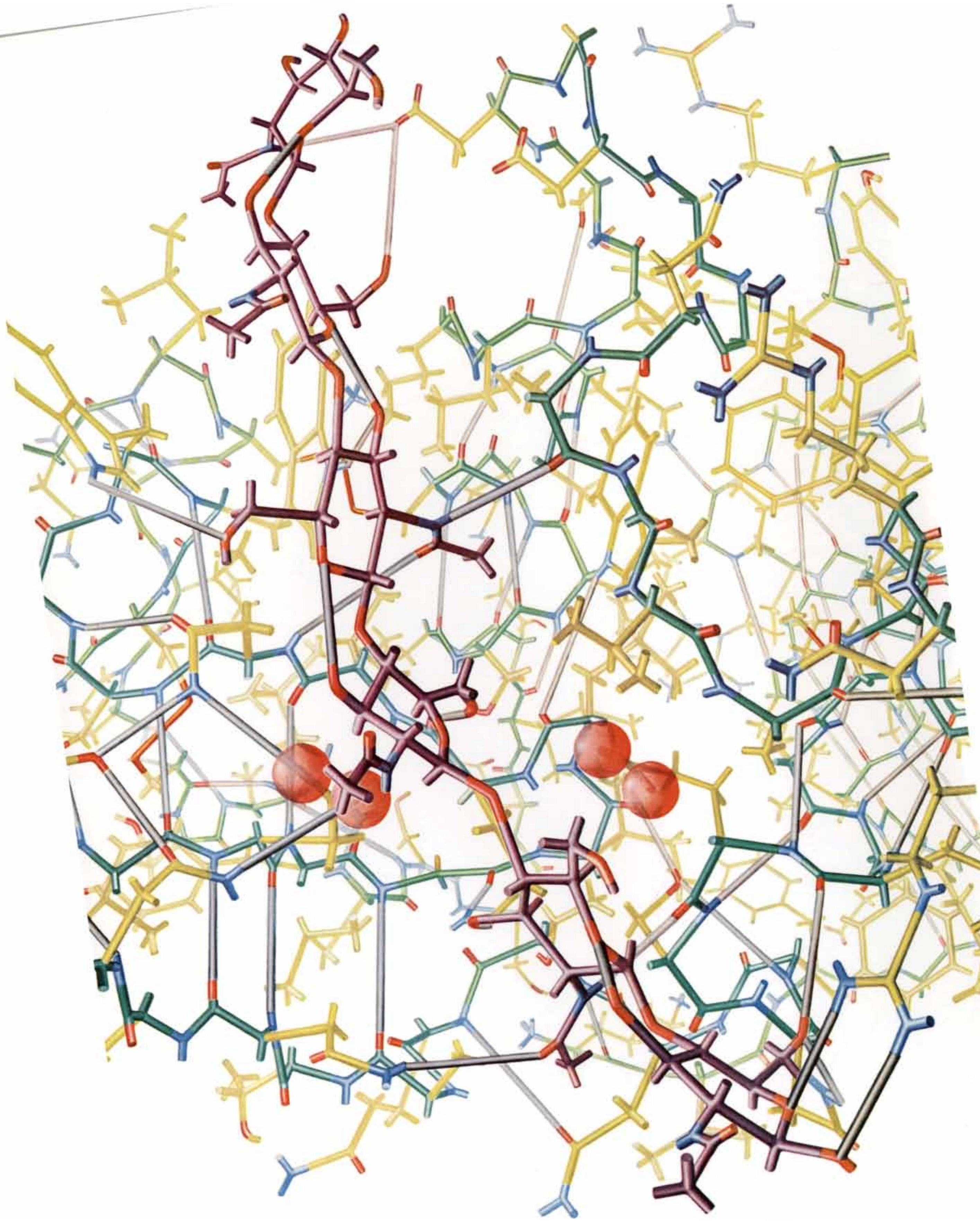




THREE-DIMENSIONAL MODEL of the lysozyme molecule, painted by Irving Geis, is based on an actual model assembled at the Royal Institution by the author and his colleagues. The painting enables one to trace and distinguish between the chemical bonds that hold together the main polypeptide chain and the bonds in the 129 side chains, one for each amino acid residue. The molecule is folded so as to form a cleft that holds the substrate molecule while it is being broken in two. The painting on the next page shows how the substrate fits into the cleft. The red balls represent oxygen atoms that are important in splitting the substrate.



The difficulties of examining molecules in atomic detail arise, of course, from the fact that molecules are very small. Within a molecule each atom is usually separated from its neighbor by about 1.5 angstrom units (1.5×10^{-8} centimeter). The lysozyme molecule, which contains some 1,950 atoms, is about 40 angstroms in its largest dimension. The first problem is to find a microscope in which the atoms can be resolved from one another, or seen separately.

The resolving power of a microscope depends fundamentally on the wavelength of the radiation it employs. In general no two objects can be seen separately if they are closer together than about half this wavelength. The shortest wavelength transmitted by optical microscopes (those working in the ultraviolet end of the spectrum) is about 2,000 times longer than the distance between atoms. In order to "see" atoms one must use radiation with a much shorter wavelength: X rays, which have a wavelength closely comparable to interatomic distances. The employment of X rays, however, creates other difficulties: no satisfactory way has yet been found to make lenses or mirrors that will focus them into an image. The problem, then, is the apparently impossible one of designing an X-ray microscope without lenses or mirrors.

Consideration of the diffraction theory of microscope optics, as developed by Ernst Abbe in the latter part of the 19th century, shows that the problem can be solved. Abbe taught us that the formation of an image in the microscope can be regarded as a two-stage process. First, the object under examination scatters the light or other radiation falling on it in all directions, forming a diffraction pattern. This pattern arises because the light waves scattered from different parts of the object combine so as to produce a wave of large or small amplitude in any direction according to whether the waves are in or out of phase—in or out of step—with one another. (This effect is seen most easily in light waves scattered by a regularly repeating structure, such as a diffraction grating made of lines scribed at regular intervals on a glass plate.) In the second stage of image formation, according to Abbe, the objective lens of the microscope collects the diffracted waves and recombines them to form an image of the object. Most important, the nature of the image depends critically on how much of the diffraction pattern is used in its formation.

X-Ray Structure Analysis

In essence X-ray structure analysis makes use of a microscope in which the two stages of image formation have been separated. Since the X rays cannot be focused to form an image directly, the diffraction pattern is recorded and the image is obtained from it by calculation. Historically the method was not developed on the basis of this reasoning, but this way of regarding it (which was first suggested by Lawrence Bragg) brings out its essential features and also introduces the main difficulty of applying it. In recording the intensities of the diffracted waves, instead of focusing them to form an image, some crucial information is lost, namely the phase relations among the various diffracted waves. Without this information the image cannot be formed, and some means of recovering it has to be found. This is the well-known phase problem of X-ray crystallography. It is on the solution of the problem that the utility of the method depends.

The term "X-ray crystallography" reminds us that in practice the method was developed (and is still applied) in the study of single crystals. Crystals suitable for study may contain some 10^{15} identical molecules in a regular array; in effect the molecules in such a crystal diffract the X radiation as though they were a single giant molecule. The crystal acts as a three-dimensional diffraction grating, so that the waves scattered by them are confined to a number of discrete directions. In order to obtain a three-dimensional image of the structure the intensity of the X rays scattered in these different directions must be measured, the phase problem must be solved somehow and the measurements must be combined by a computer.

The recent successes of this method in the study of protein structures have depended a great deal on the development of electronic computers capable of performing the calculations. They are due most of all, however, to the discovery in 1953, by M. F. Perutz of the Medical Research Council Laboratory of Molecular Biology in Cambridge, that the method of "isomorphous replacement" can be used to solve the phase problem in the study of protein crystals. The method depends on the preparation and study of a series of protein crystals into which additional heavy atoms, such as atoms of uranium, have been introduced without otherwise affecting the crystal structure. The first successes of this method were in the study of sperm-whale myoglobin by John C. Kendrew of the Medical Research Council Laboratory and in Perutz' own study of horse hemoglobin. For their work the two men received the Nobel prize for chemistry in 1962 [see "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew, SCIENTIFIC AMERICAN, December, 1961, and "The Hemoglobin Molecule," by M. F. Perutz, SCIENTIFIC AMERICAN, November, 1964].

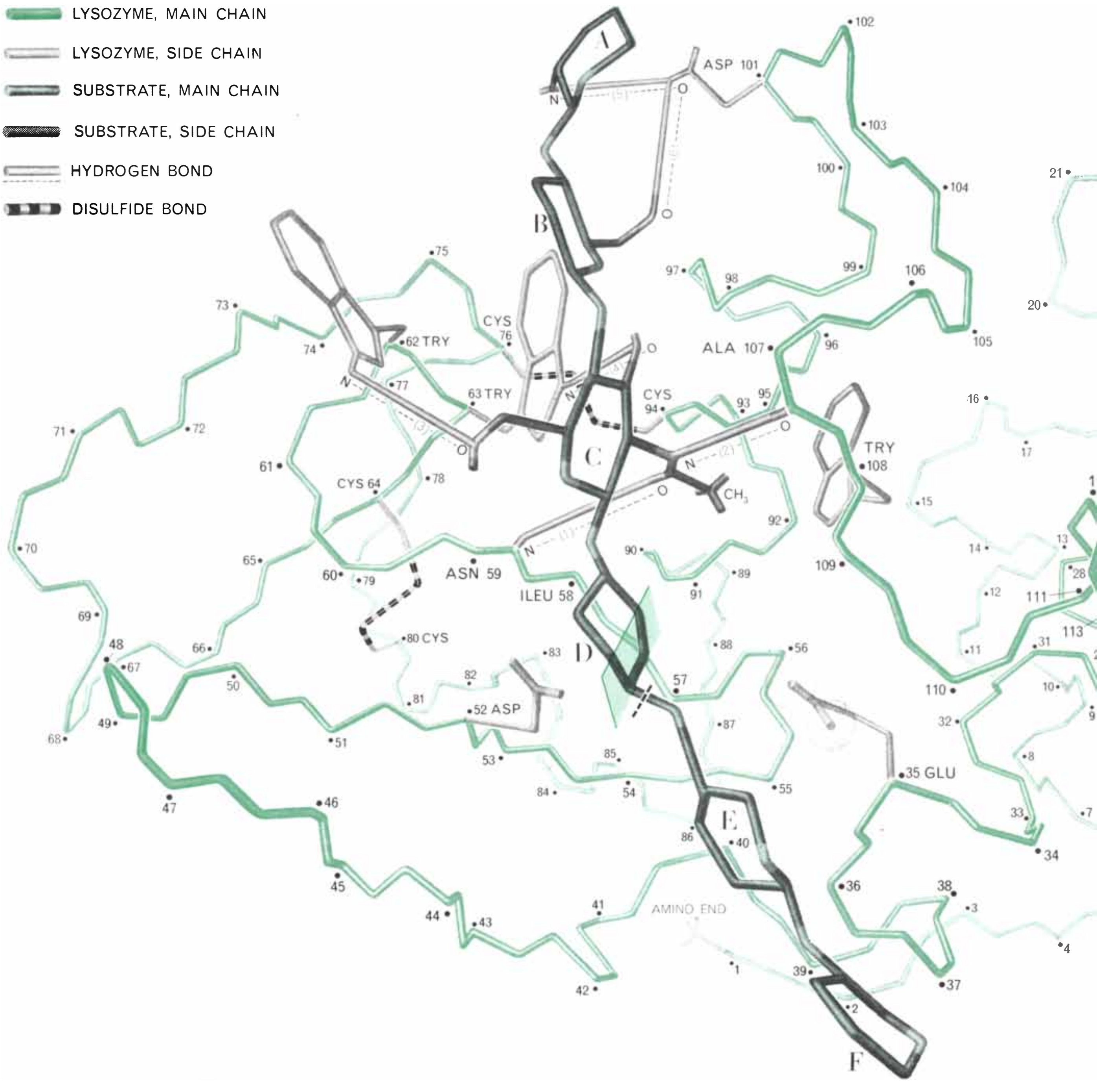
Because the X rays are scattered by the electrons within the molecules, the image calculated from the diffraction pattern reveals the distribution of electrons within the crystal. The electron density is usually calculated at a regular array of points, and the image is made visible by drawing contour lines through points of equal electron density. If these contour maps are drawn on clear plastic sheets, one can obtain a three-dimensional image by assembling the maps one above the other in a stack. The amount of detail that can be seen in such an image depends on the resolving power of the effective microscope, that is, on its "aperture," or the extent of the diffraction pattern that has been included in the formation of the image. If the waves diffracted through sufficiently high angles are included

MODEL OF SUBSTRATE shows how it fits into the cleft in the lysozyme molecule. All the carbon atoms in the substrate are shown in purple. The portion of the substrate in intimate contact with the underlying enzyme is a polysaccharide chain consisting of six ringlike structures, each a residue of an amino-sugar molecule. The substrate in the model is made up of six identical residues of the amino sugar called N-acetylglucosamine (NAG). In the actual substrate every other residue is an amino sugar known as N-acetylmuramic acid (NAM). The illustration is based on X-ray studies of the way the enzyme is bound to a trisaccharide made of three NAG units, which fills the top of the cleft; the arrangement of NAG units in the bottom of the cleft was worked out with the aid of three-dimensional models. The substrate is held to the enzyme by a complex network of hydrogen bonds. In this style of model-making each straight section of chain represents a bond between atoms. The atoms themselves lie at the intersections and elbows of the structure. Except for the four red balls representing oxygen atoms that are active in splitting the polysaccharide substrate, no attempt is made to represent the electron shells of atoms because they would merge into a solid mass.

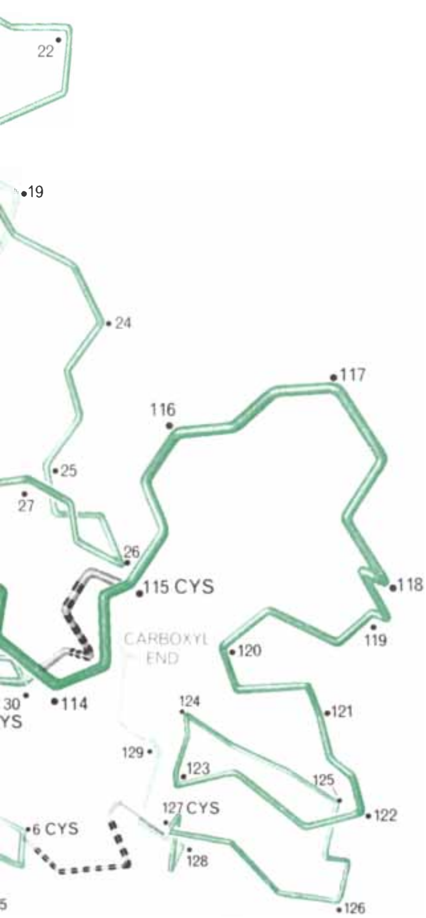
(corresponding to a large aperture), the atoms appear as individual peaks in the image map. At lower resolution groups of unresolved atoms appear with characteristic shapes by which they can be recognized.

The three-dimensional structure of lysozyme crystallized from the white of hen's egg has been determined in atomic detail with the X-ray method by our group at the Royal Institution in London. This is the laboratory in which Humphry Davy and Michael Faraday made their fundamental discoveries during the 19th century, and in which the X-ray method of structure analysis was developed between the two world wars by the brilliant group of workers led by William Bragg, including J. D. Bernal, Kathleen Lonsdale, W. T. Astbury, J. M. Robertson and many others. Our work on lysozyme was begun in 1960 when Roberto J. Poljak, a visiting worker from Argentina, demonstrated that suitable crystals containing heavy atoms could be prepared. Since then C. C. F. Blake, A. C. T. North, V. R. Sarma, Ruth Fenn, D. F. Koenig, Louise N. Johnson and G. A. Mair have played important roles in the work.

In 1962 a low-resolution image of the structure was obtained that revealed the general shape of the molecule and



MAP OF LYSOZYME AND SUBSTRATE depicts in color the central chain of each molecule. Side chains have been omitted except for those that produce the four disulfide bonds clipping the lysozyme molecule together and those that supply the terminal connections for hydrogen bonds holding the substrate to the lysozyme. The top three rings of the substrate (*A*, *B*, *C*) are held to the underlying enzyme by six principal hydrogen bonds, which are identified by number to key with the description in the text. The lysoshowed that the arrangement of the polypeptide chain is even more complex than it is in myoglobin. This low-resolution image was calculated from the amplitudes of about 400 diffraction maxima measured from native protein crystals and from crystals containing each of three different heavy atoms. In 1965, after the development of more efficient methods of measurement and computation, an image was calculated on the basis of nearly 10,000 diffraction maxima, which resolved features separated by two angstroms. Apart from showing a few well-separated chloride ions, which are present because the lysozyme is crystallized from a solution containing sodium chloride, the two-angstrom image still does not show individual atoms as separate maxima in the electron-density map. The level of resolution is high enough, however, for many of the groups of atoms to be clearly recognizable.



zyme molecule fulfills its function when it cleaves the substrate between the *D* and the *E* ring. Note the distortion of the *D* ring, which pushes four of its atoms into a plane.

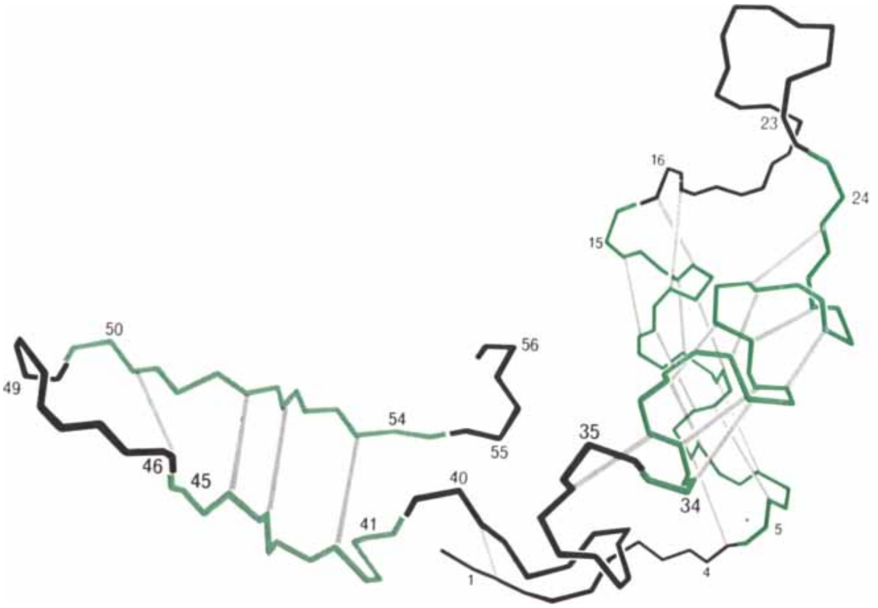
The Lysozyme Molecule

The main polypeptide chain appears as a continuous ribbon of electron density running through the image with regularly spaced promontories on it that are characteristic of the carbonyl groups (CO) that mark each peptide bond. In some regions the chain is folded in ways that are familiar from theoretical studies of polypeptide configurations and from the structure analyses of myoglobin and fibrous proteins such as the keratin of hair. The amino acid residues in lysozyme have now been designated by number; the residues numbered 5 through 15, 24 through 34 and 88 through 96 form three lengths of "alpha helix," the conformation that was proposed by Linus Pauling and Robert B. Corey in 1951 and that was found by Kendrew and his colleagues to be the most common arrangement of the chain in myoglobin. The helixes in lysozyme, however, appear to be somewhat distorted from the "classical" form, in which four atoms (carbon, oxygen, nitrogen and hydrogen) of each peptide group lie in a plane that is parallel to the axis of the alpha helix. In the lysozyme molecule the peptide groups in the helical sections tend to be rotated slightly in such a way that their CO groups point outward from the helix axes and their imino groups (NH) inward.

The amount of rotation varies, being slight in the helix formed by residues 5 through 15 and considerable in the one formed by residues 24 through 34. The effect of the rotation is that each NH group does not point directly at the CO group four residues back along the chain but points instead between the CO groups of the residues three and four back. When the NH group points directly at the CO group four residues back, as it does in the classical alpha helix, it forms with the CO group a hydrogen bond (the weak chemical bond in which a hydrogen atom acts as a bridge). In the lysozyme helixes the hydrogen bond is formed somewhere between two CO groups, giving rise to a structure intermediate between that of an alpha helix and that of a more symmetrical helix with a three-fold symmetry axis that was discussed by Lawrence Bragg, Kendrew and Perutz in 1950. There is a further short length of helix (residues 80 through 85) in which the hydrogen-bonding arrangement is quite close to that in the three-fold helix, and also an isolated turn (residues 119 through 122) of three-fold helix. Furthermore, the peptide at the far end of helix 5 through 15 is in the conformation of the three-fold helix, and the hydrogen bond from its NH group is made to the CO three residues back rather than four.

Partly because of these irregularities in the structure of lysozyme, the proportion of its polypeptide chain in the alpha-helix conformation is difficult to calculate in a meaningful way for comparison with the estimates obtained by other methods, but it is clearly less than half the proportion observed in myoglobin, in which helical regions make up about 75 percent of the chain. The lysozyme molecule does include, however, an example of another regular conformation predicted by Pauling and Corey. This is the "antiparallel pleated sheet," which is believed to be the basic structure of the fibrous protein silk and in which, as the name suggests, two lengths of polypeptide chain run parallel to each other in opposite directions. This structure again is stabilized by hydrogen bonds between the NH and CO groups of the main chain. Residues 41 through 45 and 50 through 54 in the lysozyme molecule form such a structure, with the connecting residues 46 through 49 folded into a hairpin bend between the two lengths of comparatively extended chain. The remainder of the polypeptide chain is folded in irregular ways that have no simple short description.

Even though the level of resolution achieved in our present image was not enough to resolve individual atoms, many of the side chains characteristic of the amino acid residues were readily identifiable from their general shape. The four disulfide bridges, for example, are marked by short rods of high electron density corresponding to the two relatively dense sulfur atoms within them. The six tryptophan residues also were easily recognized by the extended electron density produced by the large double-ring structures in their



FIRST 56 RESIDUES in lysozyme molecule contain a higher proportion of symmetrically organized regions than does all the rest of the molecule. Residues 5 through 15 and 24 through 34 (*right*) form two regions in which hydrogen bonds (*gray*) hold the residues in a helical configuration close to that of the "classical" alpha helix. Residues 41 through 45 and 50 through 54 (*left*) fold back against each other to form a "pleated sheet," also held together by hydrogen bonds. In addition the hydrogen bond between residues 1 and 40 ties the first 40 residues into a compact structure that may have been folded in this way before the molecule was fully synthesized (*see illustration at the bottom of these two pages*).

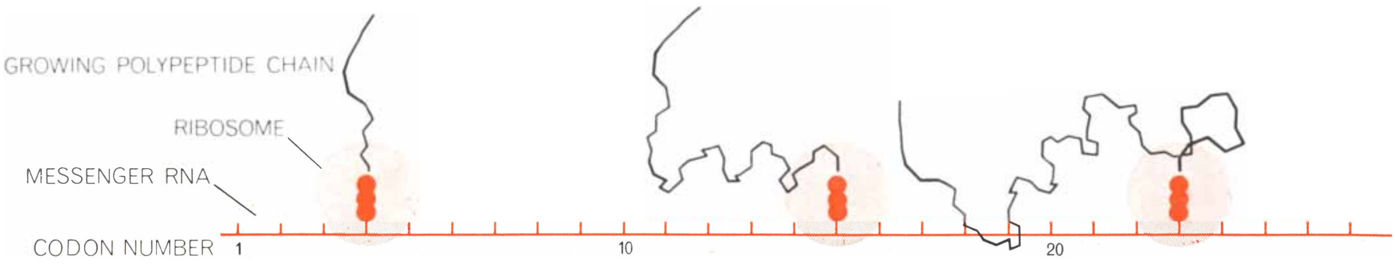
side chains. Many of the other residues also were easily identifiable, but it was nevertheless most important for the rapid and reliable interpretation of the image that the results of the chemical analysis were already available. With their help more than 95 percent of the atoms in the molecule were readily identified and located within about .25 angstrom.

Further efforts at improving the accuracy with which the atoms have been located is in progress, but an almost complete description of the lysozyme molecule now exists [*see illustration on pages 80 and 81*]. By studying it and the results of some further experiments we can begin to suggest answers to two important questions: How does a molecule such as this one attain its observed conformation? How does it function as an enzyme, or biological catalyst?

Inspection of the lysozyme molecule immediately suggests two generalizations about its conformation that agree well with those arrived at earlier in the study of myoglobin. It is obvious that certain residues with acidic and basic side chains that ionize, or dissociate, on contact with water are all on the surface of the molecule more or less readily accessible to the surrounding liquid. Such "polar" side chains are hydrophilic—attracted to water; they are found in aspartic acid and glutamic acid residues and in lysine, arginine and histidine residues, which have basic side groups. On the other hand, most of the markedly nonpolar and hydrophobic side chains (for example those found in leucine and isoleucine residues) are shielded from the surrounding liquid by more polar parts of the molecule. In fact, as was predicted by Sir Eric Rideal (who was at one time director of the Royal Institution) and Irving Langmuir, lysozyme, like myoglobin, is quite well described as an oil drop with a polar coat. Here it is important to note that the environment of each molecule in the crystalline state is not significantly different from its natural environment in the living cell. The crystals themselves include a large proportion (some 35 percent by weight) of mostly watery liquid of crystallization. The effect of the surrounding liquid on the protein conformation thus is likely to be much the same in the crystals as it is in solution.

It appears, then, that the observed conformation is preferred because in it the hydrophobic side chains are kept out of contact with the surrounding liquid whereas the polar side chains are generally exposed to it. In this way the system consisting of the protein and the solvent attains a minimum free energy, partly because of the large number of favorable interactions of like groups within the protein molecule and between it and the surrounding liquid, and partly because of the relatively high disorder of the water molecules that are in contact only with other polar groups of atoms.

Guided by these generalizations, many workers are now interested in the possibility of predicting the conforma-



FOLDING OF PROTEIN MOLECULE may take place as the growing polypeptide chain is being synthesized by the intracellular particles called ribosomes. The genetic message specifying the amino acid sequence of each protein is coded in "messenger" ribonucleic acid (RNA). It is believed several ribosomes travel simultaneously along this long-chain molecule, reading the message as they go.

tion of a protein molecule from its chemical formula alone [see "Molecular Model-building by Computer," by Cyrus Levinthal; SCIENTIFIC AMERICAN, June]. The task of exploring all possible conformations in the search for the one of lowest free energy seems likely, however, to remain beyond the power of any imaginable computer. On a conservative estimate it would be necessary to consider some 10^{129} different conformations for the lysozyme molecule in any general search for the one with minimum free energy. Since this number is far greater than the number of particles in the observable universe, it is clear that simplifying assumptions will have to be made if calculations of this kind are to succeed.

The Folding of Lysozyme

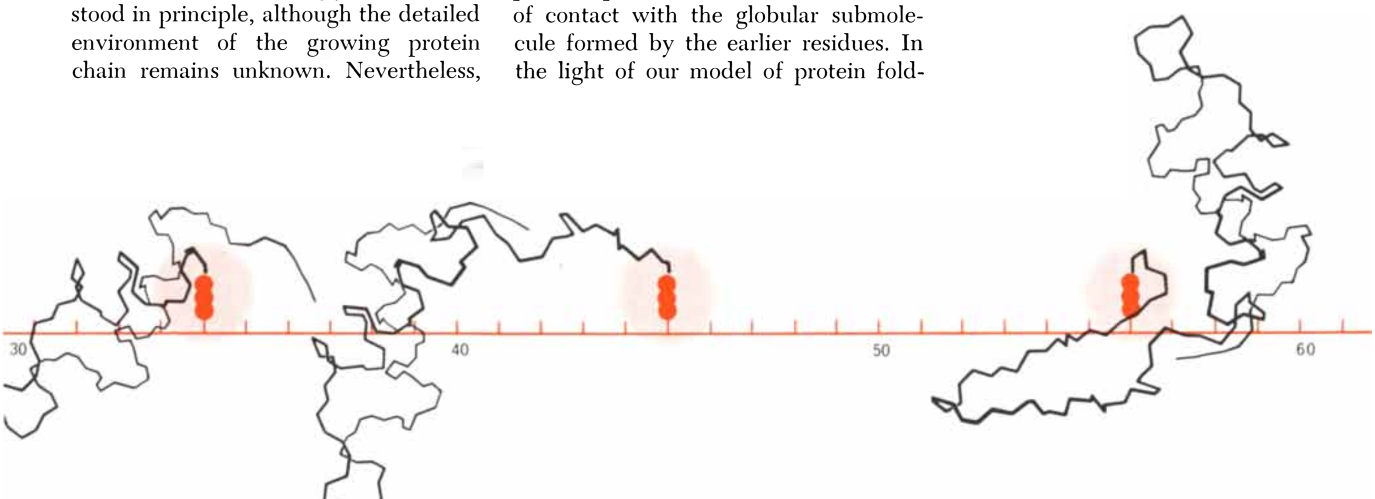
For some time Peter Dunnill and I have been trying to develop a model of protein-folding that promises to make practicable calculations of the minimum energy conformation and that is, at the same time, qualitatively consistent with the observed structure of myoglobin and lysozyme. This model makes use of our present knowledge of the way in which proteins are synthesized in the living cell. For example, it is well known, from experiments by Howard M. Dintzis and by Christian B. Anfinsen and Robert Canfield, that protein molecules are synthesized from the terminal amino end of their polypeptide chain. The nature of the synthetic mechanism, which involves the intracellular particles called ribosomes working in collaboration with two forms of ribonucleic acid ("messenger" RNA and "transfer" RNA), is increasingly well understood in principle, although the detailed environment of the growing protein chain remains unknown. Nevertheless, it seems a reasonable assumption that, as the synthesis proceeds, the amino end of the chain becomes separated by an increasing distance from the point of attachment to the ribosome, and that the folding of the protein chain to its native conformation begins at this end even before the synthesis is complete. According to our present ideas, parts of the polypeptide chain, particularly those near the terminal amino end, may fold into stable conformations that can still be recognized in the finished molecule and that act as "internal templates," or centers, around which the rest of the chain is folded [*see illustration at bottom of these two pages*]. It may therefore be useful to look for the stable conformations of parts of the polypeptide chain and to avoid studying all the possible conformations of the whole molecule.

Inspection of the lysozyme molecule provides qualitative support for these ideas [*see top illustration on opposite page*]. The first 40 residues from the terminal amino end form a compact structure (residues 1 and 40 are linked by a hydrogen bond) with a hydrophobic interior and a relatively hydrophilic surface that seems likely to have been folded in this way, or in a simply related way, before the molecule was fully synthesized. It may also be important to observe that this part of the molecule includes more alpha helix than the remainder does.

These first 40 residues include a mixture of hydrophobic and hydrophilic side chains, but the next 14 residues in the sequence are all hydrophilic; it is interesting, and possibly significant, that these are the residues in the antiparallel pleated sheet, which lies out of contact with the globular submolecule formed by the earlier residues. In the light of our model of protein folding the obvious speculation is that there is no incentive to fold these hydrophilic residues in contact with the first part of the chain until the hydrophobic residues 55 (isoleucine) and 56 (leucine) have to be shielded from contact with the surrounding liquid. It seems reasonable to suppose that at this stage residues 41 through 54 fold back on themselves, forming the pleated-sheet structure and burying the hydrophobic side chains in the initial hydrophobic pocket.

Similar considerations appear to govern the folding of the rest of the molecule. In brief, residues 57 through 86 are folded in contact with the pleated-sheet structure so that at this stage of the process—if indeed it follows this course—the folded chain forms a structure with two wings lying at an angle to each other. Residues 86 through 96 form a length of alpha helix, one side of which is predominantly hydrophobic, because of an appropriate alternation of polar and nonpolar residues in that part of the sequence. This helix lies in the gap between the two wings formed by the earlier residues, with its hydrophobic side buried within the molecule. The gap between the two wings is not completely filled by the helix, however; it is transformed into a deep cleft running up one side of the molecule. As we shall see, this cleft forms the active site of the enzyme. The remaining residues are folded around the globular unit formed by the terminal amino end of the polypeptide chain.

This model of protein-folding can be tested in a number of ways, for example by studying the conformation of the first 40 residues in isolation both di-



Presumably the messenger RNA for lysozyme contains 129 "codons," one for each amino acid. Amino acids are delivered to the site of synthesis by molecules of "transfer" RNA (*dark color*). The illustration shows how the lysozyme chain would lengthen as a ribosome travels along the messenger RNA molecule. Here, hypothetically, the polypeptide is shown folding directly into its final shape.

rectly (after removal of the rest of the molecule) and by computation. Ultimately, of course, the model will be regarded as satisfactory only if it helps us to predict how other protein molecules are folded from a knowledge of their chemical structure alone.

The Activity of Lysozyme

In order to understand how lysozyme brings about the dissolution of bacteria we must consider the structure of the bacterial cell wall in some detail. Through the pioneer and independent studies of Karl Meyer and E. B. Chain, followed up by M. R. J. Salton of the University of Manchester and many others, the structures of bacterial cell walls and the effect of lysozyme on them are now quite well known. The important part of the cell wall, as far as lysozyme is concerned, is made up of glucose-like amino-sugar molecules linked together into long polysaccharide chains, which are themselves cross-connected by short lengths of polypeptide chain. This part of each cell wall probably forms one enormous molecule—a "bag-shaped macromolecule," as W. Weidel and H. Pelzer have called it.

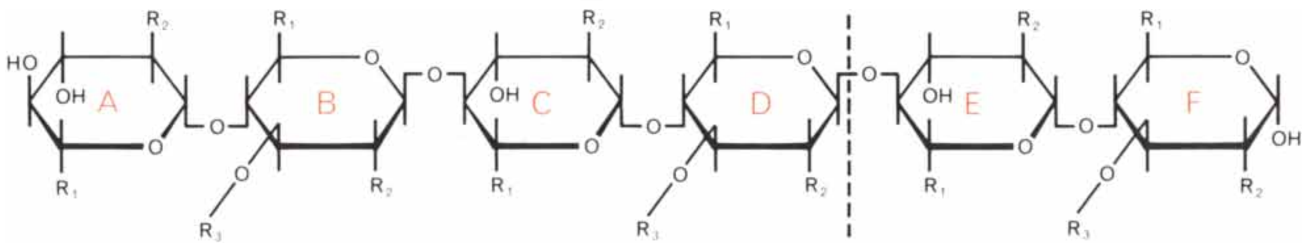
The amino-sugar molecules concerned in these polysaccharide structures are of two kinds; each contains an acetamido ($-NH \cdot CO \cdot CH_3$) side group, but one of them contains an additional major group, a lactyl side chain [*see illustration below*]. One of these amino sugars is known as N-acetylglucosamine (NAG) and the other as N-acetylmuramic acid (NAM). They occur alternately in the polysaccharide chains, being connected by bridges that include an oxygen atom (glycosidic linkages) between carbon atoms 1 and 4 of consecutive sugar rings; this is the same linkage that joins glucose residues in cellulose. The polypeptide chains that cross-connect these polysaccharides are attached to the NAM residues through the lactyl side chain attached to carbon atom 3 in each NAM ring.

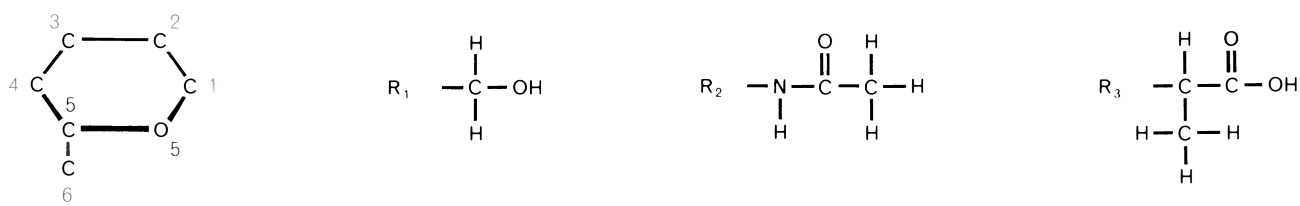
Lysozyme has been shown to break the linkages in which carbon 1 in NAM is linked to carbon 4 in NAG but not the other linkages. It has also been shown to break down chitin, another common natural polysaccharide that is found in lobster shell and that contains only NAG.

Ever since the work of Svante Arrhenius of Sweden in the late 19th century enzymes have been thought to work by forming intermediate compounds with their substrates: the substances whose chemical reactions they catalyze. A proper theory of the enzyme-substrate complex, which underlies all present thinking about enzyme activity, was clearly propounded by Leonor Michaelis and Maude Menton in a remarkable paper published in 1913. The idea, in its simplest form, is that an enzyme molecule provides a site on its surface to which its substrate molecule can bind in a quite precise way. Reactive groups of atoms in the enzyme then promote the required chemical reaction in the substrate. Our immediate objective, therefore, was to find the structure of a reactive complex between lysozyme and its polysaccharide substrate, in the hope that we would then be able to recognize the active groups of atoms in the enzyme and understand how they function.

Our studies began with the observation by Martin Wenzel and his colleagues at the Free University of Berlin that the enzyme is prevented from functioning by the presence of NAG itself. This small molecule acts as a competitive inhibitor of the enzyme's activity and, since it is a part of the large substrate molecule normally acted on by the enzyme, it seems likely to do this by binding to the enzyme in the way that part of the substrate does. It prevents the enzyme from working by preventing the substrate from binding to the enzyme. Other simple amino-sugar molecules, including the trisaccharide made of three NAG units, behave in the same way. We therefore decided to study the binding of these sugar molecules to the lysozyme molecules in our crystals in the hope of learning something about the structure of the enzyme-substrate complex itself.

My colleague Louise Johnson soon found that crystals containing the sugar molecules bound to lysozyme can be prepared very simply by adding the sugar to the solution from which the lysozyme crystals have been grown and in which they are kept suspended. The small molecules diffuse into the protein crystals along the channels filled with water that run through the crystals. Fortunately the resulting change in the crystal structure can be studied quite simply. A useful image of the electron-density changes can be calculated from





POLYSACCHARIDE MOLECULE found in the walls of certain bacterial cells is the substrate broken by the lysozyme molecule. The polysaccharide consists of alternating residues of two kinds of amino sugar: N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM). In the length of polysaccharide chain shown here *A*, *C* and *E* are NAG residues; *B*, *D* and *F* are NAM residues. The inset at left shows the numbering scheme for identifying the principal atoms in each sugar ring. Six rings of the polysaccharide fit into the cleft of the lysozyme molecule, which effects a cleavage between rings *D* and *E* (*see illustration on pages 84 and 85*).

measurements of the changes in amplitude of the diffracted waves, on the assumption that their phase relations have not changed from those determined for the pure protein crystals. The image shows the difference in electron density between crystals that contain the added sugar molecules and those that do not.

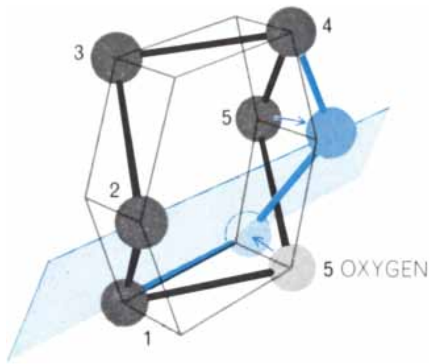
In this way the binding to lysozyme of eight different amino sugars was studied at low resolution (that is, through the measurement of changes in the amplitude of 400 diffracted waves). The results showed that the sugars bind to lysozyme at a number of different places in the cleft of the enzyme. The investigation was hurried on to higher resolution in an attempt to discover the exact nature of the binding. Happily these studies at two-angstrom resolution (which required the measurement of 10,000 diffracted waves) have now shown in detail how the trisaccharide made of three NAG units is bound to the enzyme.

The trisaccharide fills the top half of the cleft and is bound to the enzyme by a number of interactions, which can be followed with the help of the illustration on pages 84 and 85. In this illustration six important hydrogen bonds, to be described presently, are identified by number. The most critical of these interactions appear to involve the acetamido group of sugar residue *C* [*third from top*], whose carbon atom 1 is not linked to another sugar residue. There are hydrogen bonds from the CO group of this side chain to the main-chain NH group of amino acid residue 59 in the enzyme molecule [*bond No. 1*] and from its NH group to the main-chain CO group of residue 107 (alanine) in the enzyme molecule [*bond No. 2*]. Its terminal CH_3 group makes contact with the side chain of residue 108 (tryptophan). Hydrogen bonds [*No. 3 and No. 4*] are also formed between two oxygen atoms adjacent to carbon atoms 6 and 3 of sugar residue *C* and the side chains of residues 62 and 63 (both tryptophan) respectively. Another hydrogen bond [*No. 5*] is formed between the acetamido side chain of sugar residue *A* and residue 101 (aspartic acid) in the enzyme molecule. From residue 101 there is a hydrogen bond [*No. 6*] to the oxygen adjacent to carbon atom 6 of sugar residue *B*. These polar interactions are supplemented by a large number of nonpolar interactions that are more difficult to summarize briefly. Among the more important nonpolar interactions, however, are those between sugar residue *B* and the ring system of residue 62; these deserve special mention because they are affected by a small change in the conformation of the enzyme molecule that occurs when the trisaccharide is bound to it. The electron-density map showing the change in electron density when tri-NAG is bound in the protein crystal reveals clearly that parts of the enzyme molecule have moved with respect to one another. These changes in conformation are largely restricted to the part of the enzyme structure to the left of the cleft, which appears to tilt more or less as a whole in such a way as to close the cleft slightly. As a result the side chain of residue 62 moves about .75 angstrom toward the position of sugar residue *B*. Such changes in enzyme conformation have been discussed for some time, notably by Daniel E. Koshland, Jr., of the University of California at Berkeley, whose "induced fit" theory of the enzyme-substrate interaction is supported in some degree by this observation in lysozyme.

The Enzyme-Substrate Complex

At this stage in the investigation excitement grew high. Could we tell how the enzyme works? I believe we can. Unfortunately, however, we cannot see this dynamic process in our X-ray images. We have to work out what must happen from our static pictures. First of all it is clear that the complex formed by tri-NAG and the enzyme is not the enzyme-substrate complex involved in catalysis because it is stable. At low concentrations tri-NAG is known to behave as an inhibitor rather than as a substrate that is broken down; clearly we have been looking at the way in which it binds as an inhibitor. It is noticeable, however, that tri-NAG fills only half of the cleft. The possibility emerges that more sugar residues, filling the remainder of the cleft, are required for the formation of a reactive enzyme-substrate complex. The assumption here is that the observed binding of tri-NAG as an inhibitor involves interactions with the enzyme molecule that also play a part in the formation of the functioning enzyme-substrate complex.

Accordingly we have built a model that shows that another three sugar residues can be added to the tri-NAG in such a way that there are satisfactory interactions of the atoms in the proposed substrate and the enzyme. There is only one difficulty: carbon atom 6 and its adjacent oxygen atom in sugar residue *D* make uncomfortably close contacts with atoms in the enzyme molecule, unless this sugar residue is distorted a little out of its most stable "chair" conformation into a conformation in which carbon atoms 1, 2 and 5 and oxygen atom 5 all lie in a plane [*see illustration above*]. Otherwise satisfactory interactions immediately suggest themselves, and the model falls into place.



"CHAIR" CONFIGURATION (*gray*) is that normally assumed by the rings of amino sugar in the polysaccharide substrate. When bound against the lysozyme, however, the *D* ring is distorted (*color*) so that carbon atoms *1*, *2* and *5* and oxygen atom *5* lie in a plane. The distortion evidently assists in breaking the substrate below the *D* ring.

At this point it seemed reasonable to assume that the model shows the structure of the functioning complex between the enzyme and a hexasaccharide. The next problem was to decide which of the five glycosidic linkages would be broken under the influence of the enzyme. Fortunately evidence was at hand to suggest the answer. As we have seen, the cell-wall polysaccharide includes alternate sugar residues of two kinds, NAG and NAM, and the bond broken is between NAM and NAG. It was therefore important to decide which of the six sugar residues in our model could be NAM, which is the same as NAG except for the lactyl side chain appended to carbon atom 3. The answer was clear-cut. Sugar residue *C* cannot be NAM because there is no room for this additional group of atoms. Therefore the bond broken must be between sugar residues *B* and *C* or *D* and *E*. We already knew that the glycosidic linkage between residues *B* and *C* is stable when tri-NAG is bound. The conclusion was inescapable: the linkage that must be broken is the one between sugar residues *D* and *E*.

Now it was possible to search for the origin of the catalytic activity in the neighborhood of this linkage. Our task was made easier by the fact that John A.

Rupley of the University of Arizona had shown that the chemical bond broken under the influence of lysozyme is the one between carbon atom 1 and oxygen in the glycosidic link rather than the link between oxygen and carbon atom 4. The most reactive-looking group of atoms in the vicinity of this bond are the side chains of residue 52 (aspartic acid) and residue 35 (glutamic acid). One of the oxygen atoms of residue 52 is about three angstroms from carbon atom 1 of sugar residue *D* as well as from the ring oxygen atom 5 of that residue. Residue 35, on the other hand, is about three angstroms from the oxygen in the glycosidic linkage. Furthermore, these two amino acid residues have markedly different environments. Residue 52 has a number of polar neighbors and appears to be involved in a network of hydrogen bonds linking it with residues 46 and 59 (both asparagine) and, through them, with residue 50 (serine). In this environment residue 52 seems likely to give up a terminal hydrogen atom and thus be negatively charged under most conditions, even when it is in a markedly acid solution, whereas residue 35, situated in a nonpolar environment, is likely to retain its terminal hydrogen atom.

A little reflection suggests that the concerted influence of these two amino acid residues, together with a contribution from the distortion to sugar residue *D* that has already been mentioned, is enough to explain the catalytic activity of lysozyme. The events leading to the rupture of a bacterial cell wall probably take the following course [*see illustration on this page*].

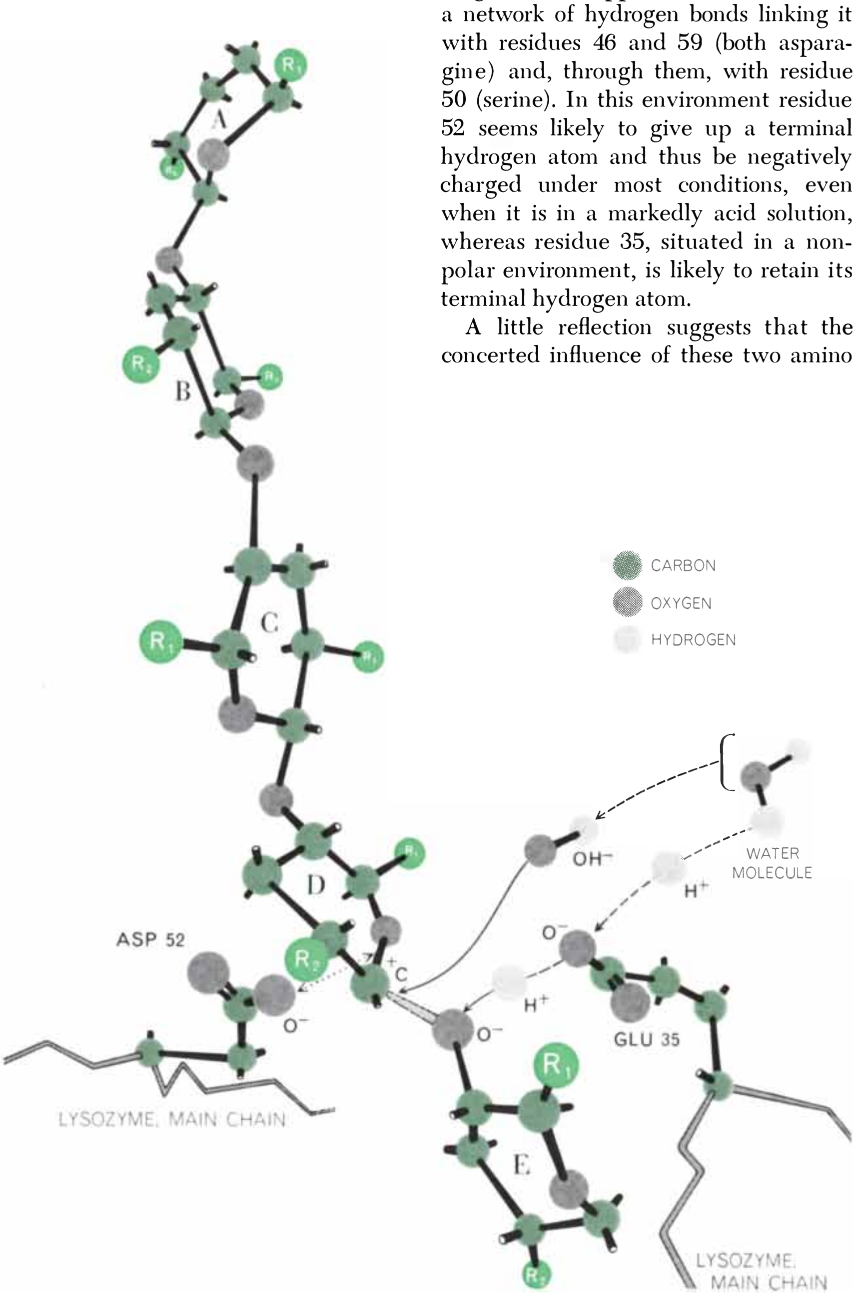
First, a lysozyme molecule attaches itself to the bacterial cell wall by interacting with six exposed amino-sugar residues. In the process sugar residue *D* is somewhat distorted from its usual conformation.

Second, residue 35 transfers its terminal hydrogen atom in the form of a hydrogen ion to the glycosidic oxygen, thus bringing about cleavage of the bond between that oxygen and carbon atom 1 of sugar residue *D*. This creates a positively charged carbonium ion (C^+) where the oxygen has been severed from carbon atom 1.

Third, this carbonium ion is stabilized by its interaction with the negatively charged aspartic acid side chain of residue 52 until it can combine with a hydroxyl ion (OH^-) that happens to diffuse into position from the surrounding water, thereby completing the reaction. The lysozyme molecule then falls away, leaving behind a punctured bacterial cell wall.

It is not clear from this description that the distortion of sugar residue *D* plays any part in the reaction, but in fact it probably does so for a very interesting reason. R. H. Lemieux and G. Huber of the National Research Council of Canada showed in 1955 that when a sugar molecule such as NAG incorporates a carbonium ion at the carbon-1 position, it tends to take up the same conformation that is forced on ring *D* by its interaction with the enzyme molecule. This seems to be an example, therefore, of activation of the substrate by distortion, which has long been a favorite idea of enzymologists. The binding of the substrate to the enzyme itself favors the formation of the carbonium ion in ring *D* that seems to play an important part in the reaction.

It will be clear from this account that although lysozyme has not been seen in action, we have succeeded in building up a detailed picture of how it may work. There is already a great deal of chemical evidence in agreement with this picture, and as the result of all the work now in progress we can be sure that the activity of Fleming's lysozyme will soon be fully understood. Best of all, it is clear that methods now exist for uncovering the secrets of enzyme action.



SPLITTING OF SUBSTRATE BY LYSOZYME is believed to involve the proximity and activity of two side chains, residue 35 (glutamic acid) and residue 52 (aspartic acid). It is proposed that a hydrogen ion (H^+) becomes detached from the OH group of residue 35 and attaches itself to the oxygen atom that joins rings *D* and *E*, thus breaking the bond between the two rings. This leaves carbon atom 1 of the *D* ring with a positive charge, in which form it is known as a carbonium ion. It is stabilized in this condition by the negatively charged side chain of residue 52. The surrounding water supplies an OH^- ion to combine with the carbonium ion and an H^+ ion to replace the one lost by residue 35. The two parts of the substrate then fall away, leaving the enzyme free to cleave another polysaccharide chain.

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THE AGING GREAT LAKES

Like all other lakes, they are subject to physical and biological processes that will eventually result in their extinction. These processes, however, are being accelerated by human activities

by Charles F. Powers and Andrew Robertson

The five Great Lakes in the heartland of North America constitute the greatest reservoir of fresh water on the surface of the earth. Lake Superior, with an area of 31,820 square miles (nearly half the area of New England), is the world's largest freshwater lake; Lake Huron ranks fourth in the world, Lake Michigan fifth, Lake Erie 11th and Lake Ontario 13th. Together the five lakes cover 95,200 square miles and contain 5,457 cubic miles of water. They provide a continuous waterway into the heart of the continent that reaches nearly 2,000 miles from the mouth of the St. Lawrence River to Duluth at the western tip of Lake Superior.

The Great Lakes are obviously an inestimable natural resource for the development of the U.S. and Canada. They supply vast amounts of water for various needs: drinking, industrial uses and so forth. They serve as a transportation system linking many large inland cities to one another and to the sea. Their falls and rapids generate huge supplies of hydroelectric power. Their fish life is a large potential source of food. And finally, they serve as an immense playground for human relaxation, through boating, swimming and fishing.

The settlements and industries that have grown up around this attractive resource are already very substantial. Although less than 3.5 percent of the total U.S. land area lies in the Great Lakes basin, it is the home of more than 13.5 percent of the nation's population (and about a third of Canada's population). In the southern part of the basin, from Milwaukee on the west to Quebec on the east, is a string of cities that is approaching the nature and dimensions of a megalopolis. Many economists believe the Great Lakes region is likely to become the fastest-growing area in the U.S. Their forecast is based mainly on the fact that whereas most other regions of the country are experiencing increasing shortages of water, the Great Lakes area enjoys a seemingly inexhaustible supply.

Unfortunately the forecast is now troubled by a large question mark. The viability of this great water resource is by no means assured. Even under natural conditions the life of an inland lake is limited. It is subject to aging processes that in the course of time foul its waters and eventually exhaust them. The Great Lakes are comparatively young, and their natural aging would not be a cause for present concern, since the natural processes proceed at the slow pace of the geological time scale. The aging of these lakes is now being accelerated tremendously, however, by man's activities. Basically the destructive agent is pollution. The ill effect of pollution is not limited to the circumstance that it renders the waters unclean. Pollution also hastens the degeneration and eventual extinction of the lakes as bodies of water.

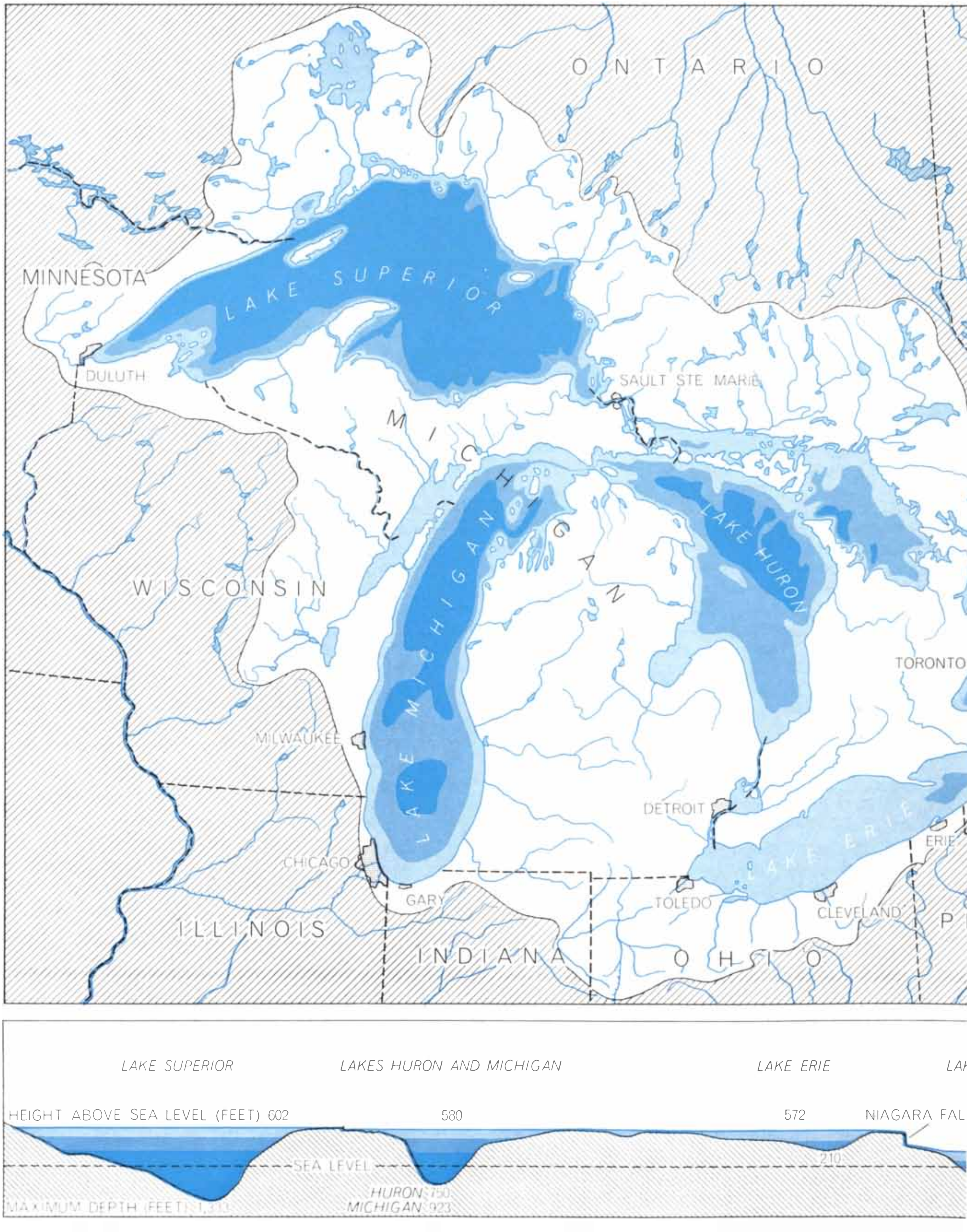
These conclusions are based on recent extensive studies of the Great Lakes by a number of universities and governmental agencies in the U.S. and Canada. Employing various research techniques, including those of oceanography, the studies have produced new basic knowledge about the natural history and ecology of the Great Lakes and recent major changes that have occurred in them.

The natural aging of a lake results from a process called "eutrophication," which means biological enrichment of its water. A newly formed lake begins as a body of cold, clear, nearly sterile water. Gradually streams from its drainage basin bring in nutrient substances, such as phosphorus and nitrogen, and the lake water's increasing fertility gives rise to an accumulating growth of aquatic organisms, both plant and animal. As the living matter increases and organic deposits pile up on the lake bottom, the lake becomes smaller and shallower, its waters become warmer, plants take root in the bottom and gradually take over more and more of the space, and their remains accelerate the filling of the basin. Eventually the lake becomes a marsh, is overrun by vegetation from the surrounding area and thus disappears.

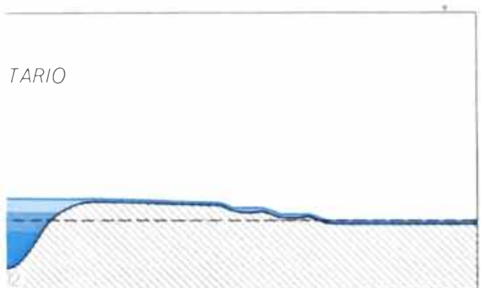
As a lake ages, its animal and plant life changes. Its fish life shifts from forms that prefer cold water to those that do better in a warmer, shallower environment; for example, trout and whitefish give way to bass, sunfish and perch. These in turn are succeeded by frogs, mud minnows and other animals that thrive in a marshy environment.

The natural processes are so slow that

PROCESS OF EXTINCTION that is the destiny of all lakes is seen in action in the aerial photograph on the opposite page. Cattaraugus Creek, a stream that forms the boundary between Erie and Chautauqua counties in New York, enters Lake Erie at this point southwest of Buffalo. (North is to the right.) The stream is not polluted but it carries silt and nutrients. The silt acts to fill the lake; the nutrients feed various forms of plant life that encroach on the shallows and add to the accumulation of bottom deposits. The aging process, which eventually converts every lake into dry land, is greatly accelerated when, as in the case of America's Great Lakes, human and industrial wastes are added to the normal runoff load.



AMERICAN GREAT LAKES comprise the world's largest fresh-water reservoir. Their drainage area (*white*) is not big enough to counteract the loss of lake water through discharge and evaporation but the lakes' level is kept stable by the inflow of groundwater and capture of the rain and snow that fall on 95,200 square miles of water surface. Superior (*left*) is the deepest of the five and Erie the shallowest (*vertical scale of profile is exaggerated*). Erosion will have destroyed the escarpment forming Niagara Falls 25,000



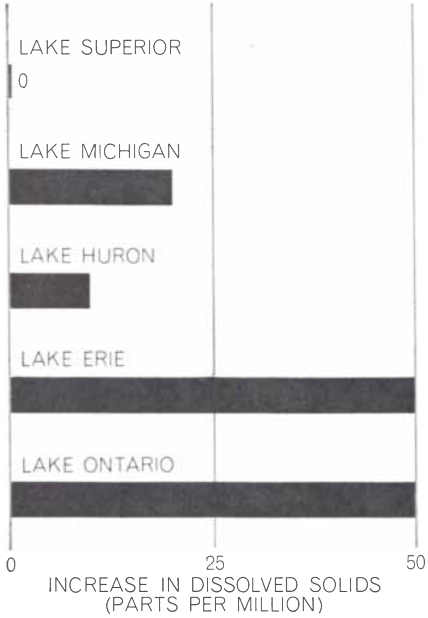
years from now; Lake Erie will then empty, leaving little more than a marshy stream to channel water from the upper lakes into Lake Ontario and on to the Atlantic Ocean.

the lifetime of a lake may span geological eras. Its rate of aging will depend on physical and geographic factors such as the initial size of the lake, the mineral content of the basin and the climate of the region. The activities of man can greatly accelerate this process. Over the past 50 years it has become clear that the large-scale human use of certain lakes has speeded up their aging by a considerable factor. A particularly dramatic example is Lake Zurich in Switzerland: the lower basin of that lake, which receives large amounts of human pollution, has gone from youth to old age in less than a century. In the U.S. similarly rapid aging has been noted in Lake Washington at Seattle and the Yahara lake chain in Wisconsin.

When the European explorers of North America first saw the Great Lakes, the lakes were in a quite youthful stage: cold, clear, deep and extremely pure. In the geological sense they are indeed young—born of the most recent ice age. Before the Pleistocene their present sites were only river valleys. The advancing glaciers deepened and enlarged these valleys; after the glaciers began to retreat some 20,000 years ago the scoured-out basins filled with the melting water. The succeeding advances and retreats of the ice further deepened and reshaped the lakes until the last melting of the ice sheet left them in their present form.

The land area drained by the Great Lakes (194,039 square miles) is relatively small: it is only about twice the area of the lakes themselves, whereas the ratio for most other large lakes is at least six to one. The drainage alone is not sufficient to replace the water lost from the Great Lakes by evaporation and discharge into the ocean by way of the St. Lawrence. Thanks to their immense surface area, however, their capture of rainfall and snowfall, supplemented by inflow of groundwater, maintains the lakes at a fairly stable level. The level varies somewhat, of course, with the seasons (it is a foot to a foot and a half higher in summer than in winter) and with longer-range fluctuations in rainfall. Prolonged spells of abnormal precipitation or drought have raised or lowered the level by as much as 10 feet, thereby causing serious flooding along the lake shores or leaving boat moorings high and dry.

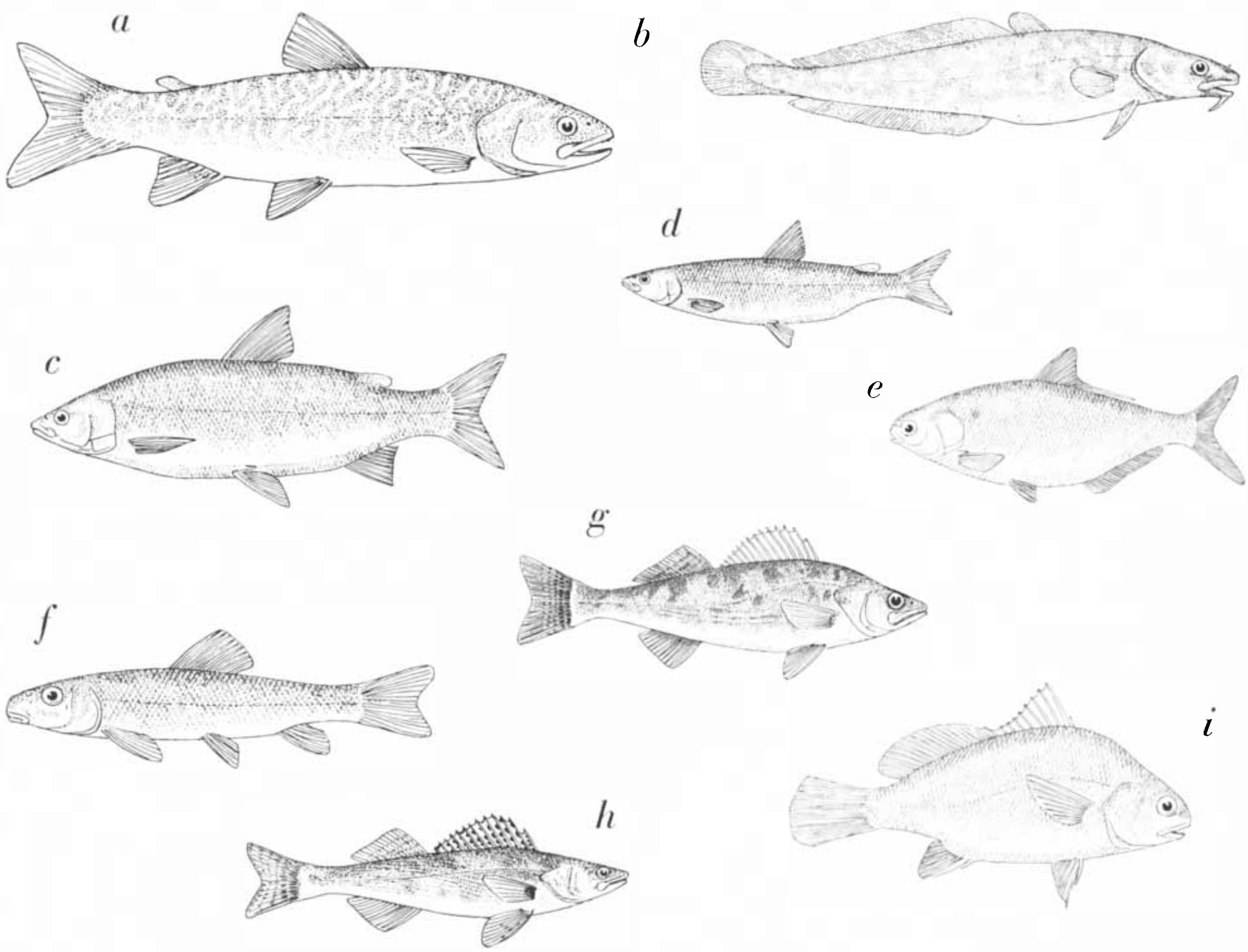
The five lakes differ considerably from one another, not only in surface area but also in the depth and quality of their waters. Lake Superior averages



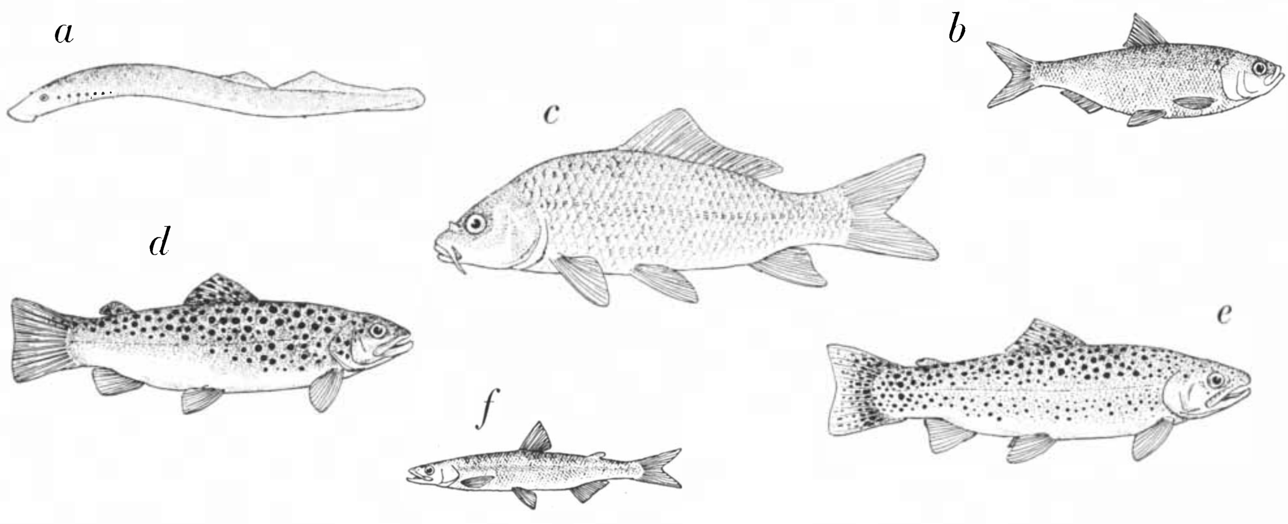
INDEX OF POLLUTION is provided by the extent to which the lakes' content of dissolved solids has increased in the past 50 years. Lake Superior shows no increase, and the modest increase for Lake Huron is attributable to its receipt of Lake Michigan water, which is more heavily polluted. Lake Erie's major cities and its small volume of water account for its rising solids content. Lake Ontario's pollution is a combination of what is received from Lake Erie and what the cities along its shores contribute.

487 feet in depth, whereas shallow Lake Erie averages only 58 feet. There is also a large difference in the lakes' altitude: Lake Superior, at the western end, stands 356 feet higher above sea level than Lake Ontario at the eastern extreme. Most of the drop in elevation occurs in the Niagara River between Lake Erie and Lake Ontario. At Niagara Falls, where the river plunges over the edge of an escarpment, the drop is 167 feet. This escarpment, forming a dam across the eastern end of Lake Erie, is continuously being eroded away, and it is estimated that in 25,000 years it will be so worn down that Lake Erie will be drained and become little more than a marshy stream.

The lakes are all linked together by a system of natural rivers and straits. To this system man has added navigable canals that today make it possible for large ocean-going ships to travel from the Atlantic to the western end of Lake Superior. Hundreds of millions of tons of goods travel up and down the Great Lakes each year, and on the U.S. side alone there are more than 60 commercial ports. The Sault Ste Marie Canal (the "Soo"), which connects Lake Su-



OLDER FISH POPULATION of the Great Lakes includes seven fishes that have nearly disappeared in the past two decades. Among them are the lakes' two largest species, the lake trout (*a*) and the burbot (*b*), and four smaller but economically important fishes, the whitefish (*c*), its close relative the chub, or lake herring (*d*), the walleye (*g*) and its close relative the blue pike (*not illustrated*). All six, as well as the sucker (*f*), have been victims of the parasitic sea lamprey, a fish that was confined to Lake Ontario until completion of the Welland Canal in 1932. Other indigenous fishes illustrated are the gizzard shad (*e*), the sauger (*h*) and the sheepshead (*i*).



INTRUSIVE FISH POPULATION, responsible for disrupting the previous ecological balance of the four upper Great Lakes, are of two classes: those introduced by man and those that have entered on their own. The lamprey (*a*) is one of the voluntary intruders, as is the alewife (*b*), which also entered the upper lakes from Lake Ontario via the Welland Canal. Not a predator of adult fishes, the alewife nonetheless threatens the indigenous fish population. It feeds on these fishes' eggs and also consumes much of the other available food. Species introduced by man are the European carp (*c*) and brown trout (*d*), the rainbow trout (*e*) and the smelt (*f*).

perior and Lake Huron, carries a greater annual tonnage of shipping than the Panama Canal. Other major man-made links in the system are the Welland Canal, which bypasses the Niagara River's falls and rapids to connect Lake Erie and Lake Ontario, and the recently completed St. Lawrence Seaway, which makes the St. Lawrence River fully navigable from Lake Ontario to the Atlantic Ocean.

One of the first signs that man's activities might have catastrophic effects on the natural resources of the Great Lakes came as an inadvertent result of the building of the Welland Canal. The new channel allowed the sea lamprey of the Atlantic, which had previously been unable to penetrate any farther than Lake Ontario, to make its way into the other lakes. The lamprey is a parasite that preys on other fishes, rasping a hole in their skin and sucking out their blood and other body fluids. It usually attacks the largest fish available. By the 1950's it had killed off nearly all the lake trout and burbot (a relative of the cod that is also called the eelpout) in Lake Huron, Lake Michigan and Lake Superior. The lamprey then turned its attention to smaller species such as the whitefish, the chub (a smaller relative of the whitefish), the blue pike, the walleye and the sucker. Its depredations not only destroyed a large part of the fishing industry of the Great Lakes but also brought radical changes in the ecology of these lakes.

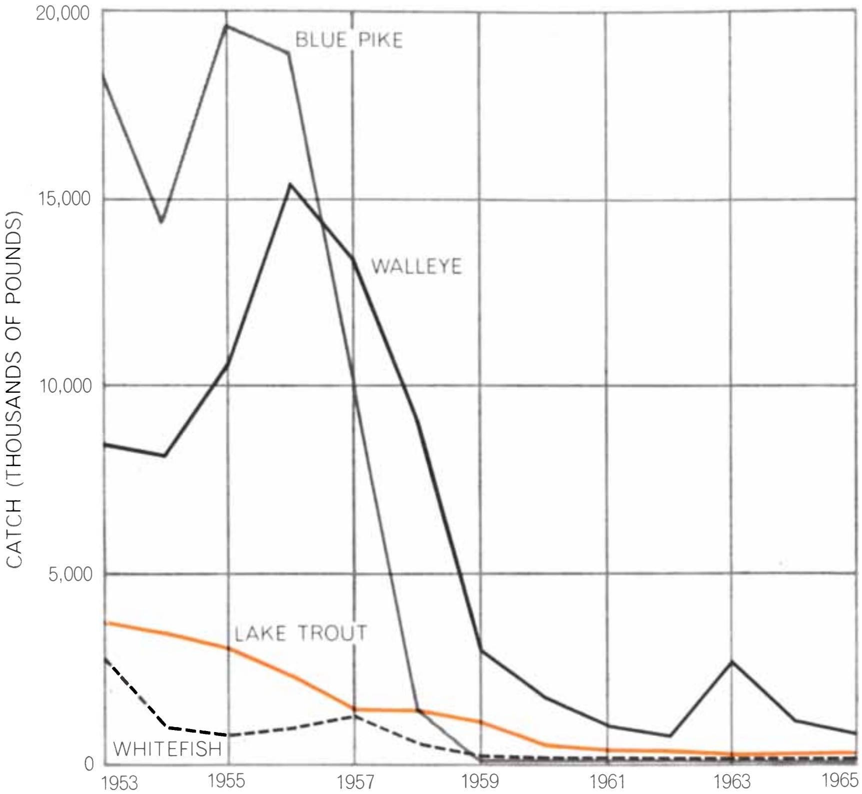
Since the late 1950's U.S. and Canadian agencies have been carrying on a determined campaign to eradicate the lamprey, using a specific larvicide to kill immature lampreys in streams where the species spawns [see "The Sea Lamprey," by Vernon C. Applegate and James W. Moffett; SCIENTIFIC AMERICAN, April, 1955]. This program has succeeded in cutting back greatly the lamprey population in Lake Superior; it is now being applied to the streams feeding into Lake Michigan and will be extended next to Lake Huron. Efforts have already been started to reestablish a growing lake-trout population in Lake Superior.

Meanwhile a second invader that also penetrated the lakes through the Welland Canal has become prominent. This fish is the alewife, a small member of the herring family. The alewife, which ranges up to about nine inches in length, does not attack adult fishes, but it feeds on their eggs and competes with their young for food. In the past decade it has multiplied so rapidly that it is now the dominant fish species in Lake Huron and Lake Michigan and seems to be on the way to taking over Lake Superior.

Recently attempts have been made to convert the alewives from a liability to an asset. The Pacific coho, or silver salmon, has been introduced into Lake Superior and Lake Michigan on an experimental basis. This fish should thrive feeding on the alewife and yet be protected from its depredations, because the eggs and young of the coho are found in tributary streams the alewives do not frequent. Other fishes such as the Atlantic striped bass are being considered for introduction to supplement the coho.

The introduction of a new fish into a lake is always an unpredictable matter. It may, as in the accidental admission of the lamprey and the alewife, disrupt the ecological balance with disastrous results. Even when the introduction is made intentionally with a favorable prognosis, it frequently does not work out according to expectations. The carp, prized as a food fish in many countries of Europe, was stocked in the Great Lakes many years ago and has established itself in all the lakes except Lake Superior. Commercial and sport fishermen in these lakes, however, have come to regard the carp as a nuisance. North Americans generally consider it inedible, chiefly because they have not learned how to prepare and cook it properly. On the other hand, the smelt, introduced into the upper lakes from Lake Ontario early in this century, has become prized by fishermen and is taken in large numbers in the Great Lakes today. What effect it will eventually have on the ecology of the lakes remains to be seen.

The Great Lakes are so young that, biologically speaking, they must be considered in a formative stage. So far only a few species of fishes have been able to invade them and adapt to their specialized environment, particularly in their deep waters. As time goes on, more species will arrive in the lakes and evolve into forms specially adapted to the environmental conditions. Lake Baikal in Siberia, a very large and ancient body of fresh water, offers a good illustration of such a history: it has developed a well-diversified and distinctive

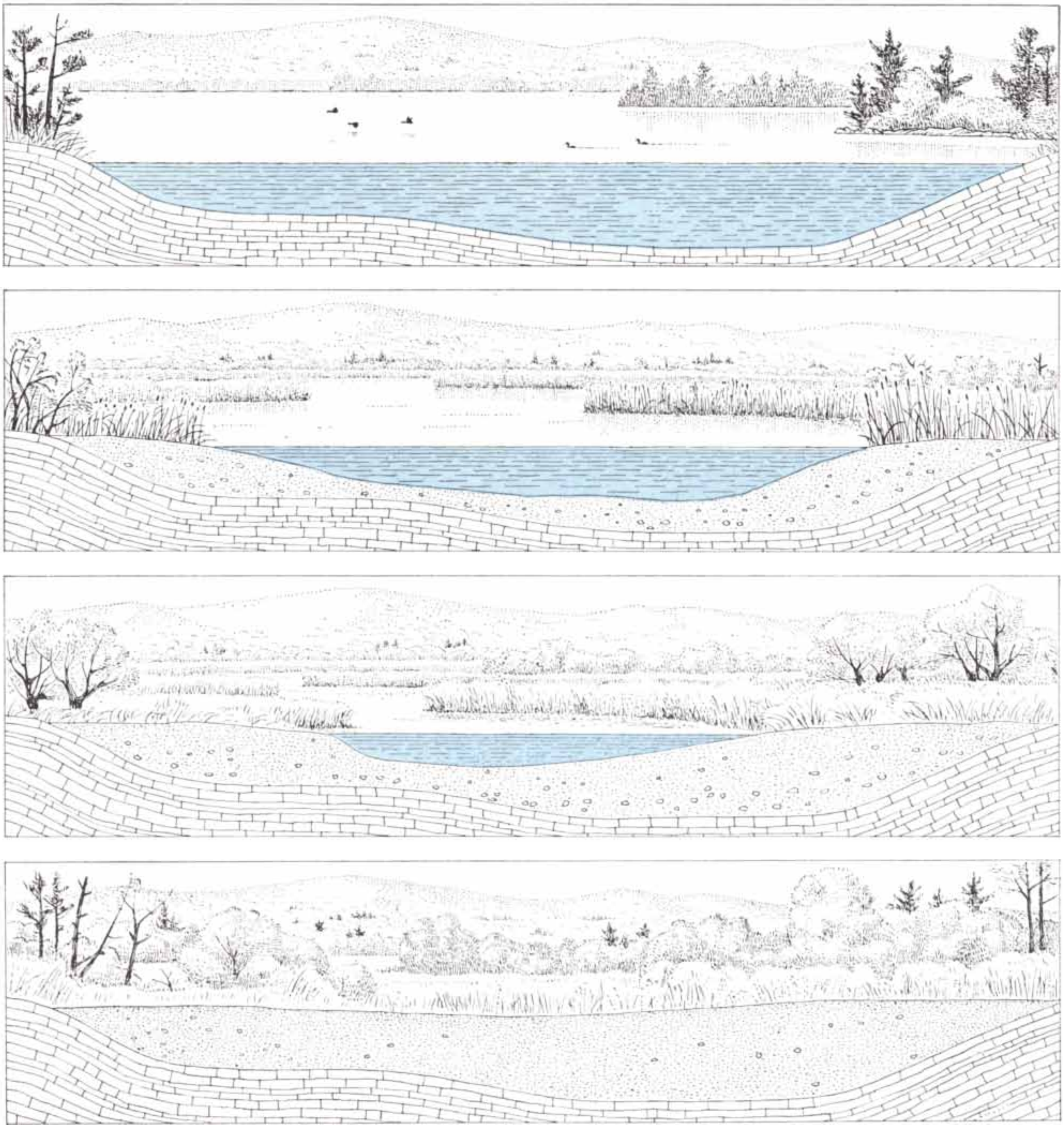


STEADY DROP in productivity of the Great Lakes commercial fisheries is reflected in the numbers of three species taken in Lake Erie (*black*) and one taken in Lake Superior (*color*) between 1953 and 1965. The lake-trout catch in Lake Michigan once rivaled Lake Superior's; from 1941 through 1946 it averaged more than six million pounds. The decline then began to be significant. Within a decade the Lake Michigan fishery ceased to yield lake trout.

population of aquatic animals including a freshwater seal. As diversity in the Great Lakes increases, it will become less and less likely that the arrival or disappearance of one or two species (such as the lake trout and burbot) will result in any profound alteration of the ecological balance.

Pollution, however, is a decidedly different factor. Its effects are always drastic—and generally for the worse. This is clearly evident in Lake Erie, the most polluted of the Great Lakes. The catch of blue pike from this lake dropped from 18,857,000 pounds in 1956 to less than 500 pounds in 1965, and that of the walleye fell from 15,405,000 pounds in 1956 to 790,000 pounds in 1965. There was also a sharp decline in lake herring, whitefish and sauger (a small relative of the walleye). While these most desirable fishes decreased, there were rises in the catch of sheepshead (the freshwater drum), carp, yellow perch and smelt. Other signs in the lake gave evidence of an environment increasingly unfavorable for desirable fish; among these were the severe depletion of oxygen in the bottom waters, the disappearance of mayfly larvae (a fish food), which used to be extremely abundant in the shallow western end of the lake, and spectacular growths of floating algae—a certain sign of advanced age in a lake.

Lake Erie receives, to begin with, the



OBLITERATION of a lake is a process that starts at the edge of the water (*top*): a few bog-adapted conifers rise in a forest of hardwoods. Next the debris of shallow-water plants turns the lake margin into marsh that is gradually invaded by mosses and bog plants, bog-adapted bushes and trees such as blueberry and willow, and additional conifers. Eventually the lake, however deep, is entirely filled with silt from its tributaries and with plant debris. In the final stage (*bottom*) the last central bog soon grows up into forest.

(Advertisement)

STEEL RESEARCH AIDS PRODUCT DESIGN

Special division makes Youngstown's complete research facilities available to the steel customer. It gives direct assistance in the design and methods of using steel in the customer's products.

by R. H. Frazier, Manager, Research Services

Normally, research for the steel industry has two purposes:

(1) To develop new processes within the mills or to improve existing processes. For example, research in this area has led to a 50% rise in blast furnace iron production in the past ten years, and a 30% reduction in coke consumed per ton of iron production. Quality has risen, too. And all this effort has helped maintain stable, nominally low prices for iron and steel.

(2) To develop new steel products to meet more sophisticated requirements in both old and new markets. For example, new petroleum drill pipe with yield strength of more than 100,000 psi has been developed and proven. Increased depth of newer wells has seen pipe used at higher stresses, thus increasing the chance of corrosion fatigue. And the yield strength level is being increased to 135,000 psi and 150,000 psi with the expectation of equally good performance.

But at The Youngstown Sheet and Tube Company, research has a third distinct purpose – perhaps the most important one of all: to be of direct assistance to the customer.

Youngstown Steel has organized a separate division of the Research Department for the specific purpose of providing customer assistance. This division makes available to the customer the complete services of the Youngstown Research facility, not just a part.

A typical example of this service concerned the redesign of a water tank. A customer was manufacturing low-pressure water tanks by welding two drawn heads to a roll-formed body section with a welded side seam. The entire assembly was galvanized by dipping the tank into molten zinc.

The manufacturer decided to try simplifying construction by making two deep drawn sections from galvanized steel sheets and joining two sections with one circumferential weld.

Youngstown's design team played a major role in designing the tank, calculated the size and thickness of the required blank and assured a satisfactory and economical solution. Many thousands of the redesigned tanks have been made, and the customer is getting ready to make another tank, newly designed with aid from Youngstown.

If desired, Youngstown researchers make studies to suggest ways to improve the product's appearance as well as its function. And it is noteworthy that a customer's size and the size of his problems do not necessarily correlate. All companies, large or small, are served on an equal basis.

While remaining in close contact with the customer to insure that all possible assistance is always available, great care is also taken to guard against intrusion. In many cases only the customer himself knows what design characteristics best fit his entire product line. In still other cases, absolute styling secrecy is imperative. The rule is this: Youngstown research facilities are ready when needed. Proof testing or prototype copies of the product are perhaps the best methods of exactly determining the customer's needs.

At the other end of the problem, Youngstown must supply information that can help the customer realize the right forming and fabricating method.

New methods of forming, such as stretch forming, electromagnetic forming, explosive forming and combinations of cold extrusion and cold heading are being used with increased efficiency. Fabrication of a steel product by using new joining methods, such as plasma arc, laser beam, ultrasonic and friction welding, can improve quality and cut cost. Assistance to the customer in the development and application of fabricating methods is given wherever possible.

Another important factor in determining whether or not a product can be produced profitably from steel is material handling. Increasing labor costs make it imperative to handle material mechanically. Using steel's magnetic properties can help reduce handling costs. The steel manufacturer does it in his own plant to transfer large tonnages of steel. The steel user has employed magnetic methods in some of his handling problems, but further economies can often be worked out. Helping improve material handling methods is just one of the Research Services Division's function.

Value Analysis, a method of determining the total cost of putting a product on the market, is used by Youngstown to help the customer reduce overall costs. For often most of the cost of a finished product is contained, not in the raw material, but in the many processes along the line.

Youngstown Steel's Research Services Division is dedicated to establishing a cooperative effort with the customer to maintain a complete exchange of all information helpful in building product quality and efficiency. Its benefits include assistance from Youngstown's Operating and Sales Departments as well.

This article gives a glimpse of what's happening in steel research at Youngstown. It's just a part of the continuing research effort going on 24 hours a day at Youngstown's research center.

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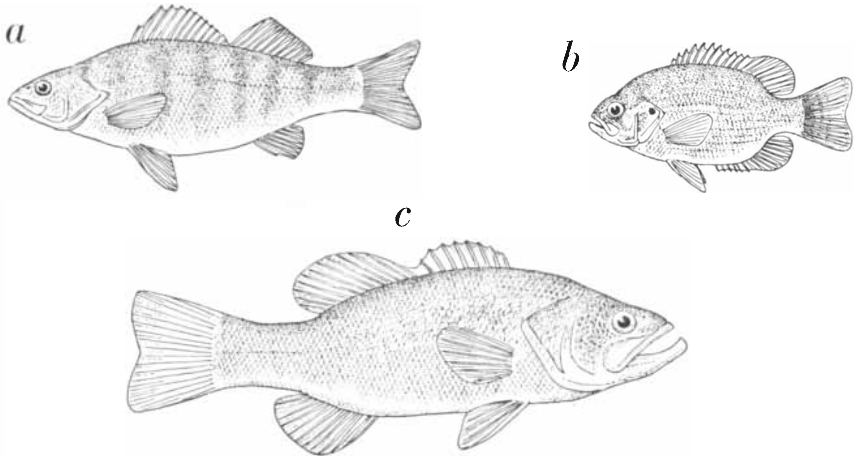


SUCCESSOR POPULATION of Great Lakes fishes when the lakes reach old age will probably include species that inhabit the lakes' shallow waters today. Among these are the yellow perch (*a*), the kind of sunfish known as rock bass (*b*) and the largemouth bass (*c*).

grossly polluted water of the Detroit River, into which 1.6 billion gallons of waste are discharged daily from the cities and industries along the riverbanks. To this pollution an enormous amount is added by the great urban and industrial complex around the lake itself. A recent study of the Detroit River by the U.S. Public Health Service showed that its waters contain large quantities of sewage bacteria, phenols, iron, oil, ammonia, chlorides, nitrogen compounds, phosphates and suspended solids. Similar waste materials are discharged into the lake by the steel, chemical, refining and manufacturing plants along the lake. Pollution is particularly serious in Lake Erie because of the lake's shallowness; its volume of water is too small to dilute the pollutants effectively. Over the past 50 years the concentrations of major contaminants in the Lake Erie waters have increased sharply.

Many of the industrial wastes, notably phenols and ammonia, act as poisons to the fish and other animal life in the lake. Solid material settles to the bottom and smothers bottom-dwelling organisms. Moreover, some of the solids decompose and in doing so deplete the water of one of its most vital constituents: dissolved oxygen. Algae, on the other hand, thrive in the polluted waters, particularly since the sewage wastes contain considerable amounts of the plant-fertilizing elements nitrogen and phosphorus. The algae contribute to the depletion of oxygen (when they die and decay), give the lake water disagreeable tastes and odors and frustrate the attempts of water-purifying plants to filter the water.

In addition to Lake Erie, the southern end of Lake Michigan has also become seriously polluted. Interestingly the city of Chicago, the dominant metropolis of this area, apparently does not contribute substantially to the lake pollution; it discharges its sewage into the Mississippi River system instead of the lake. The main discharge into Lake Michigan comes from the large industrial concentration—steel mills, refineries and other establishments—clustered along its southern shores. The Public Health Service has found that the lake water in this area contains high concentrations of inorganic nitrogen, phosphate, phenols and ammonia.

Apart from the southern end, most of the water of Lake Michigan is still of reasonably good quality. In Lake Ontario, although it receives a considerable discharge of wastes, the situation is not yet as serious as in Lake Erie because Ontario's much larger volume of water provides a higher dilution factor. Lake Huron, bordered by a comparatively small population, so far shows only minor pollution effects, and Lake Superior almost none. Nevertheless, the growth of the entire region and the spreading pollution of the lakes and their tributary waters make the long-range outlook disquieting. Already the quality of the waters over a considerable portion of the lake system has greatly deteriorated, and many bathing beaches must be closed periodically because of pollution.

It is clear that in less than 150 years man has brought about changes in the Great Lakes that probably would have taken many centuries under natural conditions. These changes, shortening the usable life of the lakes, seem to be accumulating at an ever increasing

The molecular "code" that controls life has been put into plain English

About THE LANGUAGE OF LIFE – a new book by Nobel Prize-winning geneticist, George Beadle, and his wife Muriel – "probably the most understandable introduction to the science of genetics that has ever been written."–Chicago Tribune

"The essential process by which the likeness of the parent is transmitted to the offspring . . . is as utterly mysterious to us as a flash of lightning is to a savage."

This was the opinion, in 1902, of William Bateson, the English biologist who coined the word "genetics." For many years afterwards, there was no reason for any scientist to disagree with him.

The events of the past decade are analagous to the discovery of a genetic Rosetta Stone. Science can now actually translate at least some of the messages written in the language of life – a language whose words are buried deep in the cells of our bodies. But until now, the astonishing breakthroughs made so recently have left most of us more mystified than Bateson's "savage," lost in a sea of strange initials like DNA and RNA.

The creators of the "New Genetics"

George Beadle, Nobel Laureate and President of the University of Chicago, is one of the scientists whose work has created modern genetics. Together with his wife Muriel, he has written a book that is both an introduction to the unprecedented expansion of genetic knowledge and an exciting pageant of people and ideas.

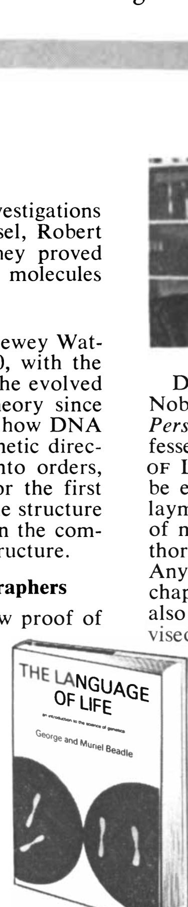
There is no question that a basic understanding of genetics is important. Genetics affects each of us every day of our lives. It affects our children and their children. Accumulating genetic defects pose one of the world's most urgent problems. The future of genetics – perhaps including human genetic selection – is perhaps the single most important issue facing mankind today.

THE LANGUAGE OF LIFE describes the momentous achievements that have relegated the fruit flies and garden peas of pre-1955 biology classes into the realm of ancient history. You will meet the Swiss biochemist Friedrich Miescher, who tried to break down protein when that substance was thought to contain the key to heredity, and was left with a residue of unexplained white powder. For decades, this powder – nucleic acid – lay on the chemists'shelves until, finally, the pioneering investigations of men such as Albrecht Kossel, Robert Feulgen, and Albert D. Hershey proved that it contained the master molecules of life.

You will also meet James Dewey Watson, not yet 25 when, in 1950, with the British chemist Francis Crick, he evolved the most important genetic theory since Mendel's – one that explained how DNA makes copies of itself, how genetic directions are written, translated into orders, and modified by mutation. For the first time, scientists could discuss the structure and behavior of living things in the common language of molecular structure.

Geneticists become cryptographers

You will read too about how proof of this theory rapidly came from many quarters. Finally, in 1956, Arthur Kornberg succeeded in synthesizing DNA, giving rise to sensational news stories about "life in a test-tube," and turning scientists into code-breakers. An example of just how talented geneticists have had to become as cryptographers came when Beadle won the Nobel Prize. He was sent a telegram by virologist Max Delbruck which consisted of an unbroken line of 123 letters – A, B, C, and D only. Deciphered, it read: "Break this code or give back the Nobel Prize."



Critical acclaim for THE LANGUAGE OF LIFE

Reading THE LANGUAGE OF LIFE requires no code-breaking talents. Acclaim has come from both general publications and from scientific journals. The *Chicago Tribune* says "the Beadles have surmounted the scholarly language barrier that has been the downfall of other authors. Each scientific word and concept has been pounded into everyday language."

The *New York Times Book Review* adds that "the pitfalls which the authors had to avoid, *and have avoided,* was that science simplified may be science falsified . . . the experiment is successful."

Archie Lieberman

Dr. Albert Szent-Gyorgi, himself a Nobel Laureate, reviewing the book in *Perspectives in Biology and Medicine* confessed that before reading THE LANGUAGE OF LIFE he "doubted that genetics could be explained clearly and satisfactorily to laymen who are not soaked with the idea of molecules." But, he goes on, "the authors of this book succeed wonderfully . . . Anybody who wants an insight into this chapter of human history . . . and wants also to have a good time, is urgently advised to buy it."

Indexed, and illustrated with more than 100 diagrams and drawings, THE LANGUAGE OF LIFE is a book for every reader of *Scientific American.* You may examine a copy for two weeks without obligation. If you don't agree that it is a lucid introduction to the modern science of genetics, and is therefore as much a "breakthrough" as the one it describes, you may return it and owe nothing.

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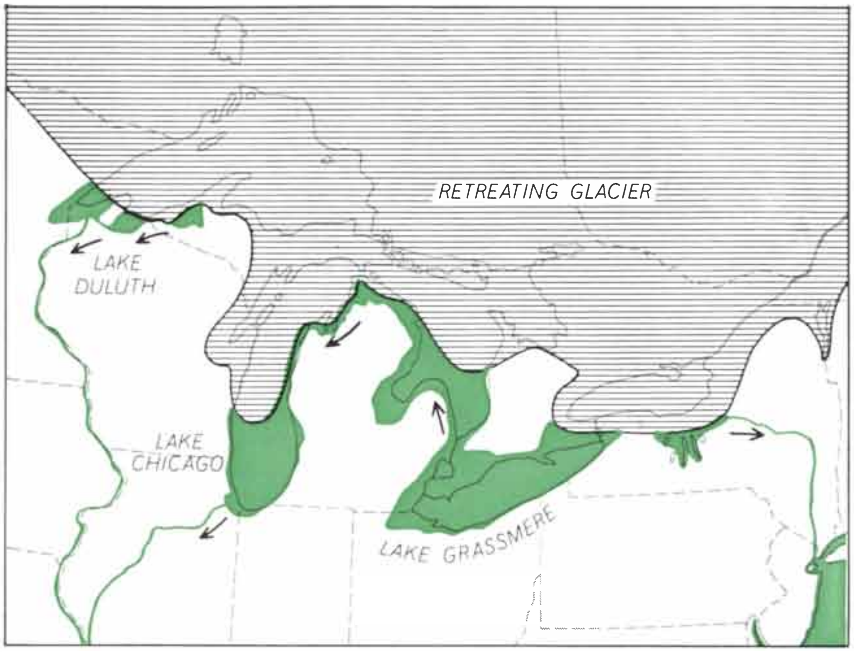
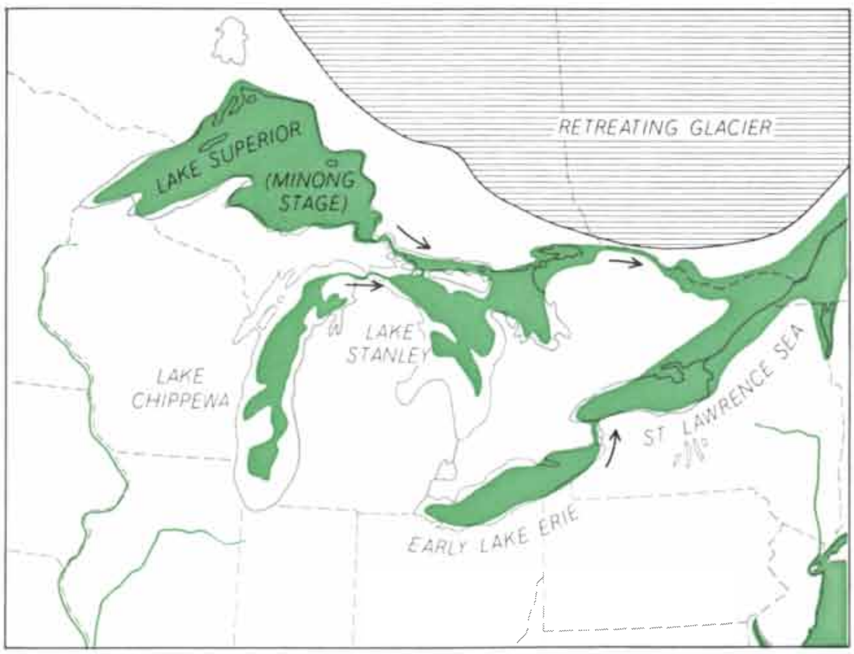
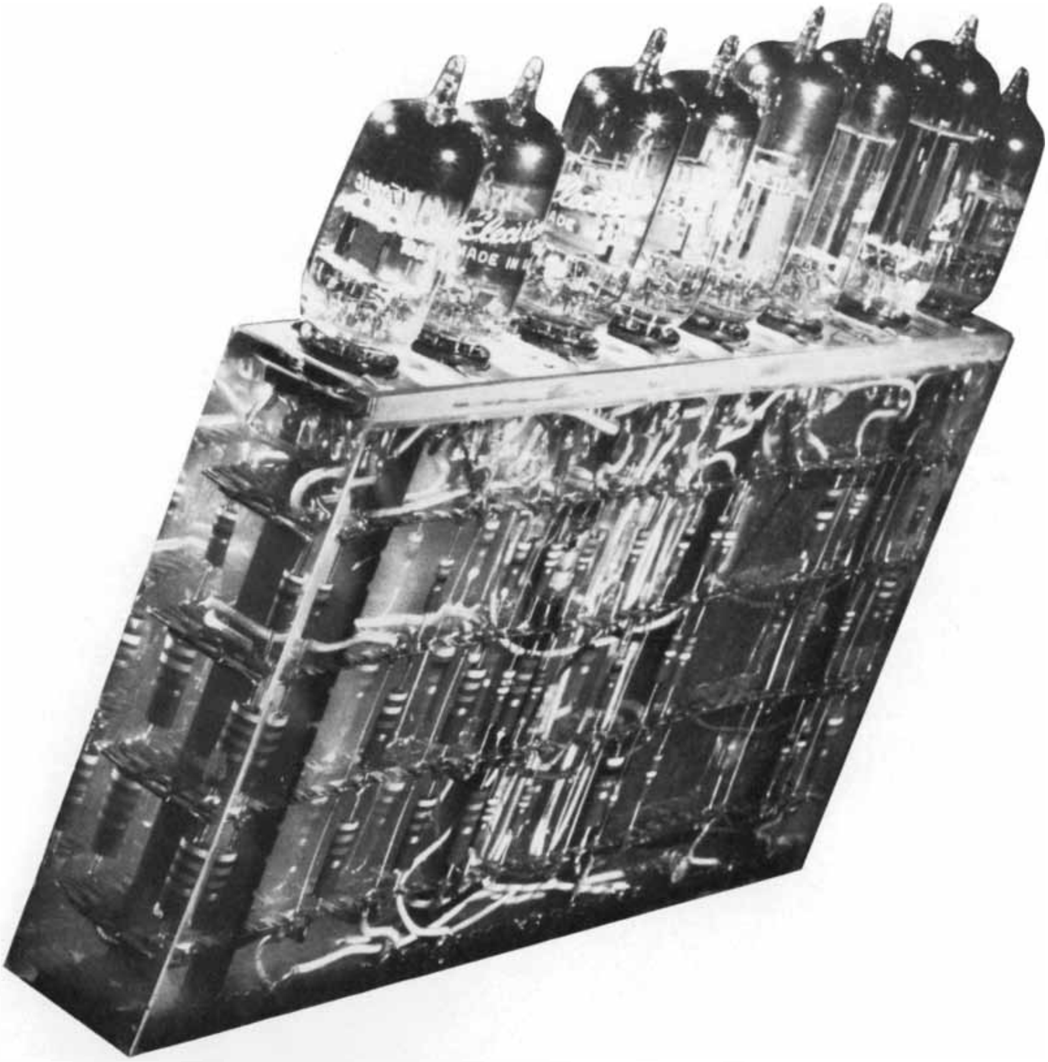
rate. We still know far too little about the complicated processes that are under way or about what measures are necessary to conserve this great continental resource. Obviously the problem calls for much more study and for action that will not be too little and too late. No doubt the Great Lakes will be there for a long time to come; they are not likely to dry up in the foreseeable future. But it will be tragic irony if one day we have to look out over their vast waters and reflect bitterly, with the Ancient Mariner, that there is not a drop to drink. To realize that this is not an unthinkable eventuality we need only remind ourselves of the water crisis in New York City, where water last year had to be drastically rationed while billions of gallons in the grossly polluted Hudson River flowed uselessly by the city.



YOUNG LAKES drained southward, via the Mississippi to the west and the Mohawk and Hudson to the east, during the last glacial retreat of the Pleistocene some 10,000 years ago.



MATURING LAKES altered the southward drainage pattern and began to channel their waters eastward into the prehistoric St. Lawrence Sea as the glacial retreat continued.



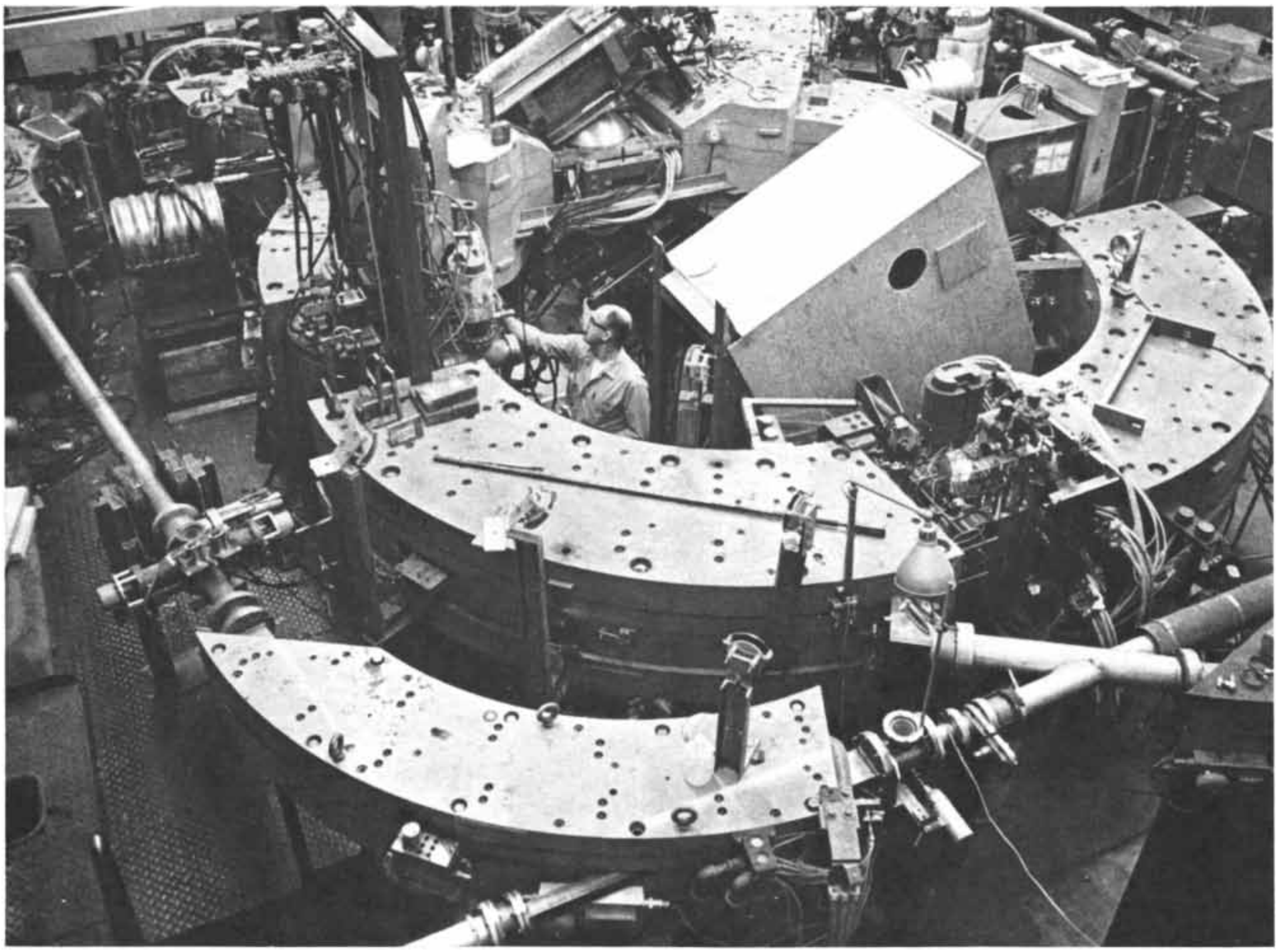
Particle Storage Rings

A new method of achieving particle interactions exploits the fact that the head-on collision of two moving objects releases greater energy than if one of the moving objects hits a stationary target

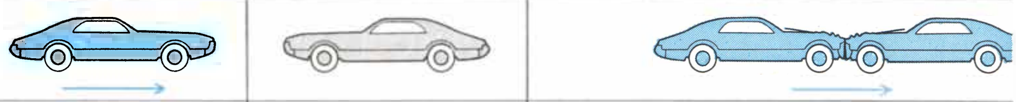
by Gerard K. O'Neill

During the past 18 months a new method of carrying out experiments in high-energy physics has achieved its first successes. The method was a subject of interest and controversy in the years after it was first put forward, and even now the prospects for its future development are bright in general but uncertain in detail. It consists of inducing subatomic particles to collide with each other head on, in contrast to conventional high-energy experiments in which accelerated particles collide with particles that are at rest. Since it is very difficult to arrange for particles in two beams to collide, the rewards must be high enough to justify the effort. The rewards are in terms of energy.

When two objects collide—two automobiles, two billiard balls, two protons



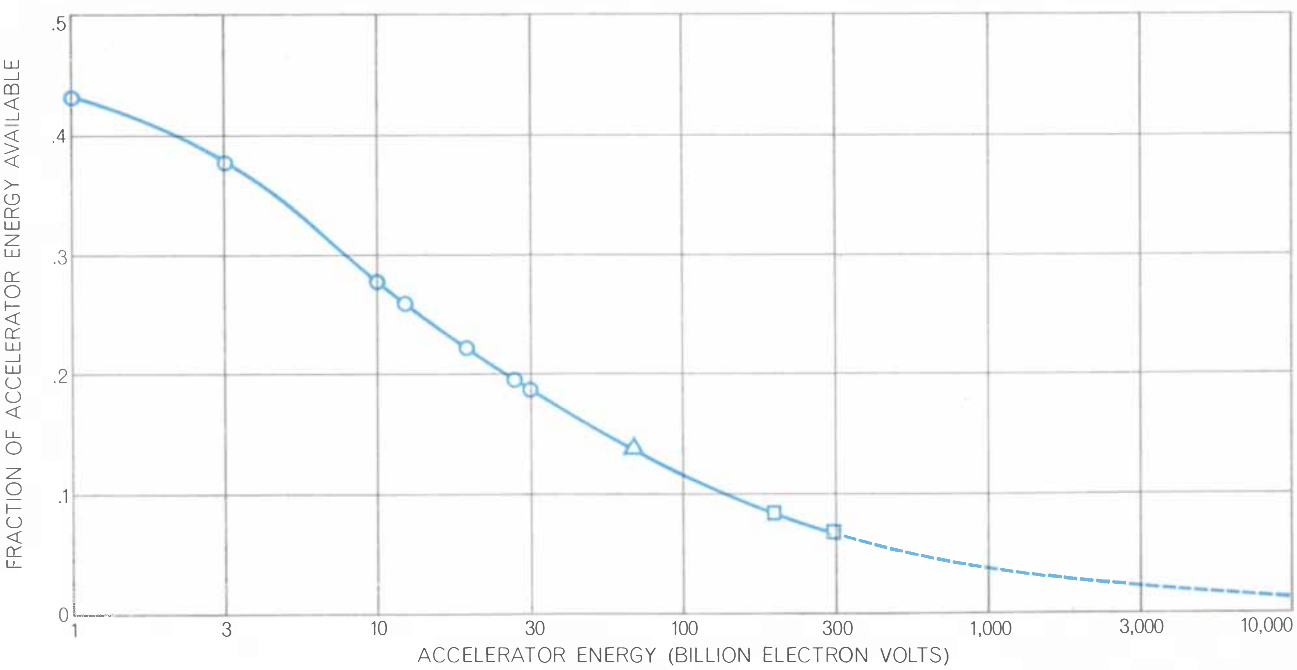
PRINCETON-STANFORD STORAGE RINGS contain circulating beams of electrons that collide where the two rings join at the top center of the picture. Spark chambers located next to this region record the tracks of charged particles created by the collisions. The pipes in the foreground carry electrons injected into the rings from a nearby linear accelerator of one billion electron volts (one GeV).

	BEFORE COLLISION		AFTER COLLISION
	FIRST CAR	SECOND CAR	WRECKAGE
	MOVING TO THE RIGHT	STANDING STILL	MOVING TO THE RIGHT HALF AS FAST
(STATIONARY-TARGET CASE)			
MOMENTUM	$+mv$	0	$(2m)(v/2) = mv$
KINETIC ENERGY	$1/2\ mv^2$	0	$1/2(2m)(v/2)^2 = 1/4\ mv^2$

IMPACT ON STATIONARY TARGET resembles the situation in a conventional particle accelerator. The automobiles each have mass m and one is moving with velocity v. Only half of the original energy of the moving car, $1/4\ mv^2$, goes into crumpling metal.

	MOVING TO THE RIGHT	MOVING TO THE LEFT	STANDING STILL
(HEAD-ON COLLISION CASE)			
MOMENTUM	$+mv$	$-mv$	0
KINETIC ENERGY	$1/2\ mv^2$	$1/2\ mv^2$	0

COLLISION OF TWO MOVING OBJECTS represents the situation that can be achieved by using storage rings to produce electron-electron or proton-proton collisions. In this case the kinetic energy of both automobiles, two times $1/2\ mv^2$, or mv^2, goes into crumpling metal. This is four times the "collision energy" made available in the stationary-target case shown at the top of the page.



AVAILABLE COLLISION ENERGY for stationary proton targets is a decreasing fraction of accelerator energy as the energy of the impacting particle increases. Curve shows accelerators in operation (*circles*), under construction (*triangle*) or projected (*squares*).

or any other two objects—the total energy present after the collision is the same as the energy present before. Some of the energy may have been converted into heat, or in the case of particle collisions some may have been turned into mass according to Einstein's relation $E = mc^2$, but the total remains unchanged. The total momentum in the system also remains constant.

At speeds much less than the speed of light (the c of $E = mc^2$) the kinetic energy of an object of mass m is $1/2\ mv^2$, where v is the speed of the object. Under the same conditions the momentum of the object is simply mv. Keeping in mind that the total energy and the total momentum are unchanged in any collision, one can follow where the energy goes in either of two cases: a collision between a moving object and a stationary target and a head-on collision between moving objects [*see top and middle illustrations on opposite page*].

It is easy to see that if a moving object, say an automobile, hits another object of equal mass that is at rest, the subsequent velocity of the wreckage (assuming that it is in one piece) is just half that of the object that was moving. But how much energy has gone into the crumpling of metal? The answer is the difference between the initial kinetic energy and the final kinetic energy, or $1/4\ mv^2$, which is half the kinetic energy originally possessed by the moving car. This is the true "collision energy." If we had been dealing with subatomic particles rather than automobiles, this would have been the energy available for creating new particles according to Einstein's equation for converting energy into mass.

Suppose now two automobiles moving at equal speed collide head on, leaving wreckage that is motionless. Here all the kinetic energy originally present (two times $1/2\ mv^2$, or simply mv^2) would have gone into the crumpling of the metal. This is four times as much energy as the energy that was made available before.

All collision experiments in high-energy physics before last year involved stationary targets. That was not a serious disadvantage when particle speeds were relatively low, but accelerators built in the past few years can accelerate their particles to speeds quite close to the speed of light. At such speeds the formulas of the special theory of relativity must be used, and they replace our simple expressions for energy and momentum by somewhat more complicated ones. The relativistic formulas show that for stationary targets the collision energy is a smaller and smaller fraction of the input energy as the speed of the incident particle approaches the speed of light. For the largest existing accelerators the collision energy is only a fifth of the input energy, and for the largest accelerators now being planned it is less than a tenth [*see bottom illustration on opposite page*].

It is customary to express the energies of high-energy physics in units of billions of electron volts, a unit that used to be abbreviated BeV but is now usually designated GeV. The "G" stands for "giga," which is defined as 10^9, the American billion, and thus cannot be confused with the European billion, which is 10^{12}. An energy of one GeV is roughly equivalent to the mass of one proton or of 2,000 electrons. A proton with one GeV of kinetic energy is traveling at about 90 percent of the speed of light, and an electron with one GeV is moving at so nearly the speed of light that the difference is only one part in 10 million.

It is clear from the low conversion of input energy to collision energy in conventional accelerators that there is good reason to press for the development of colliding-beam devices. To make the idea practical one must first solve the problem of achieving a reasonable rate of interaction between particles in the two beams. The number of interactions per second in a given volume is proportional to the number of target particles in the volume and to the number of incident particles per second. In a typical experiment with a stationary target consisting of liquid hydrogen, the product (called the luminosity) of the two critical quantities is about 10^{27}. At this luminosity there would be one interaction per second for each centimeter of target thickness, assuming that in a collision each particle acts as though it shadowed an area of 10^{-27} square centimeter.

If two ordinary accelerators were to fire their particle beams at each other, the luminosity would be only 10^{18}, a figure that is a billion times smaller than 10^{27}. The way to gain the needed factor of a billion is to greatly increase the number of particles in each beam and to give each particle many chances to interact with those of the opposing beam. Both goals can be attained by collecting the particles from many acceleration cycles and storing them in some ringlike device where they can circulate until they collide. The basic idea now seems obvious, and it was arrived at independently by a number of people in various places over a period of more than a decade.

To my knowledge the first person to suggest a practical way of making beams collide was Rolf Wideroe, a Norwegian physicist. In 1949 he applied for a German patent on his idea, but in the words of a recent letter from Wideroe, "the patent people regarded the interesting energetic point of colliding beams as obvious and quite unsuitable for obtaining a patent, so I had to bring in some other arguments for my idea." These other arguments were quite secondary and need not concern us. Wideroe's basic proposal was to store particles of the same electric charge traveling in opposite directions on a single circular orbit. To provide the bending force needed to hold the particles in orbit he proposed to use electrostatic fields. It happens that attainable electrostatic forces are only about 1 percent as strong as magnetic ones, and hence a proton-proton storage ring based on Wideroe's concept would have to be of enormous size to achieve even modest energy. I first learned of his work after several reinventions of the basic idea.

In the early 1950's it occurred to physicists at the Midwest University Research Association (MURA) in Wisconsin that a special type of synchrotron they had invented could be used for both acceleration and particle storage; they therefore proposed an accelerator in which beams of high intensity could be made to collide. Unfortunately the special types of machines required for simultaneous acceleration and beam storage would have been particularly large and inflexible. Their cost would have wiped out much of the economic advantage of colliding beams, and partly for that reason no such machine was ever built.

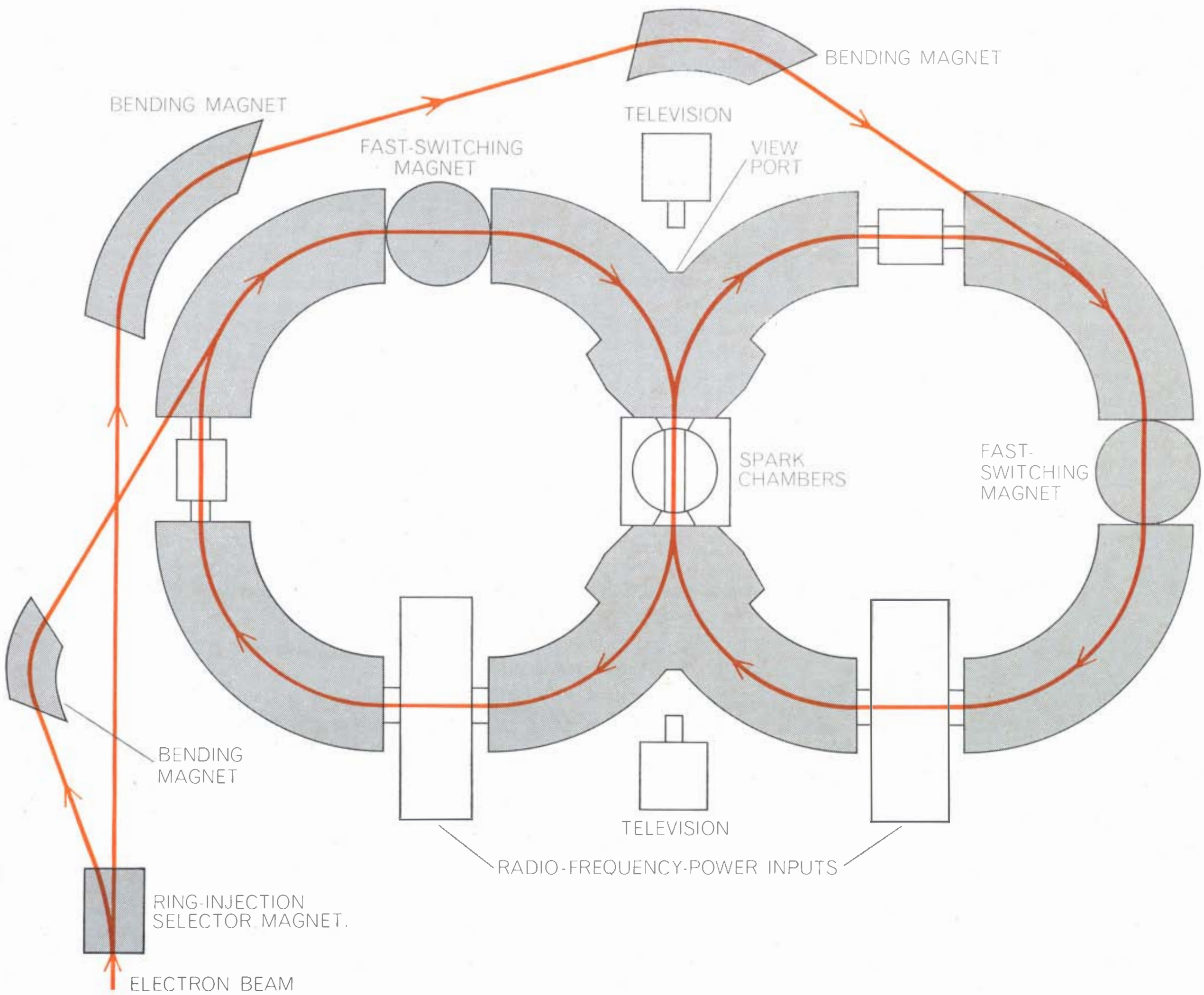
Early in 1956 there occurred independently what were in some respects three simultaneous reinventions of Wideroe's idea. The new version was the basis for theoretical and technical development toward a practical device. After considering the MURA proposal I thought of a way to combine the advantages of beam storage with the comparative simplicity of conventional accelerator design. Almost simultaneously W. M. Brobeck of the University of California at Berkeley and Don B. Lichtenberg, Roger Newton and Marc Ross of MURA had the same idea. The concept was to build two synchrotron-like guide fields near an ordinary accelerator. These extra guide fields, called storage rings, would have a common straight section—a region free of magnetic fields and common to the two orbits. Each ring would be filled by the accumulation of many bursts of particles that had been kicked out of the source accelerator, guided through the intervening space and kicked into the orbit of the ring. The bending force was to be applied by magnetic fields, as is usual in accelerators. The storage of high-energy beams had been worked out in theory and tested with electrons by physicists at MURA. Some years later E. J. Woods and I showed that in principle the storage ring solution to the colliding-beam problem was capable of achieving the same luminosity as the proposed MURA accelerator-storage ring.

The development of the storage ring idea into practical hardware depended first on the invention of special fast-acting magnets, which could exert strong magnetic fields of well-controlled shape within a ten-millionth of a second. In 1957 V. Korenman and I, working at Princeton University, built a magnet of that kind. Then it was necessary to turn to the most advanced technology of producing ultrahigh vacuums, so that the stored beams could circulate with low rates of particle loss.

The first successful application of the colliding-beam principle to high-energy physics was achieved in 1965 with electrons. They were selected over protons for the initial experiment for two reasons. First, the electron's mass is only 1/1,836th of the mass of the proton; therefore an electron can be accelerated to a given fraction of the velocity of light with only 1/1,836th as much energy as is needed to accelerate a proton. Second, an electron circulating in a magnetic field radiates energy in the form of visible light and soft X rays. The energy lost in this way provides a frictional damping that greatly simplifies the process of injecting electrons into the storage ring. With protons a useful energy loss of that kind would occur only at many thousands of GeV.

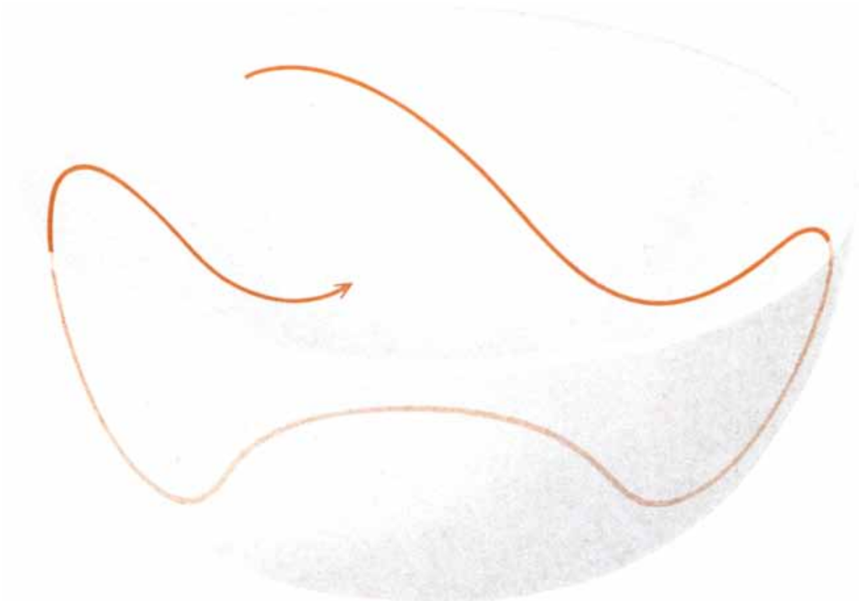
Late in 1956 I began to design an experiment that would involve colliding electron beams in storage rings. I chose as a goal the collision of one electron with another at an energy of .5 GeV for each electron. The apparatus required would be of moderate size, but the radiation damping would be strong at that energy. To perform the same experiment with a conventional electron beam and a stationary electron target would require an electron accelerator of 1,000 GeV, or 1,000 times more energy than that of any machine then in operation.

After about a year of initial design



PLAN OF PRINCETON-STANFORD STORAGE RINGS shows how colliding beams of electrons are built up and maintained. The fast-switching magnets are needed to inject incoming bursts of electrons into the guide field of each ring. Radio-frequency power is supplied to replace the energy that is radiated by the circulating electrons. Each circulating beam has an energy of .56 GeV.

work at Princeton I enlisted the support of Wolfgang K. H. Panofsky of Stanford University. Within the next year a partnership of physicists at Princeton and Stanford was formed. Another year of detailed design passed, Government support was obtained from the Office of Naval Research and the Atomic Energy Commission, and in 1959 construction was begun on a pair of storage rings to be located at the Stanford one-GeV linear electron accelerator [*see illustration on opposite page*]. I chose the linear accelerator for the work because it would automatically solve part of the transfer problem—the extraction of an intense electron beam in a short burst. In a circular accelerator it is quite difficult to bring out a good external beam. In a linear accelerator the beam comes out whether you want it to or not. The Stanford members of the partnership were W. C. Barber and B. Richter; the Princeton members were B. Gittelman and I. We collaborated closely in solving one by one the various problems that came up in the course of making the new technique work.

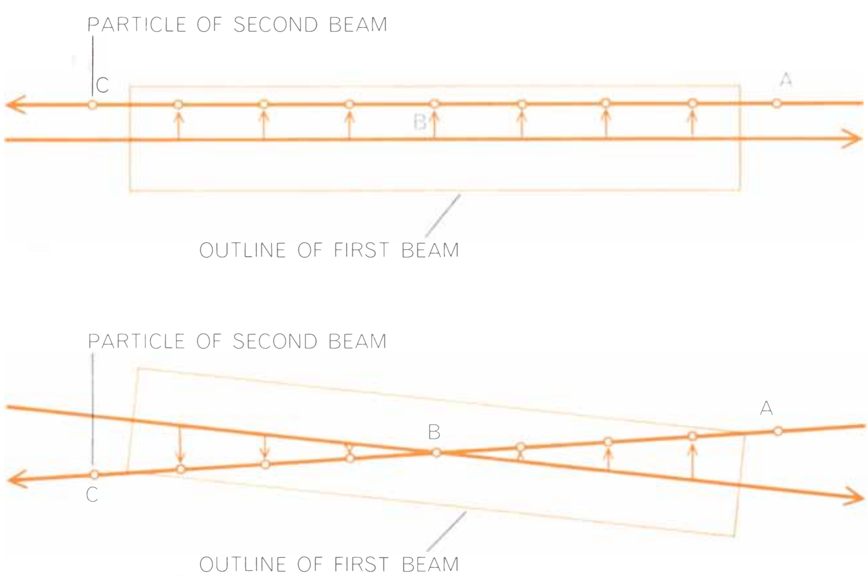


ANALOGUE OF CIRCULATING PARTICLE is provided by a ball traveling inside a bowl. Unless the ball is started in just the right direction it will oscillate up and down as it travels. An electron in a guide field, to which radio-frequency power is applied, acts like a ball in a bowl with some friction, being given a forward kick each time it completes one orbit.

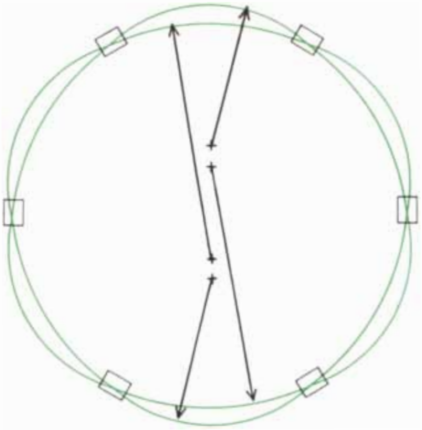
Electrons at full energy in the .5-GeV storage rings radiate about a hundred-thousandth of their energy on each turn. The energy is continuously replaced by radio-frequency power fed in from outside, a process that is essential for particle storage in that particular ring. Our first unpleasant surprise was that the X rays from the circulating electrons raised the gas pressure in the evacuated ring to a level that prevented useful operation. The effect was finally explained by E. Garwin of Stanford University as a two-step process in which the X rays liberated electrons from the walls of the vacuum chamber and the electrons in turn released gas atoms that had been adsorbed on the chamber walls. M. Bernardini of the Italian National Laboratory at Frascati and L. Malter of Varian Associates subsequently worked out the consequences of Garwin's suggestion in a quantitative way. The solution to the problem was to increase the number of vacuum pumps connected to the storage ring.

Our second unpleasant surprise was of a more subtle nature. In any synchrotron or storage ring the circulating particles are held in their circular orbit by magnetic focusing forces, and when they are disturbed from that orbit, they go through oscillations around it. Their motion is much like that of a ball rolling around a bowl [*see top illustration on this page*]. In the case of a particle in a magnetic field there are horizontal and vertical oscillations, each of different frequency, and neither of them can be allowed to be a simple multiple of the circulation frequency. If there is such a resonant relation, unavoidable slight imperfections of the guide field will cause one of the oscillations to grow until the particles strike the wall of the vacuum chamber and are lost. In designing the .5-GeV experiment I anticipated that when the two beams passed through each other, their oscillation frequencies would be driven into a resonance. For this reason I included in the design a magnet to produce a slight zigzag in the particle orbits, so that the electrostatic force of one beam on the particles of the other would tend to average to zero [*see illustration below*].

Until 1962, when we began storing circulating electron currents of a few



FORCES ACTING ON CROSSING BEAMS must be considered when designing storage rings. If beams of particles of like charge, such as electrons or protons, are allowed to meet head on (*top*), the electrostatic force at each instant will add to give a net upward kick to a particle traveling from *A* to *C*. The solution is to have the beams intersect at a small angle (*bottom*). In this case a particle receives an upward kick in going from *A* to *B* and a compensating downward kick in going from *B* to *C*, so that the net effect is nearly zero.



CONCENTRIC DESIGN of storage ring enables particles circulating in opposite direction to cross paths several times in each revolution. This is achieved by designing orbits in which sections of short radius alternate with sections of longer radius. Experiments can be done at each intersection.

milliamperes in the .5-GeV rings, we had been unable to think of any other beam instability that might cause difficulty. We were rudely reminded that nature is an ingenious troublemaker. We found that when we stored currents of a few milliamperes in a single beam, guided by a well-shaped magnetic field free of residual ions, the beam nevertheless developed vertical oscillations that grew until after about a million turns, requiring less than a second, the beam was entirely lost. At about the same time a similar effect was observed in a proton accelerator at the Brookhaven National Laboratory. After several months in which many new theories were advanced and discarded, D. DePackh of the Naval Research Laboratory found a clue to the effect in work done by John R. Pierce at the Bell Telephone Laboratories in 1951. Pierce's work had to do with an exotic type of microwave-amplifying electron tube.

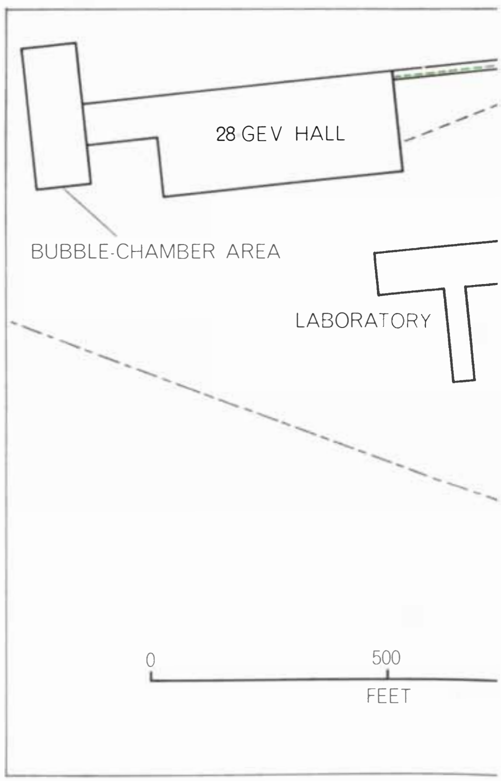
DePackh was able to show that our puzzling instability was caused by the "wake" of electromagnetic charges and currents left on the walls of the vacuum chamber after the beam went by. It had escaped notice before because it required that the walls be conductors, but not very good conductors, and theories up to that time had neglected that subtlety. We found that the electrostatic forces due to residual ions were enough to kill the oscillations, and so we concluded that the oscillations could grow only in a guide field of unusually high quality, in which the oscillation frequency was independent of the oscillation amplitude. At the suggestion of D. Ritson of Stanford we added magnets to distort the shape of the field and were then able to operate even when the ions were cleared away.

When beams were stored in both rings, we found that one beam occasionally knocked out the other. That effect too was not predicted, and it is still not completely understood. Several of the ideas that have helped to provide an intuitive understanding of the more complicated instabilities were expressed at a small conference held in March, 1965, at the Russian "Science City" near Novosibirsk, where G. Budker and his colleagues were our hosts. The ideas were developed in more detail during a summer study held at Stanford later that year. Ernest D. Courant of Brookhaven and A. M. Sessler of the University of California at Berkeley have been particularly active in clarifying the nature of the various instabilities.

Fortunately it has turned out that operating conditions could be found at which none of the instabilities were serious, and by early 1965 we were able to achieve a luminosity exceeding our minimum goal of 10^{27}. The apparatus for detecting collision events consisted of spark chambers and counters [*see illustration on page 114*]. With these detectors we photographed about 400 electron-electron collisions at an energy of .3 GeV for each electron. Recently we made a number of improvements in the apparatus and now are able to operate at an energy of .56 GeV for each particle, somewhat higher than the original design energy. We have collected data that provide a particularly clean test of quantum electrodynamics, the theory for which the 1965 Nobel prize in physics was awarded.

In the years during which we were slowly working up to the intense circulating beams needed for high-energy experiments, another research group contributed much to the understanding of storage rings and achieved some specific goals sooner than we did. This group, consisting of Italian physicists based at the University of Rome and a few miles away at the National Laboratory in Frascati, decided early in 1960 to make a small storage ring for both negative and positive electrons (positrons) of .25 GeV. They called their machine "Ada" for *annelli d'accumulazione* (accumulation rings). Because of its lower energy and because electrons and positrons can circulate in opposite directions in the same magnetic guide field, Ada was only about a quarter the size of our apparatus. Its small size and simplicity permitted its being brought into operation rapidly. There was no intention of using it for a real experiment in high-energy physics; rather it was for the study of storage rings themselves. The Ada injection system was quite simple but not capable of building up a large stored beam. Nearly all the measurements with Ada were based on electron currents of one or two milliamperes, as compared with the 50 milliamperes we have obtained in the electron-electron rings at Stanford.

By late 1961 Ada was equipped with an ultrahigh-vacuum chamber, and in it stored electrons were made to circulate for several hours. In 1962 the entire ring, still at high vacuum, was transported by truck to the French one-GeV linear accelerator at Orsay, near Paris. There, where a more intense beam was available for injection, it was found that the lifetime of the circulating particles decreased when many of them were stored at once. The new effect was explained by Bruno Touschek of the Ada research group, who showed that when the electron density became high, the electrons elbowed each other out of the storage ring by an indirect effect of their electrostatic repulsion. Fortunately the "Touschek effect" is important only for electron storage rings at low energy and is not serious above .3 GeV. At the



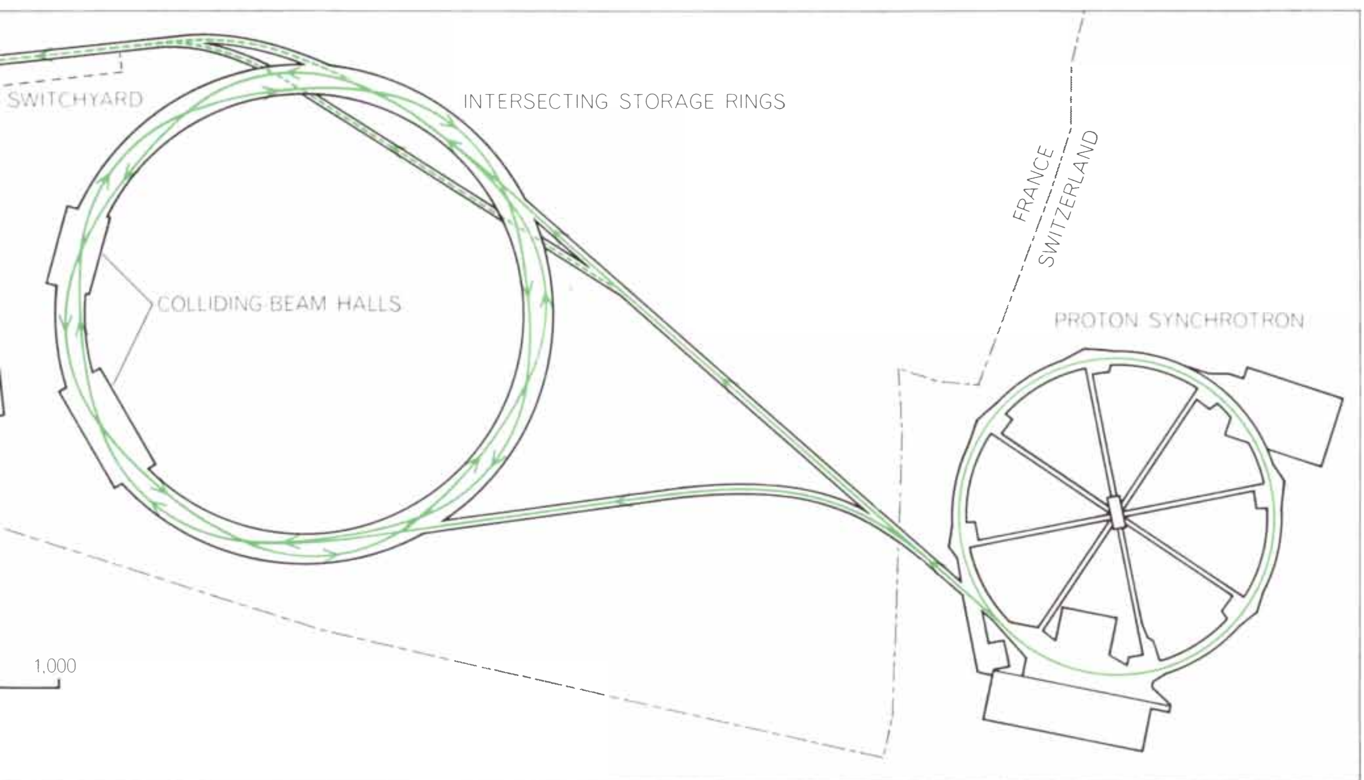
STORAGE RINGS AT CERN (the European Organization for Nuclear Research), will circulate protons accelerated by the end of 1963 the Ada group recorded the first definite colliding-beam reactions. The process they observed had a high probability of occurrence but could not provide information of importance for high-energy physics; it simply showed that a collision of electrons had taken place. Later Ada was used for the systematic study of beam size, and in 1965 it was retired. In contrast, our more ambitious electron-electron storage ring, begun several years earlier than Ada, did not demonstrate colliding-beam reactions until January, 1964, and did not yield high-energy data until 1965. Later that year an electron-electron storage ring at Novosibirsk began producing data at .04 GeV.

The range of experiments that can be done is much greater for electron-positron rings than for electron-electron rings, and today we believe our increased understanding of storage rings is sufficient to outweigh the fact that the rate at which one can inject positrons into rings is about 1,000 times smaller than the electron-injection rate. Accordingly a number of electron-positron rings are now being designed or built. These include new rings at Orsay, Stanford and Novosibirsk in which the energy per beam will range from .45 GeV to 4 GeV. A ring with 1.5-GeV beams is well along at Frascati [*see illustration on page 116*]. A ring with 3-GeV beams has been partly authorized for Stanford and a 4-GeV ring will be built at Cambridge, Mass., by modifying the joint Harvard and Massachusetts Institute of Technology electron synchrotron. At Novosibirsk a ring with .38-GeV beams has just begun operating, and another to circulate beams of 4 GeV is under construction.

The principal reaction for rings storing electrons (e^-) and positrons (e^+) will be the production of particle-antiparticle pairs, according to the reaction $e^+ + e^- \rightarrow A + \bar{A}$. A can be any particle and $\bar{A}$ its antiparticle, as long as the energy of the beam particle exceeds the rest energy of A. Nearly all particles that have a lifetime longer than about 10^{-20} second have rest energies less than 1.3 GeV, and so do many shorter-lived particles. The new 1.5-GeV storage ring facility at Frascati, called "Adone" (for "big Ada"), will therefore be able to open up many new reactions for study. The Adone ring will have four straight sections at which experiments can be simultaneously set up, and of these straight sections two can be in use at one time. The electron-positron storage ring at Orsay has begun to operate but has not yet stored large positron currents. The ring at Novosibirsk has just begun to produce high-energy physics data.

In 1956, at the beginning of the present interest in colliding-beam devices, the primary goal was proton-proton storage rings. In the intervening decade it was recognized that the initial goal was much harder to reach than that of building electron-electron storage rings. It was known that useful proton-proton rings cannot be built in small sizes, but there turned out to be other technical hurdles as well.

Protons, which do not radiate as electrons do, have the peculiar property of "remembering" everything that is done to them from the beginning of the acceleration process. In particular if they once begin to oscillate they continue in oscillation. In my first proposal for a proton storage ring I suggested the exploration of systems that would deliberately induce energy losses in the hope of reducing unwanted oscillations. Studies with a computer subsequently showed no conditions of energy loss that would achieve the desired result. Late in 1956 K. R. Symon and Sessler, then at MURA, were able to prove that no system based on energy loss could substitute for the electron's radiation. Only

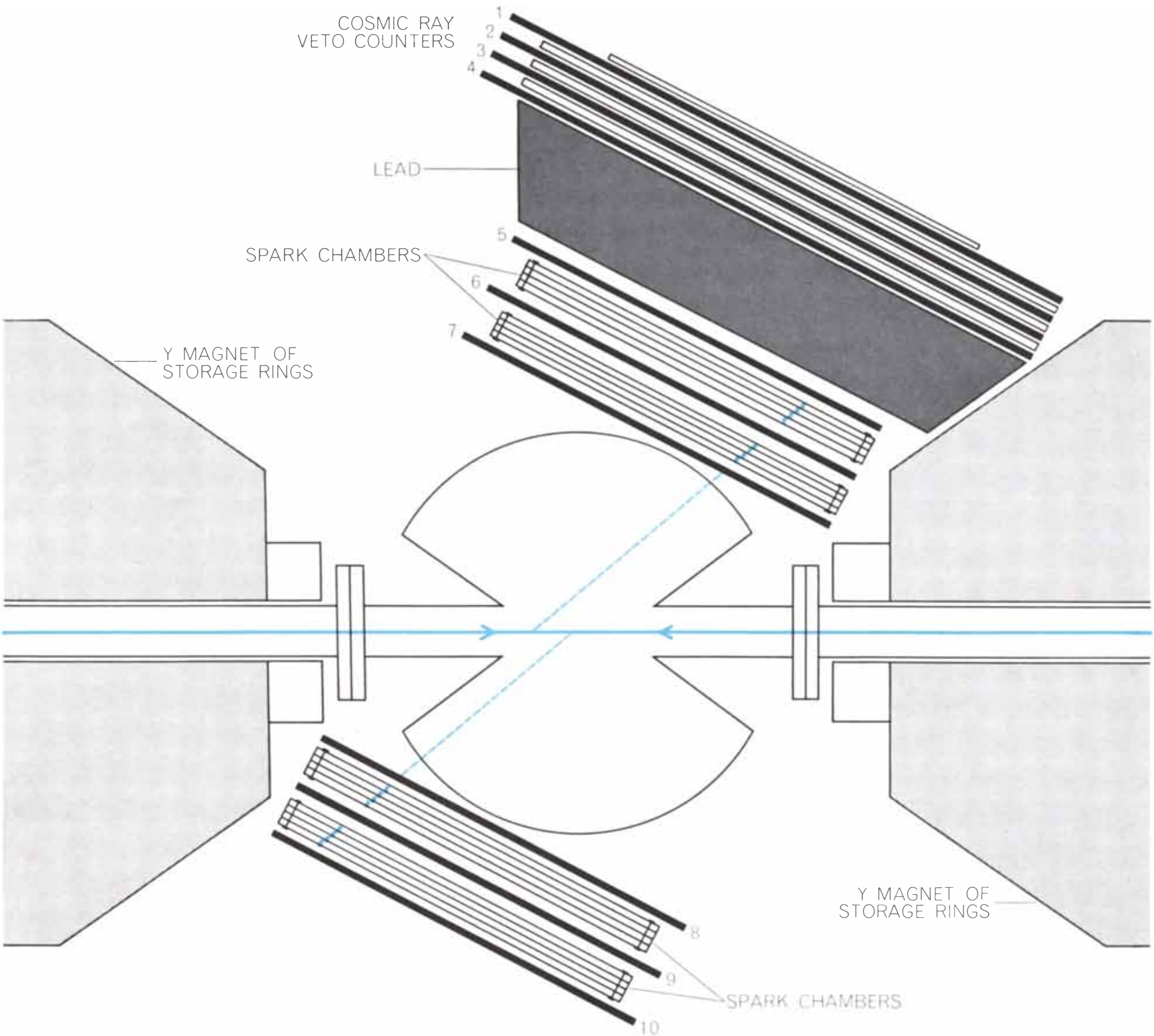


existing 28-GeV synchrotron located on Swiss territory. The 1,000-foot-diameter storage rings, of concentric design, will be across the border in France. This plan view shows how protons can either be switched into the rings or sent to the "switchyard" outside the 28-GeV hall, where they can be directed into a variety of stationary targets. CERN intersecting rings should be in operation by 1971.

after the development of fast-switching magnets (which could transfer proton beams without loss) and after more theoretical work was it clear that large currents of stored protons could be achieved.

By 1958, when the construction of large proton storage rings finally seemed feasible, it made sense to ask how colliding beams of protons might be used. Two new developments helped greatly. One was the invention by T. Collins, a member of the electron-accelerator group at the University of Cambridge, of a way to increase substantially the length of the field-free straight sections in which experiments could be performed. The second was a new geometry for the path of the circulating protons that made it possible to carry out several experiments simultaneously [*see top illustration on page 112*]. In the new geometry the proton beam followed a path in which curvatures of large and small radii alternated, so that beams traveling in opposite directions would cross each other several times. The new "concentric" design was discussed at a conference in Geneva in 1959, about the same time that Collins' ideas for long straight sections were put forward. Enthusiasm for storage rings was increased by the successful development of spark chambers for recording the paths of charged particles involved in nuclear events [see "The Spark Chamber," by Gerard K. O'Neill; SCIENTIFIC AMERICAN, August, 1962]. Although spark chambers have proved useful for many kinds of high-energy experiments, they seem made to order for storage rings, which enhance their advantages and tolerate their limitations.

After 1960, when the technical situation became fairly clear, there were several attempts to initiate construction projects for proton rings. Of these the most consistent, well-organized and systematic was carried out at CERN in Geneva. That laboratory, operated as a joint venture by more than a dozen European nations, is a leading example of successful international cooperation in



SPARK CHAMBERS of the Princeton-Stanford electron storage ring are installed at an angle that maximizes the number of particle tracks it can record. A spark chamber is triggered to fire only when a particle meeting certain requirements passes through a system of counters (*5, 6, 7, 8, 9, 10*). The particle track is then photographed. If the particle passing through the spark chamber happens to be one produced by a cosmic ray, it will trigger other counters (*1, 2, 3, 4*) that have a veto over the triggering of the chamber.

science. One of its significant achievements was the completion in 1959, several months ahead of schedule, of a 28-GeV proton synchrotron. Many of the same physicists and engineers who worked on that project joined a group now headed by Kjell Johnsen that initiated a theoretical study of storage rings. In 1962 they adopted a concentric design and conducted a study program on the design of experiments. In 1965 the CERN nations gave their final approval to the construction of the CERN intersecting storage rings (I.S.R.). After a year of detailed design the construction of the rings was begun, and their completion is expected about 1971.

The operating characteristics of the CERN rings are impressive and for a long time will be unique. Twenty amperes of protons will circulate in each ring, and the total energy available in each collision will be 56 GeV. The $85-million cost of the project, although large, is less than the cost of the last major accelerator project authorized: the two-mile Stanford linear accelerator. It is only a small fraction of the $350-million cost of the projected American 200-GeV proton synchrotron. Conventional synchrotrons are unlikely to equal the energy of the CERN I.S.R. for many years, since to do so they would need to have 1,700 GeV. The CERN 28-GeV synchrotron that will supply protons for the new storage ring is in Switzerland, but the ring itself will be just across the border in France [*see illustration at bottom of pages 112 and 113*].

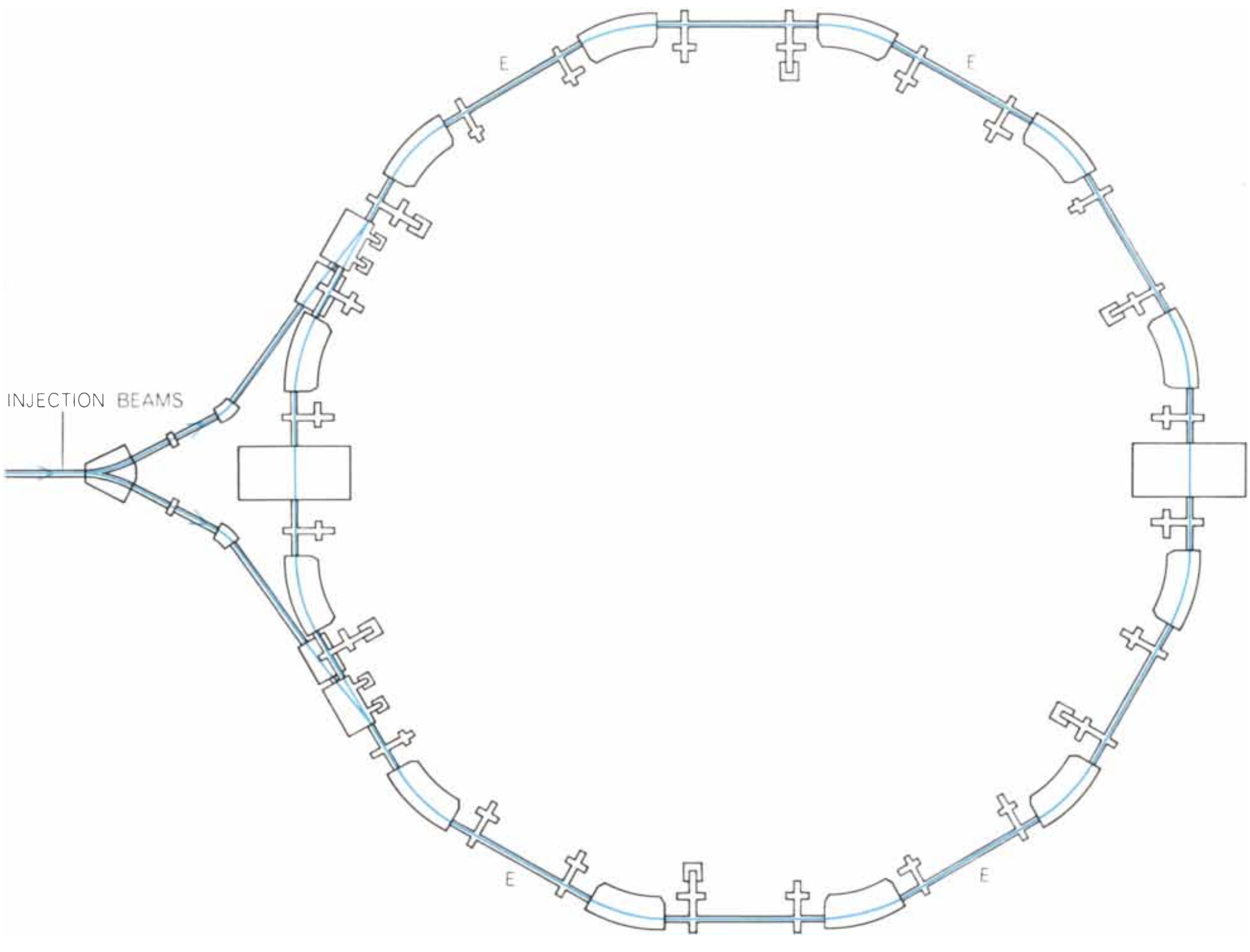
Very recently an ingenious and daring design for a proton-antiproton storage ring was described by Budker, who is director of the Nuclear Physics Institute at Novosibirsk. The ring is already under construction and will use several technical tricks that have been developed at Novosibirsk. It will also use a technique for the damping of antiproton oscillations that several of us at Princeton considered in 1956 but rejected as too advanced and complicated to be practicable at that time.

In the U.S. the practical, as opposed to the theoretical, development of proton storage rings has been less happy. Early in 1963 a subcommittee of the President's Science Advisory Committee recommended that storage rings be built at the 31-GeV Brookhaven alternating-gradient synchrotron, which is nearly a twin of the CERN synchrotron. Later that year the directorate of the Brookhaven laboratory conducted a two-month study of storage rings, but the high-energy physicists then most active at Brookhaven did not approve the initiation of a construction proposal. Their reasons were, first, that the range of experiments accessible to a storage ring would be narrower than that for a conventional synchrotron; second, that they could see more direct and understandable benefits if a comparable amount of money were spent on improvements to the existing synchrotron, and third, that if a storage ring were built at Brookhaven the consequences might well be to dim Brookhaven's chances of winning the controversial site-selection contest for a 200-GeV synchrotron. There is no active study for a proton-proton ring in the U.S. now, even though such a line of development is the only foreseeable alternative to a continued indefinite escalation of conventional accelerator sizes and costs.

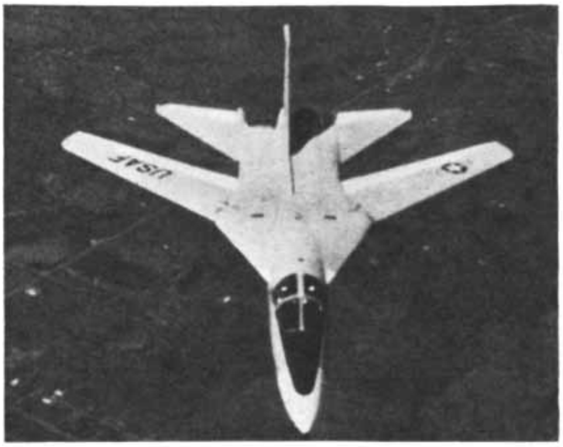
Once the present generation of storage rings is operating it seems to me that one direction of development will inevitably be toward the storage of unstable particles, and probably toward strong fields to achieve orbits of small radius. Existing high-energy physics experiments involving particle-particle collisions have nearly all been done with mesons or with stable particles striking targets that were also of necessity stable (nucleons or electrons). A wide range of novel experiments will be opened up if electrons, protons or deuterons (nuclei of deuterium, or heavy hydrogen) are stored in one ring and muons, pions or K mesons are stored in another. At ordinary magnetic fields a muon in a storage ring would live for about 400 turns, a pion for three turns and a K meson for half a turn. The CERN storage ring may be used for muon-proton collisions. Ultimately it seems likely that storage rings can be built using strong magnetic fields in which intense, concentrated single proton beams can be stored. These can then serve as targets for short-lived particles, which can be beamed in directly or circulated in another strong-field ring of small radius.

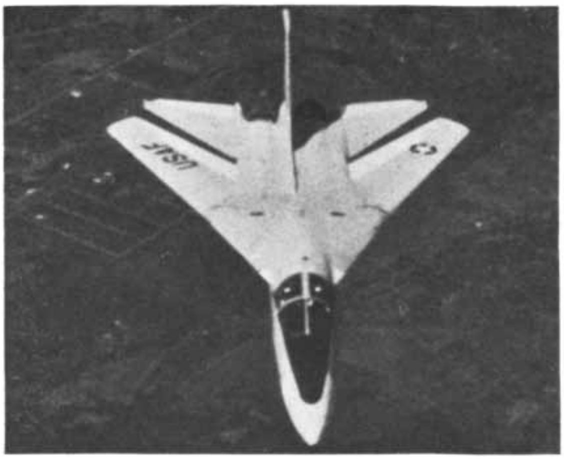
With the large American electron-positron storage ring projects several years away, and no proton-proton colliding-beam project even under discussion in this country, it is fortunate that both at Frascati and at CERN there is an attitude of hospitality toward American participation in colliding-beam experiments. That attitude is particularly laudable when one recalls that these are strictly European projects, to which the U.S. is contributing no money.

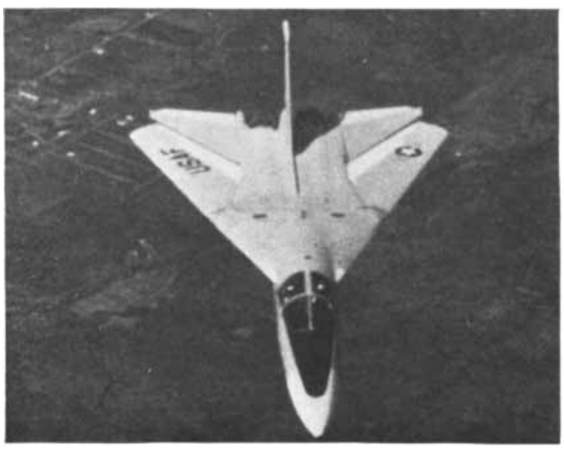
For someone like myself, who wants to continue to do colliding-beam experiments, the prospects for the next five or 10 years seem to imply a lot of commuting. The storage ring projects now near completion at Frascati and CERN will open the door to an almost unknown world of ultrahigh energy. As one of my Princeton colleagues remarked some years ago, "the principal research tool of the high-energy physicist is the Boeing 707." As long as one can buy a million transatlantic plane fares for the price of one 200-GeV synchrotron I expect he will be right.



ELECTRON-POSITRON STORAGE RING "Adone" is scheduled for completion next year at the Italian National Laboratory near Rome. The energy of particles in each beam will be 1.5 GeV. The ring has four straight sections (*E*) for conducting experiments.







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ACETABULARIA: A USEFUL GIANT CELL

This marine alga grows to a length of an inch but has only one cell and one nucleus. It is therefore almost ideal for studying the relations between the nucleus and other parts of the cell

by Aharon Gibor

One of the outstanding problems of biology is the clarification of the subtle relations between the nucleus of the living cell and its surrounding cytoplasm. If a biologist could design an ideal cell for the purpose of looking into this problem, he would probably specify properties remarkably like those of *Acetabularia*, a tropical seaweed that is sometimes called the mermaid's wineglass because of its graceful shape. *Acetabularia*, which is classified among the green algae, is a single-celled organism that grows more or less vertically to a length of several centimeters. Its nucleus is invariably located at the bottom. Hence the experimenter can easily separate nucleus and cytoplasm to see how they fare independently and what happens when they are put back together in various ways.

Experiments with *Acetabularia* have already yielded considerable information about relations between the nucleus and the cytoplasm. The work has been done mostly in the laboratories of Joachim Hämmerling at the Max Planck Institute for Marine Biology in Wilhelmshaven and of Jean Brachet at the Free University of Brussels. Recently the organism has attracted interest in a number of laboratories in the U.S. With the advances that are occurring in the techniques of cell biology, the experiments now under way with *Acetabularia* promise further disclosures about the roles played by the components of the cell in the cell's activity.

The group of plants in which *Acetabularia* is classified, along with the other green algae, is the order Siphonales. Members of the order are distinguishable by a kind of growth called "coenocytic," a term derived from two Greek words translated roughly as "common-celled." The body of such a plant is made up of an elongated and branched filament. No cross walls separate the filament into individual cells; the cytoplasm is thus continuous throughout the plant. Most plants of the order contain many nuclei and the smaller cell bodies called plastids and mitochondria. The family Dasycladaceae, to which *Acetabularia* belongs, is further characterized by the development of specialized branches that at their apexes become the reproductive organs of the plant.

Hämmerling, studying the life history

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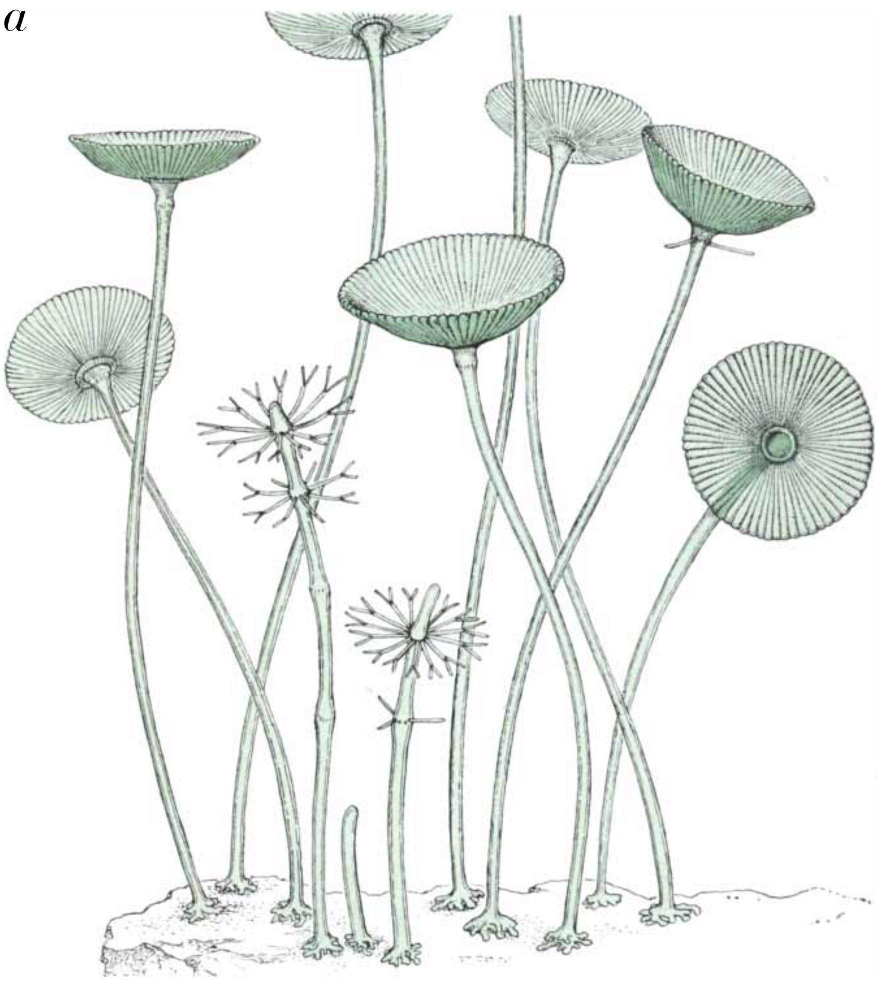


VIEWS OF *ACETABULARIA* at increasing enlargements begin (*a*) with a representation of *A. mediterranea* in its natural habitat. The cap (*b*) consists of rays that at maturity develop cysts as shown in one ray at right. The rhizoid (*c*) attaches the organism to a rock

of *Acetabularia,* discovered that the organism differs from other plants of the order Siphonales in a most important feature. In *Acetabularia* the nucleus does not divide during the period in which the cell grows. In other words, the cell contains a single nucleus during the entire period of growth.

Another feature of the plant is that the end containing the nucleus develops a special structure called the rhizoid. This structure serves to attach the cell to a solid object, usually a rock. (The natural habitat of *Acetabularia* is a shallow tropical sea with a rocky bottom.)

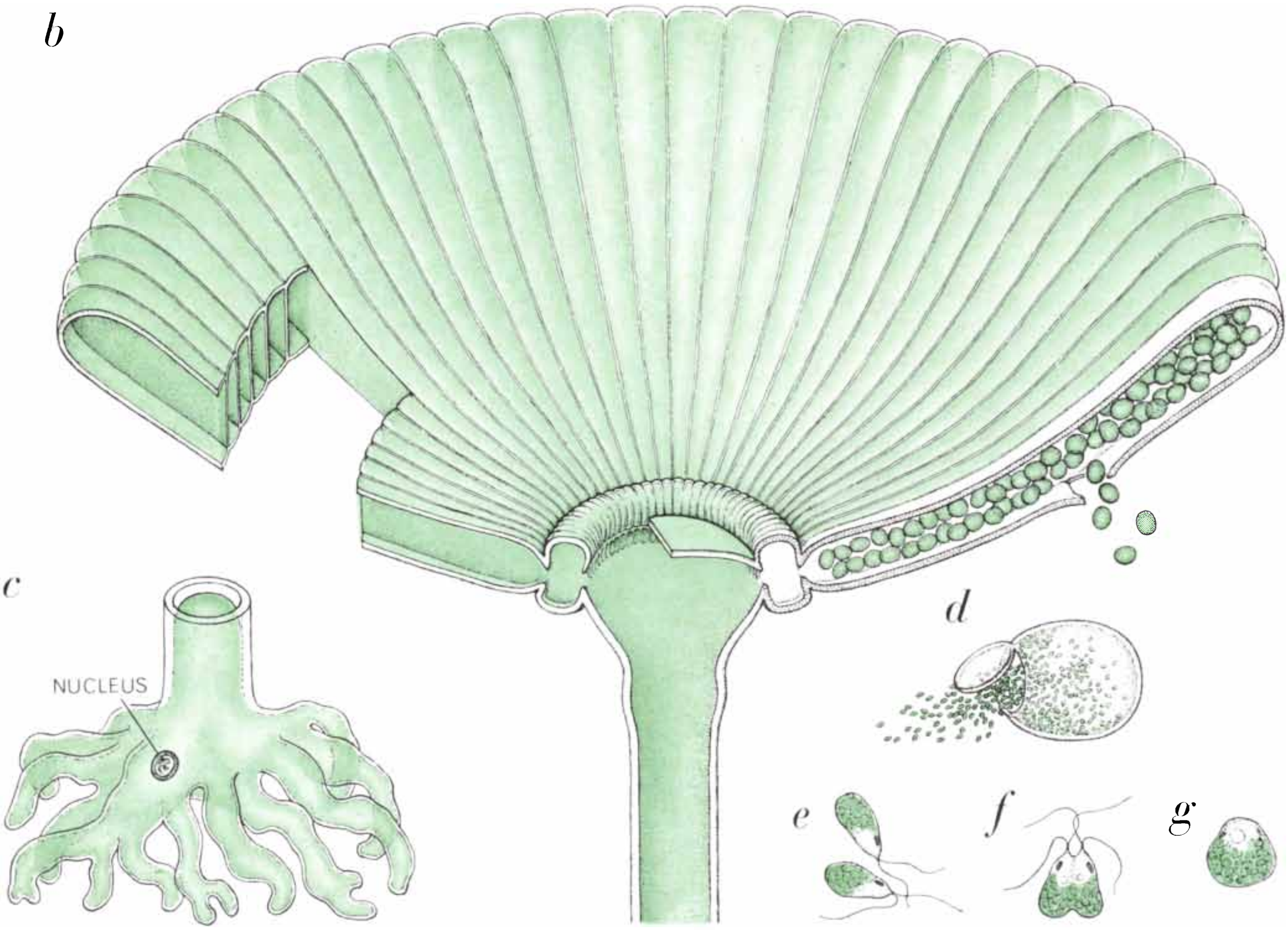
At the top of the cell a second special structure called the cap develops at about the time the growth of the cell ends. The cap matures to become the reproductive organ of the cell. Only when this happens does the nucleus begin to divide. Until that time the organism can be regarded as a giant single cell. Once the division of the nucleus starts, the plant becomes similar to all other coenocytic algae of the order Siphonales.

A further relevant characteristic of *Acetabularia* is apparent when the cell is cut or bruised. The cell rapidly seals off the damaged portion, heals and proceeds to regenerate a new part. If an immature cap is cut from the top of the stalk, for example, a new cap develops in its place.

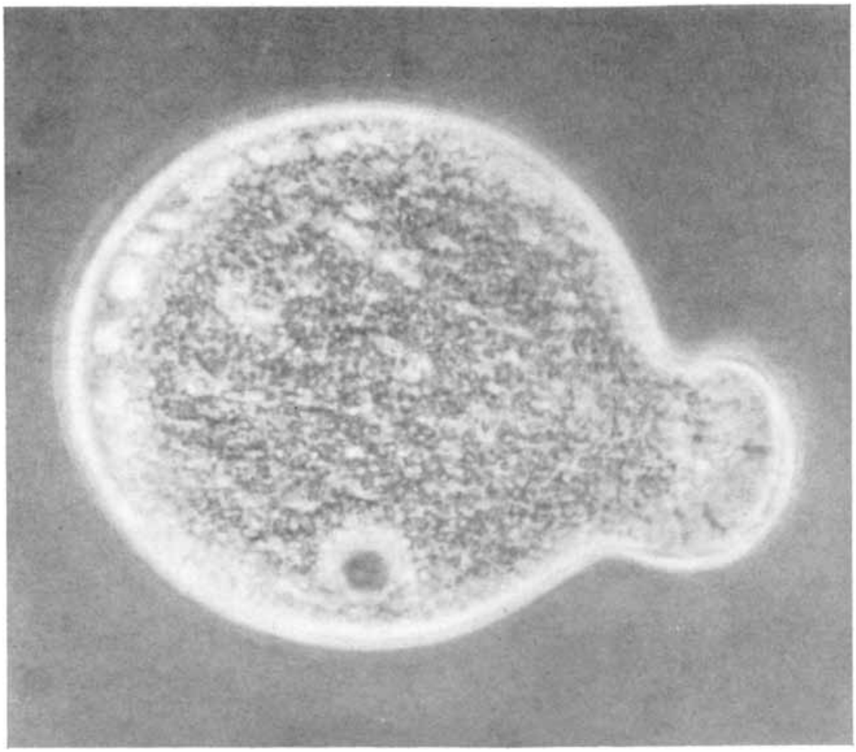
The value of the regenerative cap to the experimenter is enhanced by the fact that nature has provided several species of *Acetabularia.* The Mediterranean species, *A. mediterranea,* has a cap that looks like a small umbrella with a smooth rim. The species *A. crenulata,* found in the Caribbean, has a cap that looks like several small bananas arranged radially at the tip of the cell. Since the appearance of each cap is so distinctive the experimenter can readily see the effect of transferring a nucleus from one species to another.

In sum, four properties give *Acetabularia* its remarkable value as an experimental organism: (1) the delay in the division of the nucleus until the cell has attained its full size and the cap has matured, (2) the location of the nucleus in a particular and recognizable region of the cell, (3) the difference in the caps of different species and (4) the organism's capacity for regenerating parts. These properties have lent themselves admirably to the examination of the influence of the nucleus on the development of the cytoplasm and the influence of the cytoplasm on processes in the nucleus.

The nucleus of a cell in any organism is known to carry genetic information in its chromosomes. Yet the translation of the information into the orderly development of a cell from an immature state to a mature one is not all accomplished by the nucleus. Indeed, the genetic information in the nucleus represents only a potential. An intricate mechanism regulates the realization of the potential; by means of the mecha-



and also is the site of the nucleus. The rhizoid and cap are enlarged 20 diameters. At *d* is a ripe cyst, enlarged some 150 diameters, from which gametes, or mature germ cells, are emerging. A gamete fuses with another gamete (*e*–*g*) to give rise to a zygote, which is the immature cell that will grow into a new *Acetabularia.* The enlargement of the drawings *e*, *f* and *g* is about 1,000 diameters.



YOUNG CELL of *Acetabularia* contains a prominent nucleus, which is the dark spot at bottom. The rest of the material in the cell is cytoplasm. This cell is in the early stage of growth and has just begun to develop a stalk. The enlargement is about 2,000 diameters.

nism different genes are perhaps activated to function at different times. It is evident from numerous experiments that the process involves both commands from the nucleus to the cytoplasm and commands from the cytoplasm to the nucleus.

Before the unique properties of *Acetabularia* could be exploited in order to explore the details of the nuclear-cytoplasmic interaction, the first workers in the field had to study the organism's life cycle intensively in the laboratory to familiarize themselves with its normal events. The study proved to be difficult. It is not easy to take algae from a marine environment and maintain them in the laboratory, particularly when, as in the case of *Acetabularia,* the nutritional requirements of the organism are not known.

When Hämmerling began his studies, he was associated with the laboratory of the late Max Hartmann at the Kaiser Wilhelm Institute in Berlin. The laboratory was trying to maintain various species of marine algae. In time the workers at the laboratory developed a special culture medium—the Erd-Schreiber medium—in which many delicate algae seemed to thrive. The secret of the medium was the addition to seawater of a special brew prepared by cooking a particular kind of garden soil for many hours. With the Erd-Schreiber medium Hämmerling was able to domesticate *Acetabularia* and establish the details of its life cycle.

Hämmerling found that a mature cap develops cysts that are the key to reproduction [*see illustration on preceding two pages*]. Each cyst contains several nuclei, many chloroplasts and mitochondria and other materials that can form a new cell. The reproductive process begins when the cap releases the cysts, which germinate to produce the gametes, or mature germ cells. Two gametes meet and fuse to form a zygote that immediately begins to grow and develop. It takes about 60 days for the cell to grow to the stalklike stage that precedes the formation of a cap.

With the life cycle established Hämmerling was ready to begin his experiments. One of the first questions he considered was whether or not an *Acetabularia* cell could continue to live and function without its nucleus. It was easy to remove the nucleus by cutting off the rhizoid. Cells thus enucleated continued to grow in length and eventually developed a typical cap. Of course, such a cap would not mature to produce ripe cysts because no nuclei were present. An enucleated cell would, however, remain alive and active for several months.

It therefore appeared that the growth of the cell and even the development of a complex structure such as the cap were independent of the nucleus. Elaborations of the experiment showed that the independence was somewhat conditional. The fact that an enucleated cell can both grow and develop new structures proved to arise from the accumulation in the cell of substances that originated in the nucleus.

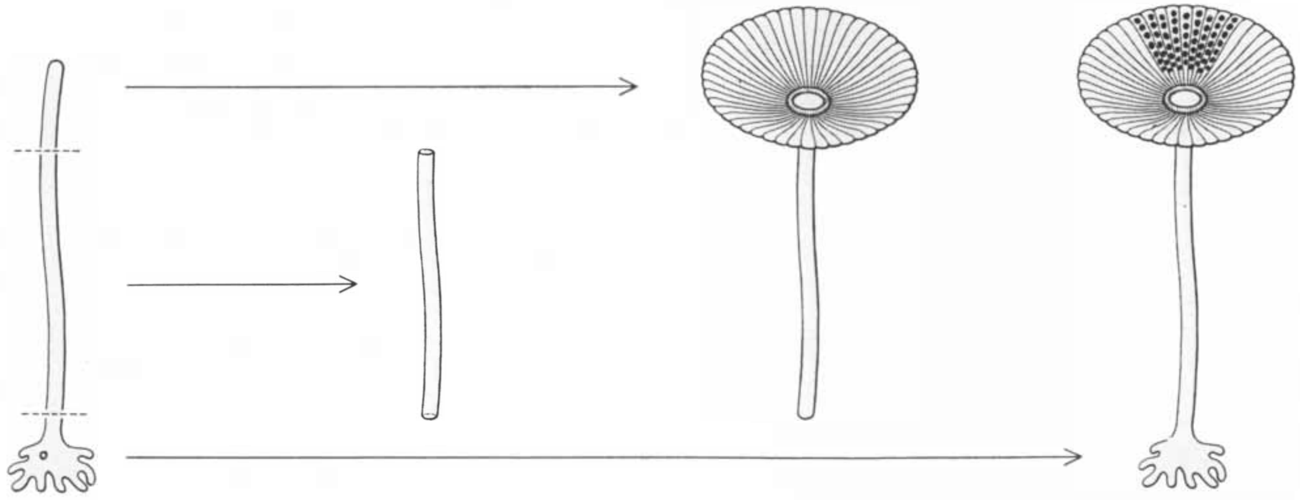
The experiment that led to this conclusion can be summarized as follows. If the top segment of a cell is cut off, that segment continues to grow in length; it also develops a cap. The bottom segment of the cell, which contains the nucleus, can regenerate a complete and normal cell [*see top illustration on opposite page*]. The middle segment of the cell, however, lacks the ability to increase in length or regenerate a cap.

The next step was to remove a small top segment of a complete plant but to delay cutting off a middle segment for several days. If the middle segment was then separated from the bottom segment, it was found to have acquired the capacity to grow and to form a cap. Evidently the middle segment acquired the properties of growth and cap-forming because it was attached to the rhizoidal segment, which contained the nucleus.

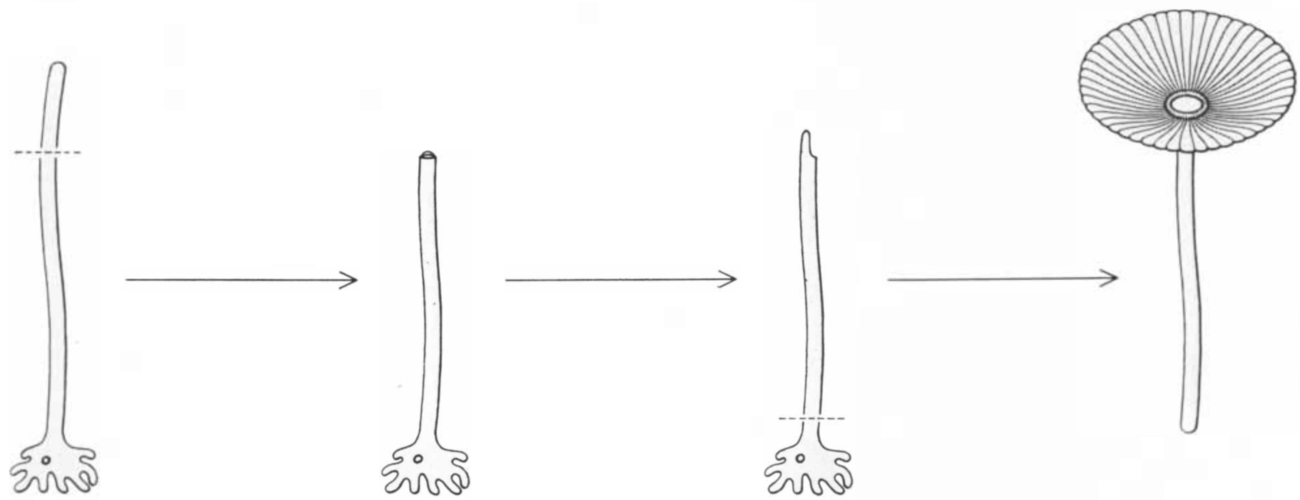
One naturally asks next if the acquired properties of the middle segment arose from the nucleus. The question was answered affirmatively by an experiment in which a nucleus was squeezed out of a cell, washed to remove most of the adhering cytoplasm and then transplanted into the isolated middle section of another cell. New growth began several days later.

Here was a finding of considerable importance. It implied that the nucleus produces a diffusible substance that migrates and concentrates in the top region of the cell. The substance controls the ability of the cell to grow and to develop a cap. It is a stable substance and can remain active for many days.

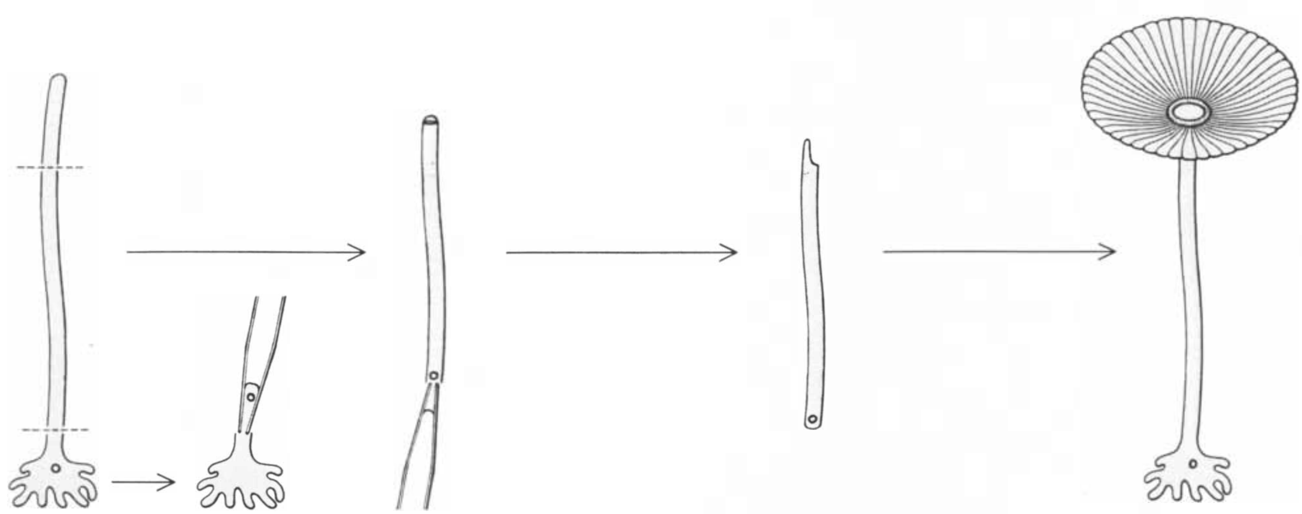
Another important observation came from the transfer of a nucleus to the middle section of a stalk. New rhizoids developed in the vicinity of the transplanted nucleus. The implication is that the position of the nucleus in the cell establishes a polarity in the cell; the rhizoid always develops near the nucleus and the cap develops at the point farthest from the nucleus. Since one type of message clearly concentrates at one end of a cell and another



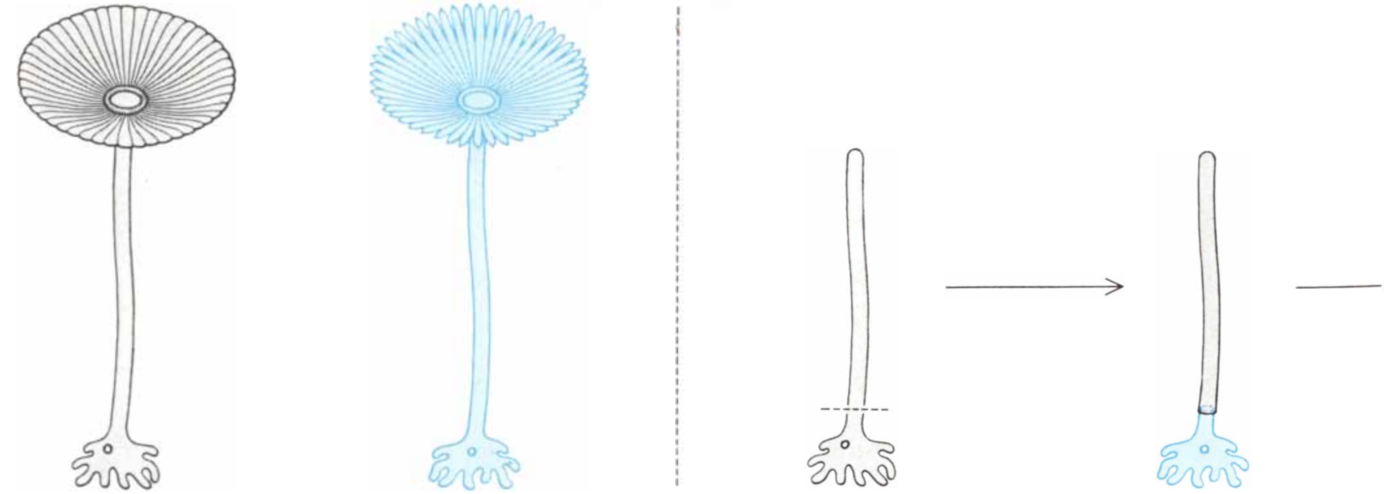
CUTTING EXPERIMENTS show the effect of the nucleus on the growth of a cell of *Acetabularia*. A young plant (*left*) is cut in two places. The middle section remains alive but does not grow. The tip develops a cap. The base develops into a fully mature cell.



FURTHER CUTTING introduces a time factor. The tip of a cell is cut off (*left*) and the remaining part is left alone for several days. Then it is cut in two. Its top part, which was originally the middle section, has acquired from the nucleus the ability to develop.



TRANSPLANTATION OF NUCLEUS into what was originally the middle section of a cell of *Acetabularia* is accomplished by pipette. Segment receiving the nucleus begins to show growth after several days and eventually develops into a mature cell (*right*).



EFFECT OF NUCLEUS is further demonstrated in experiments involving the transfer of nuclei between species. At left are species of *A. mediterranea* (*black*) and *A. crenulata* (*color*). The cell of *mediterranea* is cut in two and the rhizoid, containing the nucleus,

type concentrates at the other end, it is evident that messages do not simply diffuse out of the nucleus. They are also spatially organized in the cytoplasm.

It soon became apparent that the diffusible message from the nucleus carries specific genetic information. This fact was demonstrated when a nucleus of one species was introduced into an enucleated cell of another species. The cap that eventually developed was typical of the species of the transplanted nucleus [*see illustration at top of these two pages*].

In some cases, when the enucleated cell was well developed and apparently contained a considerable amount of the diffusible message from its own nucleus, the first cap to develop after the implantation of a foreign nucleus showed characteristics intermediate between the two species. If such a hybrid cap was removed, however, the cap that then developed was typical of the kind found on the species from which the nucleus came. Here was a clear demonstration that the genetic factors in the nucleus determine the ultimate form of the cell. Moreover, the nucleus exercises its control by secreting diffusible messages into the cytoplasm; the messages thereupon migrate to the region of the cell where the information they bear will be utilized.

What is the chemical nature of the diffusing message? Indirect evidence suggests that here, as in all other mechanisms of genetic information that have been studied, molecules of ribonucleic acid (RNA) function in the transfer of information from the deoxyribonucleic acid (DNA) of the genes into protein enzymes. Three kinds of indirect evidence implicated RNA in the mature cell of *Acetabularia*. First, if an enucleated top segment was treated with ultraviolet light, which is known to damage nucleic acids, the segment lost its ability to grow. Second, treatment of such a segment with ribonuclease, an enzyme that specifically breaks down molecules of RNA, also prevented growth. Finally, antibiotics such as actinomycin, which inhibit the synthesis of the kind of RNA called messenger RNA, curtailed the accumulation of growth-initiated substances in decapitated cells that still had their nuclei.

The experiments I have described owe their success to the remarkable hardiness of the *Acetabularia* nucleus. Such a nucleus can be taken out of the cell, washed repeatedly in a sucrose solution and then reimplanted in a cell without loss of viability. In contrast, transplantations of the nuclei of amoebae or other animal cells must be performed in such a way that the nucleus is never exposed to the culture medium.

As a result of the experiments with the nuclei of *Acetabularia,* the genetic role of the nucleus was considerably clarified. The experiments showed that the nucleus, by its production of messenger RNA, makes possible the vegetative growth of the cell and its differentiation into a rhizoid at one end and a cap at the other. The next question to be asked concerned the cytoplasm. Does it have some control over the development and function of the nucleus? Several experiments provided an affirmative answer to the question.

One line of experimentation was based on the fact that the nucleus of a cell with a developing cap is quite large. The experiments involved decapitating such cells. Invariably the result was that the nucleus shrank to a fraction of its former size. Hämmerling was able to keep such cells growing for several years, repeatedly removing the cap and thus apparently rejuvenating the nucleus.

In other experiments a mature cap was grafted onto the top of a young cell. The result was an early onset of nuclear divisions in the still small nucleus [*see illustration at bottom of these two pages*]. Both sets of experiments lead to the inference that cytoplasmic factors govern the developmental state of the nucleus. When a cap is fully developed, it signals the nucleus at the other pole of the cell to start dividing. What the signal may be is unknown.

A straightforward way of studying the nature of the substances that might affect a nucleus or cytoplasm is to add

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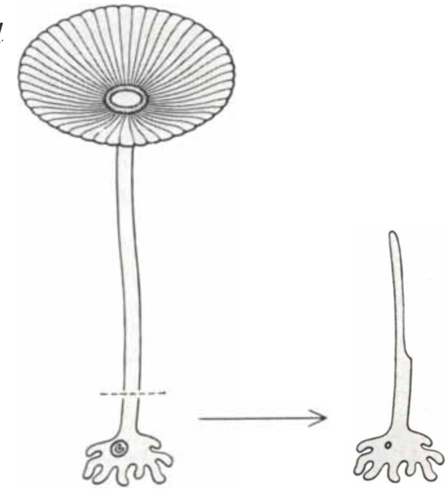
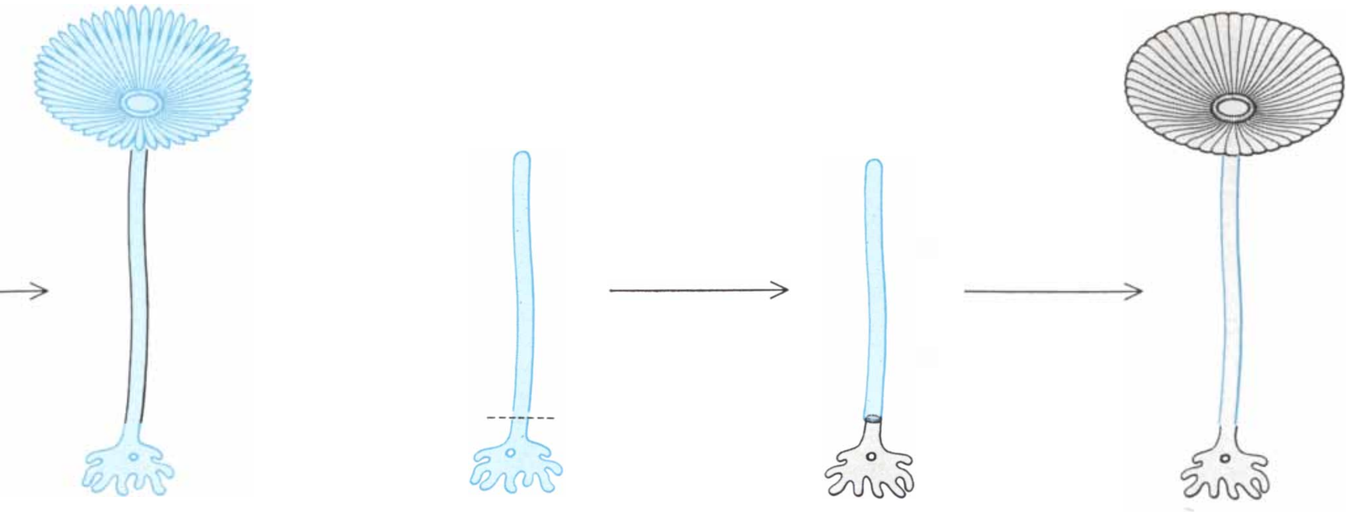


EFFECT OF CYTOPLASM on the nucleus appears in two experiments. If a mature cap



is removed. Then a rhizoid from a cell of *crenulata* is grafted onto the *mediterranea* stem. Eventually the stem develops a cap characteristic of the *crenulata* species. A comparable result occurs (*far right*) when a *mediterranea* rhizoid is put on a *crenulata* stem.

known substances to a culture medium containing cells. If an additive of known properties produces results similar to those produced naturally by the unknown substance, the experimenter has a clue to the properties of the unknown substance. To be meaningful, however, such experiments should be performed on cultures that are free of bacteria, since any added organic substance is more likely to be used or changed by the actively metabolizing microorganisms than by the relatively sluggish alga.

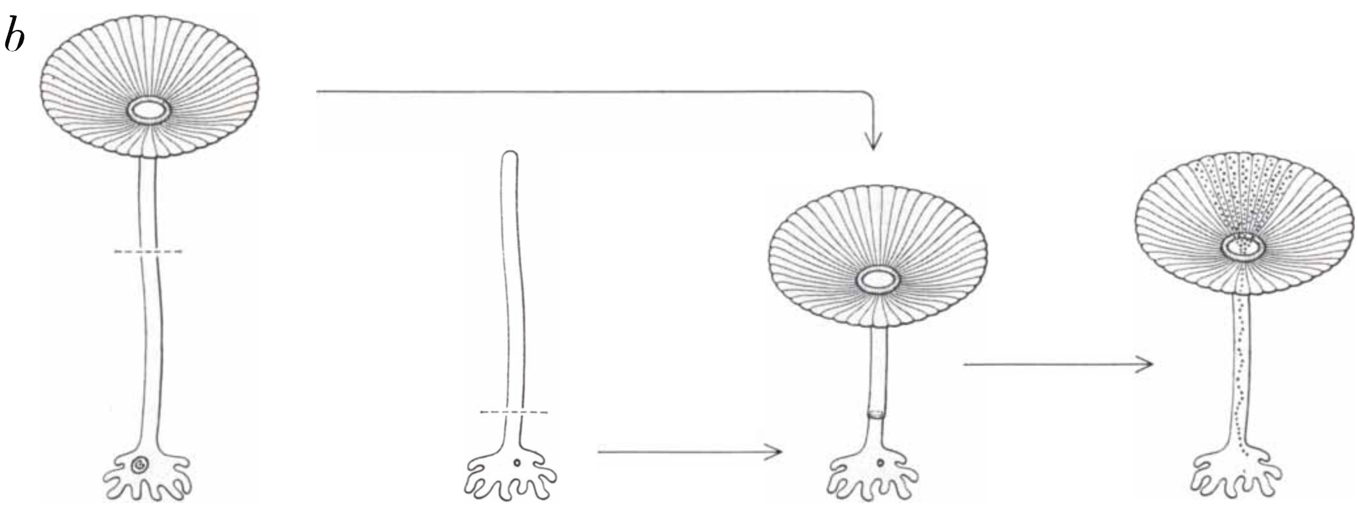
In recent years my colleagues at Rockefeller University and I have been able to obtain and grow cultures of bacteria-free *Acetabularia*. With them we undertook first to find what organic growth factors are needed by intact cells. We found that thiamine (vitamin B_1) can replace the soil extract in the Erd-Schreiber medium. Another factor, perhaps vitamin B_{12}, is usually supplied in sufficient quantities in natural seawater but must be added if artificial seawater is used.

Pure cultures have also enabled us to settle a long debate concerning the presence of DNA in organelles, or intracellular bodies, other than the nucleus. Organelles such as mitochondria and chloroplasts can be isolated from disrupted cells, and their composition can then be determined. Since the quantity of DNA in organelles thus obtained is very small, it must be determined that the DNA does not come from broken nuclei or contaminating bacteria.

Our technique for determining if chloroplasts of *Acetabularia* contained DNA was to remove nuclei from uninfected cells by cutting off the rhizoid ends. From the stalks that remained we isolated chloroplasts. We found that the chloroplasts indeed contained small but significant amounts of DNA.

Furthermore, we were able to show that the DNA of the chloroplasts is synthesized even in the absence of the nucleus. We did so by growing enucleated cells in a radioactive environment. Afterward we isolated chloroplasts from the cells; radioactive DNA was found in the chloroplasts. The experiment indicated that the chloroplasts may possess a degree of genetic autonomy.

Recently we have found that we can prepare very small droplets of *Acetabularia* cytoplasm [*see bottom illustration on next page*]. The droplets continue to live and grow in vitro. We call the droplets cytoplasts. They represent an intermediate system between the complex intact cell and the completely disorga-



is removed from a cell, such as the *A. mediterranea* shown at *a*, the nucleus, which was previously well developed, shrinks markedly. If a developed cap is transferred to a young rhizoid (*b*), the nuclear divisions characteristic of a mature rhizoid soon start.

ISOLATED NUCLEUS of a cell of *Acetabularia* can be used for experiments in transplantation. A normal nucleus is 100 to 200 microns (thousandths of a millimeter) in diameter.

DROPLET OF CYTOPLASM without a nucleus can be used to study function of such cytoplasmic bodies as chloroplasts and mitochondria. This synthetic cell is called a cytoplast.

nized homogenized cell preparations commonly studied by biochemists interested in the function of the various components of cells. A typical cytoplast is surrounded by a membrane and contains many chloroplasts and mitochondria. The cytoplasm in it exhibits for several weeks the streaming, or continuous motion, characteristic of living cytoplasm.

We hope the cytoplasts will provide suitable simplified material for further studies of nuclear-cytoplasmic relations. We wonder, for example, if we could induce a cytoplast to develop a new cell wall and to differentiate further if we supplied it with appropriate messenger RNA. If such a cytoplast could be made to grow, could we simplify conditions still further and grow isolated organelles such as chloroplasts and mitochondria outside the cell? The ability to do so would make it possible to establish and to study in detail the degree of independence of different components of a cell.

Another interesting contribution to fundamental biological problems from studies of *Acetabularia* is the recent finding by Hans Schweiger and his colleagues at the Max Planck Institute in Wilhelmshaven that the nucleus plays a role in setting the cell's "clock." Schweiger established different photosynthetic rhythms in *Acetabularia* cells grown under various regimes of light and darkness. When nuclei were transferred between *Acetabularia* cells that differed in the timing of their photosynthetic activity, it was discovered that the introduced nucleus caused a shift in the rhythm of the cytoplasm. Although photosynthesis is a process that is restricted to the chloroplasts, the experiments show that it is somehow regulated by the nucleus. Further work with *Acetabularia* should shed more light on the still poorly understood phenomenon of biological clocks.

Some of the other unique properties of *Acetabularia* await further exploitation. The messages of the nucleus are conveyed to specific parts of the cytoplasm. What organizes their distribution? The cytoplasm influences divisions of the nucleus. What is the nature of the cytoplasmic message to the nucleus? The nuclear divisions in the rhizoid of *Acetabularia* are separated in time and space from the organization of the cytoplasm and membranes around nuclei in the ripe cap to form cysts. What would study of the separation reveal about cell division?

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After the rubber is allowed to "relax", the edges are overlapped and bonded together with adhesive.

Rubber surface is anchored in a shallow trench dug around edge of reservoir. Trench is then filled and tamped.

Accelerated age tests indicate a 15 to 25 year life expectancy for Royal-Seal liners that are installed in exposed areas. And even longer where the liner is covered.

Continued...

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Portable tennis court made by Uniroyal can be rolled up and stored between matches. This one is located at California State College, Pa.

One of a series briefly describing GM's research in depth

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One part in a billion. Hard to even imagine.

A second in 31 years. A single bean in a line of peas laid end to end from New York to Berlin. Our research chemists are isolating, identifying, and measuring similar amounts of hydrocarbons in exhaust gas.

It's done by gas chromatography—using new techniques developed in over 10 years of intensive research on analytical methods.

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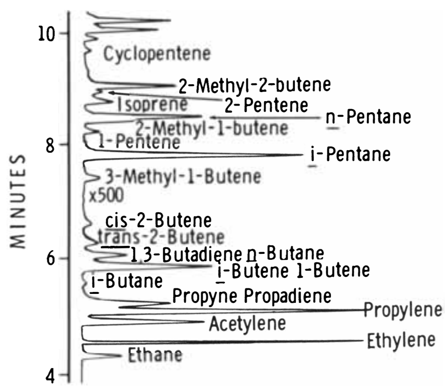
Academic? Not at all, although it's frequently a long step from research to the production line. Hydrocarbons differ widely in smog-forming potential. To effectively evaluate proposed solutions to the smog problem, we must be able to identify and measure the more reactive compounds. Our studies in the microworld of analytical chemistry are just beginning to contribute the data we need . . . new knowledge about how exhaust control systems, fuel composition, and engine variables influence the distribution of individual hydrocarbons in exhaust gas.

Often in industrial research, practical problems stimulate development of advanced techniques. That isn't new. Sometimes, though, the advances go a step beyond the practical . . .

To a new frontier.



Section of chromatogram of hydrocarbons in exhaust gas—from a recent paper.

General Motors Research Laboratories
Warren, Michigan 48090

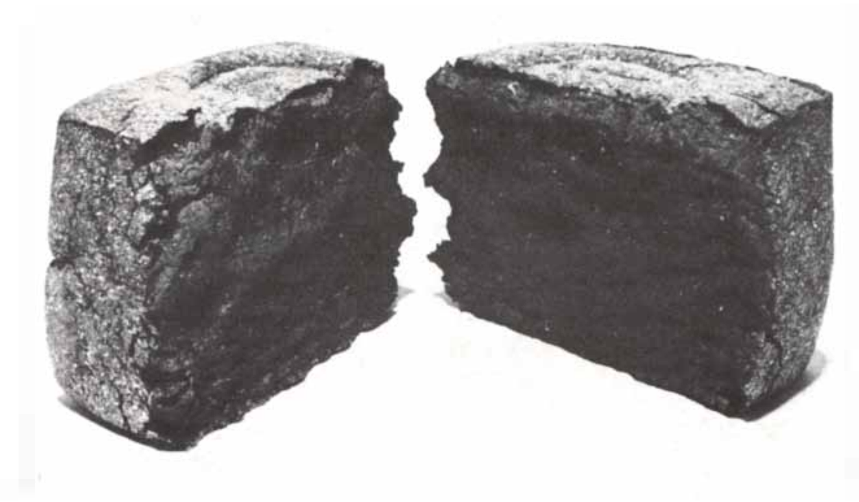
ANALGESIC DRUGS

For severe pain the most widely used drug is still morphine. Other useful drugs have been found, however, in the course of the search for substances with morphine's good qualities but not its bad ones

by Marshall Gates

Early man, omnivorous and inquisitive, had discovered the use of opium by the time of the earliest written records. Babylonian and Egyptian writings contain many references to the value of opium preparations for the relief of pain. Hippocrates, Dioscorides, Galen and other early physicians formed a regard amounting to veneration for opium's almost miraculous power to "lull all pain and anger and bring relief to every sorrow." With the progress of medicine the respect of physicians for the drug increased. Thomas Sydenham, the 17th-century pioneer of English medicine, wrote: "Among the remedies which it has pleased Almighty God to give to man to relieve his sufferings, none is so universal and so efficacious as opium." Today, although opium is clearly no longer regarded as a universal remedy,

OPIUM POPPY (*Papaver somniferum*) is the source of morphine. The technique of obtaining the raw opium is to make a cut in the unripe seed capsule of the plant (*enlarged drawing at right*). The rubbery exudate that oozes from the cut is then collected and dried.



RAW OPIUM contains some 20 alkaloid substances, one of which is morphine. A typical yield of morphine from opium is 10 percent. The drug was first isolated from opium in 1805.

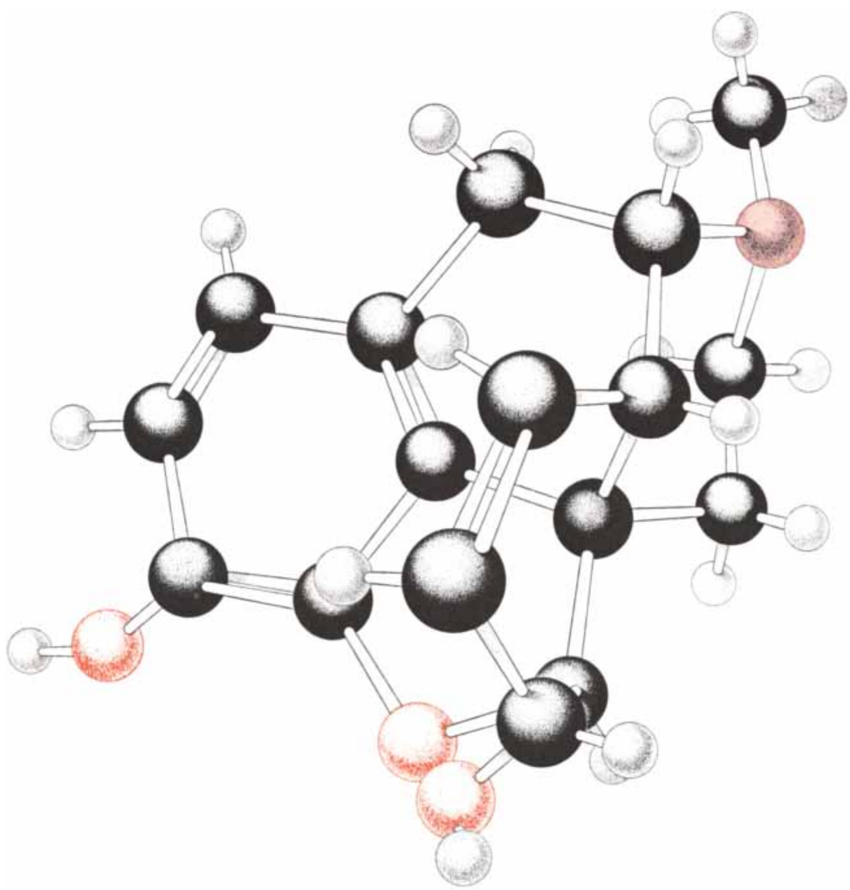
its active principle, morphine, is still the drug that is most commonly prescribed by physicians for the relief of severe pain.

The defects of the drug have long been well known. The ancients could scarcely have been unaware of the addicting property of opium; it appears, however, that Thomas De Quincey's *Confessions of an English Opium Eater*, published in a magazine in 1821, was the first detailed description of opiate addiction. De Quincey was a brilliant man of letters who developed an addiction to laudanum (an opium preparation) while he was a student at Oxford. Opiate addiction is too vast a subject to be discussed in detail here. For our purposes it is enough to note that prolonged use of an opiate generally leads to a physiological and psychological dependence on the drug, and this dependence is shown by the onset of highly unpleasant and sometimes dangerous symptoms when use of the drug is stopped. In addition to the opiates' addicting property, they have a depressing effect on respiration. It is no wonder, then, that in this century chemists and clinical investigators have conducted a tireless and expensive search for an analgesic that would be as potent as morphine but free of its dangerous effects.

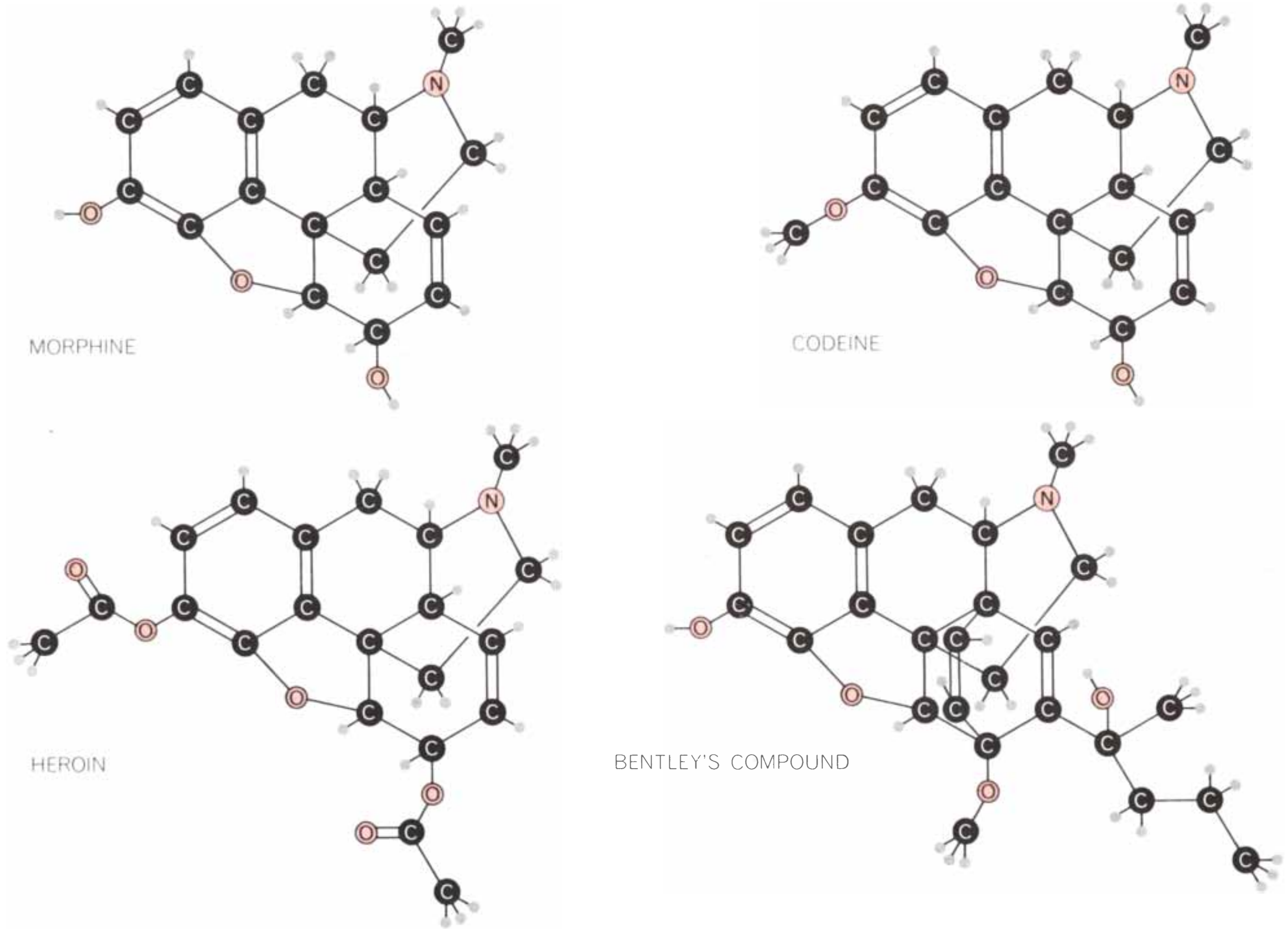
Opium is obtained from the opium poppy (*Papaver somniferum*) by scarifying the unripe seed capsule and collecting and drying the exudate. The dried material, pressed into bricks, is the opium of commerce. The substance is a complex mixture containing at least 20 alkaloids. Morphine, which constitutes about 10 percent of opium and is primarily responsible for its physiological effects, was first isolated in 1805 by Friedrich Sertürner, an apothecary's assistant in Paderborn, Germany. The isolation of this alkaloid was the beginning of alkaloid chemistry, which has yielded many important medicinal substances, including (to cite a recent example) the tranquilizing and blood-pressure-reducing drug reserpine, extracted from the Indian snakeroot (*Rauwolfia serpentina*).

Morphine itself became an object of increasingly intensive study. The unraveling of its structure is a fascinating story. The difficulty involved in the work is apparent from the fact that the correct basic structure of the alkaloid was not suggested until 120 years after the isolation of the drug. The workers who ascertained the structure in 1925 were John M. Gulland and Robert Robinson, then at the University of Manchester. Even at that time the subtleties of morphine's three-dimensional structure were largely unresolved.

The chemical investigations of morphine made available a number of substances closely related to it structurally. Many of them—including codeine (also occurring in opium), heroin, Dilaudid and Bentley's compound—were physiologically active [*see illustration on opposite page*]. Bentley's compound, recently prepared by the British chemist K. W. Bentley, is of particular interest. In tests on small animals it has proved to be 10,000 times more potent than



THREE-DIMENSIONAL MODEL of the morphine molecule shows the characteristic structure of the drug. The black balls in the model are carbon atoms, the dark-colored ball is a nitrogen atom, the light-colored balls are oxygens and the gray balls are hydrogens.



CHEMICAL STRUCTURES of morphine and several of its close relatives are markedly similar. Codeine, heroin and Bentley's compound were produced by altering the structure of morphine. In these two-dimensional diagrams the hydrogens are small gray dots.

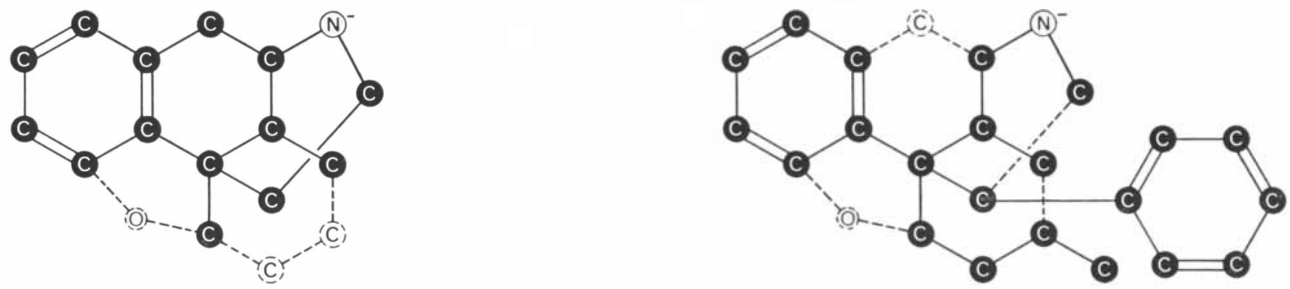
morphine, and some of Bentley's preparations have been used to subdue elephants on African game preserves at doses of one milligram per elephant! Unfortunately the Bentley compounds have disappointed early hopes that they might, at analgesic doses, produce less respiratory depression than morphine, and they have also given evidence that they are dangerously addicting.

Of the many fragments or synthetic assemblies of fragments of the morphine molecule that have been studied, only a few have shown a significant degree of analgesic activity [*see top and middle illustrations on next page*]. And in these compounds, whose structure is sometimes only vaguely related to that of morphine, addiction liability seems to parallel analgesic activity. Only the substances with very mild analgesic activity are nonaddicting.

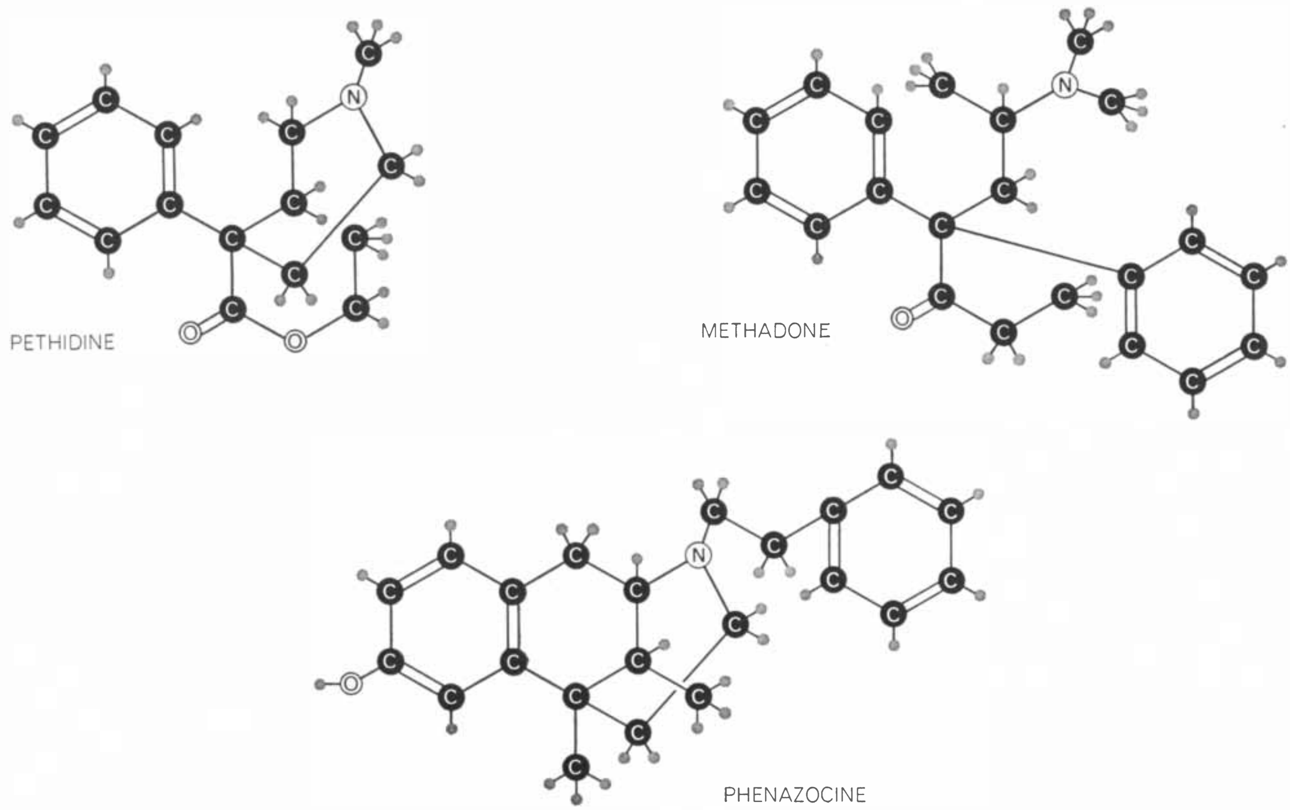
What general principles might be drawn from these analytic studies? In 1955 Nathan B. Eddy of the National Institutes of Health, examining the experimental results, attempted to identify the structural features that might account for the analgesic activity of a drug of the morphine type. The most active drugs, he noted, all seemed to be characterized by (1) the presence of a tertiary or trisubstituted amine with a small group attached to the nitrogen atom, (2) a central carbon atom, none of whose valences was occupied by a hydrogen atom, (3) a phenyl or closely analogous group attached to the central carbon atom and (4) separation of the tertiary or trisubstituted amino group from the central carbon atom by an intervening string of two carbon atoms. Events later showed that this categorical description missed the mark. Since 1955 it has been found that all four of these criteria can be violated without destroying analgesic activity.

Although a satisfactory theory of analgesic structure or action still eludes us, experimenters have developed a number of useful synthetic analgesics related to the morphine model. The oldest and perhaps the best-known is pethidine (also called meperidine, Demerol and by some 40 other names). It was synthesized in 1939 by Otto Eisleb of Germany. Less potent than morphine, pethidine is widely used for the relief of postoperative pain and in obstetrics. It was acclaimed originally as a nonaddicting drug but was soon found to have dangerous addiction liability—a constantly recurring theme in the field of analgesic drugs. (Even heroin was originally introduced as a nonaddicting substitute for morphine.) Analgesics related to pethidine have since been prepared in great variety and in widely varying potency; pethidine itself, however, remains the most widely used of these substances.

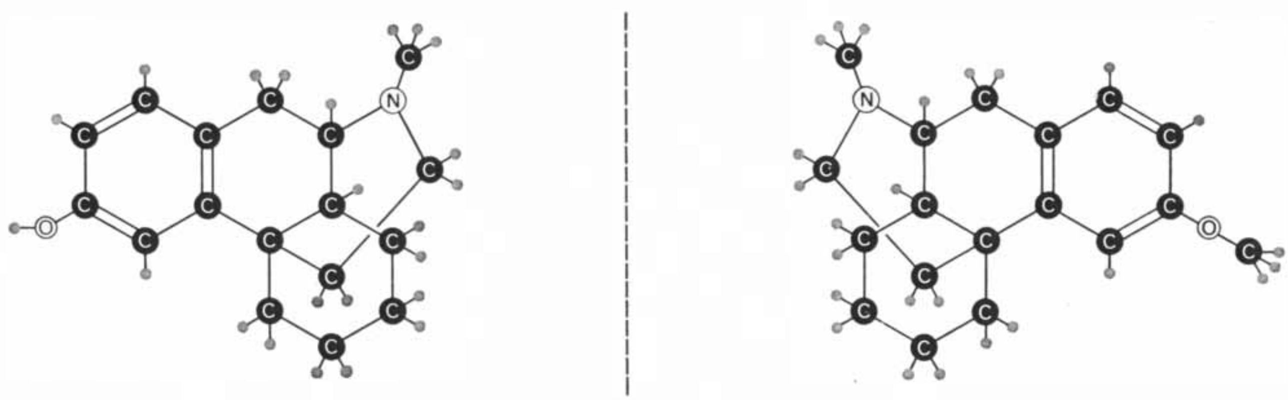
Another family of synthetic analgesics, less closely related structurally to morphine, is the one represented by methadone, which has attracted interest recently as a relatively harmless substitute for heroin in experiments on the management of addicts. Still another, recently developed by Everett L. May of the National Institutes of Health, is the group of substances called benzomorphans. The best-known member of this group, phenazocine, is seven to 10



STRUCTURAL ALTERATIONS of the morphine molecule have produced several fragments that have proved to be analgesically active. Some, such as the one at left, bear a close structural relation to morphine; others, such as that at right, a less apparent relation.



SYNTHETIC ANALGESICS have been developed by various experimenters. Pethidine, the oldest, most closely resembles the structure of morphine. Methadone is less like morphine structurally. Phenazocine, a recent development, is the best-known member of a group of substances called benzomorphans. Phenazocine is more effective than morphine against pain but is highly addicting.



MIRROR-IMAGE MOLECULES proved to have notably different effects. The synthetic drug levorphan (*left*), with a morphine-like structure, is more potent than morphine against pain and also is strongly addicting. Dextrorphan (*right*), the right-handed form of the molecule, is neither analgesic nor addicting. The difference indicates the importance of molecular geometry in analgesic activity.

times more potent than morphine as an analgesic and possesses some other advantages, but like morphine it is dangerously addicting.

That analgesic activity depends quite specifically on molecular geometry is strikingly illustrated by the synthetic drug levorphan, a member of the group called the morphinans, which are closely akin to morphine in structure [*see bottom illustration on opposite page*]. Levorphan is several times more potent than morphine and is strongly addicting. Curiously the mirror image of this molecule (that is, the dextrorotatory, or right-handed, form) has no analgesic activity or addiction liability. (Slightly modified by the substitution of a methyl ether group for the hydroxyl group in the molecule, the dextrorotatory form has been found to be a useful cough-suppressing drug without narcotic properties and seems likely to supplant codeine for that purpose.) The geometric specificity exhibited by levorphan has been demonstrated to apply also to morphine, whose molecule is levorotatory. There is no mirror image of morphine in nature, but the Japanese chemist Kakuji Goto has synthesized a dextrorotatory counterpart of the molecule, using a method developed in my laboratory at the University of Rochester, and found that the mirror form possesses none of morphine's properties.

I have cited only a few representative examples of the synthetic analgesics; there are now a great number of them. Many have certain advantages over morphine, but none has supplanted morphine as the mainstay of physicians for the control of severe pain. The continued preference for morphine stems in part from the confidence developed from long experience with the drug; fundamentally, however, the fact remains that there is not yet available a fully satisfactory substitute that avoids morphine's principal shortcomings. Indeed, the properties of analgesic activity, addiction liability and depression of respiration seem to go together, and until recently there appeared to be no hope of separating one of these properties from another.

We now come to a most interesting development in the story. Its beginning actually goes back to a rather old discovery. Nearly 50 years ago Julius Pohl of the University of Breslau reported he had prepared a substance that suppressed the respiratory depression produced by morphine. The substance was a modification of codeine: in place of the methyl group (CH_3) attached to the nitrogen atom in codeine he substituted the unsaturated allyl group ($CH_2CH{=}CH_2$), forming a compound called N-allyl-nor-codeine. This drug, administered to an experimental animal that had received a narcotic dose of morphine, reversed morphine's respiration-depressing effect.

The significance of Pohl's finding was overlooked at the time, and it lay largely unnoticed for 27 years. In 1942 John Weijlard and A. E. Erickson at the laboratories of Merck & Co. took up this old lead and performed the same operation on the morphine molecule itself, substituting the allyl group for the methyl group. Their product, nalorphine, proved to be capable of counteracting most of the physiological effects of morphine. It not only reversed the respiratory depression but also acted as an antidote for acute morphine poisoning, and when administered to a narcotics addict it rapidly precipitated a severe withdrawal syndrome. In addition, screening tests on small animals indicated that nalorphine, in contrast to morphine, had no analgesic effect.

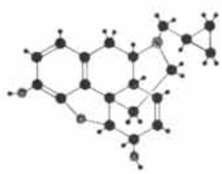
A surprising finding emerged, however, when nalorphine was administered to human patients. In 1954 Henry K. Beecher and Louis Lasagna conducted an experiment to examine the possibility that nalorphine, given with morphine, might reduce morphine's respiratory depression without weakening its analgesic activity. At the Massachusetts General Hospital they gave one group of patients both morphine and nalorphine and gave a control group only nalorphine. Unexpectedly nalorphine alone proved to be as effective in relieving pain in the control group as the combination of morphine and nalorphine was in the test group. This finding was quickly confirmed in experiments by Arthur S. Keats and Jane R. Telford of the Baylor University Medical School. Harris Isbell at the Addiction Research Center of the National Institute of Mental Health then proceeded to demonstrate by further tests with human subjects that nalorphine is not addicting in man.

For the first time analgesia had been divorced from addiction liability. The new drug, however, produced hallucinations when given at analgesic doses. Perhaps for this reason it did not immediately precipitate the rash of new investigations that might have been expected to follow so promising a lead. For some time only Keats and his group at Baylor actively pursued the study of nalorphine and related morphine antagonists.

In 1958 Sydney Archer and his coworkers at the Sterling-Winthrop Institute for Therapeutic Research undertook to seek nonaddicting analgesics among morphine antagonists structurally related to the benzomorphans (represented by phenazocine). Their attack was based on the supposition that the D'Amour-Smith rat-tail-flick test, one of the most widely used means of determining the analgesic effectiveness of drugs in animals, was at least as good a test for addiction liability as for analgesic activity. Therefore they reasoned that any substance active in the test should be discarded. In the test an intense beam of light is used as the pain stimulus. Normally when the light is focused on a rat's tail the animal quickly flicks its tail out of the beam; this reaction is delayed, however, if the rat has been given an analgesic drug. The test has been found to give a good measure of a drug's analgesic potency. Moreover, the results of this test on rats usually correlate well with the clinical effectiveness of a drug in man (although they failed to do so in the case of nalorphine).

From the benzomorphans Archer and his group succeeded in preparing a number of derivatives that combine analgesic activity with some degree of antagonism to morphine. Among these products is cyclazocine, an extremely interesting substance that is one of the most potent morphine antagonists discovered so far [*see illustration on next page*].

In January, 1959, our laboratory independently began a search for a nonaddicting drug among the morphine antagonists. We thought it might be possible, by modifying the allyl group in the nalorphine molecule, to transform it into a more acceptable analgesic, although perhaps somewhat less active as an antagonist of addicting drugs. As a replacement for the allyl group we chose the cyclopropylmethyl group, which is well known to affect the chemical and physical properties of a substance in much the same way as the allyl group (and which is the distinguishing feature of cyclazocine). Thomas Montzka, a graduate student working in our laboratory, prepared a number of cyclopropylmethyl derivatives of morphine-type drugs, and these substances were screened in small animals for us by Louis S. Harris, then at the Sterling-Winthrop Institute, and by Charles A.

STRUCTURE	NAME	RELATIVE ACTIVITY
	NALORPHINE	1.00
	LEVALLORPHAN	2.6
	NALOXONE	18
	CYCLAZOCINE	28
	PENTAZOCINE	1/30
	N-CYCLOPROPYLMETHYL-NOR DIHYDROMORPHINONE	10
	CYCLORPHAN	4
	N-CYCLOPROPYLMETHYL-NOR MORPHINE	3

ANTAGONISTS TO MORPHINE suppress the addicting effects of the drug without impeding its analgesic effects. Indeed, several of them have analgesic properties in addition to their counteraction against morphine, as shown in the column headed "Relative activity."

Winter of the Merck Institute for Therapeutic Research.

The new series of substances proved to be highly active antagonists of morphine and pethidine. We selected one, which we call cyclorphan, for further study. It is a considerably more potent morphine antagonist than nalorphine and appears to have pharmacological properties quite similar to those of cyclazocine.

Both cyclazocine and cyclorphan have been found to be capable, at very low doses, of precipitating the withdrawal syndrome in monkeys that have been addicted to narcotics and also in human addicts. This capability can be taken as good evidence that the drugs will not produce addiction in man. William R. Martin, who has studied the addiction liability of cyclazocine with subjects at the Addiction Research Center of the National Institute of Mental Health, reports that it generates a mild, typical dependence that does not seem very likely to lead to serious consequences.

Cyclazocine and cyclorphan have also been examined clinically, cyclazocine extensively, cyclorphan in preliminary fashion. Both drugs have been found to be potent analgesics, perhaps 30 to 50 times more potent than morphine on a weight basis. Both, however, produce hallucinations, much less commonly than nalorphine does but still frequently enough to raise some question as to their acceptability as drugs for general use.

Perhaps the most promising of the new analgesics discovered so far is pentazocine, one of the morphine antagonists prepared from the benzomorphans by workers at the Sterling-Winthrop Institute. Although it is only weakly antagonistic to morphine, pentazocine has been shown in exhaustive clinical tests to be devoid of addiction liability. Yet it is as effective as morphine in controlling postoperative pain, labor pains, the pains of terminal cancer, cardiac pain and traumatic pains. Thus pentazocine is the first really potent analgesic that has proved in practice to be nonaddicting. It does, however, produce respiratory depression, and so it cannot be said to be the last word.

What can be said with reasonable confidence is that, in view of the recent demonstrations that analgesic potency can be separated from addiction liability, it seems not too much to hope that we shall soon have an ideal analgesic: effective, free of side effects such as respiratory depression and hallucinogenic activity—and nonaddicting.

The scientific American reads

MATHEMATICAL GAMES

Is it possible to visualize a four-dimensional figure?

by Martin Gardner

The children were vanishing.
They went in fragments, like thick smoke in a wind, or like movement in a distorting mirror. Hand in hand they went, in a direction Paradine could not understand....

—Lewis Padgett,
from "Mimsy Were the Borogoves"

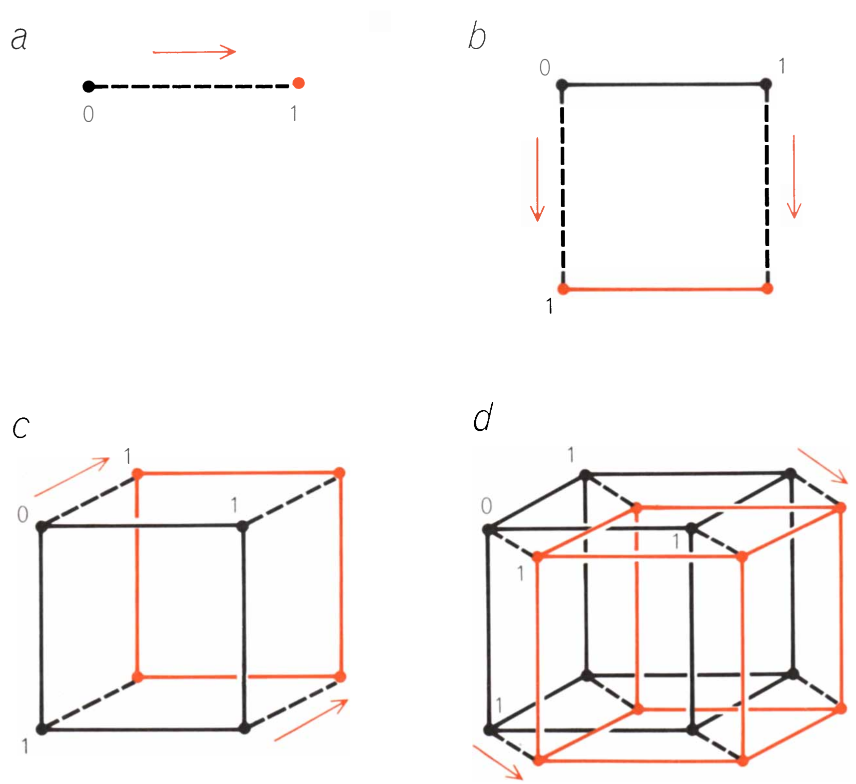
The direction that Paradine, a professor of philosophy, could not understand is a direction perpendicular to each of the three coordinates of space. It extends into four-space in the same way a chess piece extends upward into three-space with its axis at right angles to the x and y coordinates of the chessboard. In Padgett's great science fiction story Paradine's children find a wire model of a tesseract (a hypercube of four dimensions) with colored beads that slide along the wires in curious ways. It is a toy abacus that had been dropped into our world by a four-space scientist tinkering with a time machine. The abacus teaches the children how to think four-dimensionally. With the aid of some cryptic advice in Lewis Carroll's *Jabberwocky* they finally walk out of three-space altogether.

Is it possible for the human brain to visualize four-dimensional structures? The 19th-century German physicist Hermann von Helmholtz argued that it is, provided that the brain is given proper input data. Unfortunately our experience is confined to three-space and there is not the slightest scientific evidence that four-space actually exists. (Euclidean four-space must not be confused with the non-Euclidean four-dimensional space-time of relativity theory, in which time is handled as a fourth coordinate.) Nevertheless, it is conceivable that with the right kind of mathematical training a person might develop the ability to visualize a tesseract. "A man who devoted his life to it," wrote Henri Poincaré, "could perhaps succeed in picturing to himself a fourth dimension." Charles Howard Hinton, an eccentric American mathematician who once taught at Princeton University and who wrote a popular book called *The Fourth Dimension*, devised a system of using colored blocks for making three-space models of sections of a tesseract. Hinton believed that by playing many years with this "toy" (it may have suggested the toy in Padgett's story) he had acquired a dim intuitive grasp of four-space. "I do not like to speak positively," he wrote, "for I might occasion a loss of time on the part of others, if, as may very well be, I am mistaken. But for my own part, I think there are indications of such an intuition. . . ."

Hinton's colored blocks are too complicated to explain here (the fullest account of them is in his 1910 book *A New Era of Thought*). Perhaps, however, by examining some of the simpler properties of the tesseract we can take a few wobbly first steps toward the power of visualization Hinton believed he had begun to achieve.

Let us begin with a point and move it a distance of one unit in a straight line, as shown at *a* in the illustration at the left. All the points on this unit line can be identified by numbering them from 0 at one end to 1 at the other. Now move the unit line a distance of one unit in a direction perpendicular to the line [*b*]. This generates a unit square. Label one corner 0, then number the points from 0 to 1 along each of the two lines that meet at the zero corner. With these x and y coordinates we can now label every point on the square with an ordered *pair* of numbers. It is just as easy to visualize the next step. Shift the square a unit distance in a direction at right angles to both the x and the y axes [*c*]. The result is a unit cube. With x, y, z coordinates along three edges that meet at a corner, we can label every point in the cube with an ordered *triplet* of numbers.

Although our visual powers boggle



Steps toward generating a hypercube

at the next step, there is no logical reason why we cannot assume that the cube is shifted a unit distance in a direction perpendicular to all three of its axes [*d*]. The space generated by such a shift is a four-space unit hypercube—a tesseract—with four mutually perpendicular edges meeting at every corner. By choosing a set of such edges as w, x, y, z axes, one might label every point in the hypercube with an ordered *quadruplet* of numbers. Analytic geometers can work with these ordered quadruplets in the same way they work with ordered pairs and triplets to solve problems in plane and solid geometry. In this fashion Euclidean geometry can be extended to higher spaces with dimensions represented by any positive integer. Each space is Euclidean but each is topologically distinct: a square cannot be continuously deformed to a straight line, a cube deformed to a square, a hypercube to a cube, and so on.

Accurate studies of figures in four-space can be made only on the basis of an axiomatic system for four-space, or by working analytically with the w, x, y, z equations of the four-coordinate system. But the tesseract is such a simple four-space structure that we can guess many of its properties by intuitive, analogical reasoning. A unit line has two end points. When it is moved to generate a square, its ends have starting and stopping positions and therefore the number of corners on the square is twice the number of points on the line, or four. The two moving points generate two lines, but the unit line has a start and a stop position and so we must add two more lines to obtain four as the number of lines bounding the square. In similar fashion, when the square is moved to generate a cube, its four corners have start and stop positions and therefore we multiply four by two to arrive at eight corners on the cube. In moving, each of the four points generates a line, but to those four lines we must add the square's four lines at its start and the four lines at its stop, making $4 + 1 + 1 = 6$ square faces on the cube's surface.

Now suppose the cube is pushed a unit distance in the direction of a fourth axis at right angles to the other three, a direction in which we cannot point because we are trapped in three-space. Again each corner of the cube has start and stop positions, so that the resulting tesseract has $2 \times 8 = 16$ corners. Each point generates a line, but to these eight lines we must add the start and stop positions of the cube's 12 edges to make $8 + 12 + 12 = 32$ unit lines on the hypercube. Each of the cube's 12 edges generates a square, but to those 12 squares we must add the cube's six squares before the push and the six after the push, making $12 + 6 + 6 = 24$ squares on the tesseract's hypersurface.

It is a mistake to suppose the tesseract is bounded by its 24 squares. They form only a skeleton of the hypercube, just as the edges of a cube form its skeleton. A cube is bounded by square faces and a hypercube by cubical faces. When the cube is pushed, each of its squares moves a unit distance in an unimaginable direction at right angles to its face, thereby generating another cube. To the six cubes generated by the six moving squares we must add the cube before it is pushed and the same cube after it is pushed, making eight in all. These eight cubes form the hypercube's hypersurface.

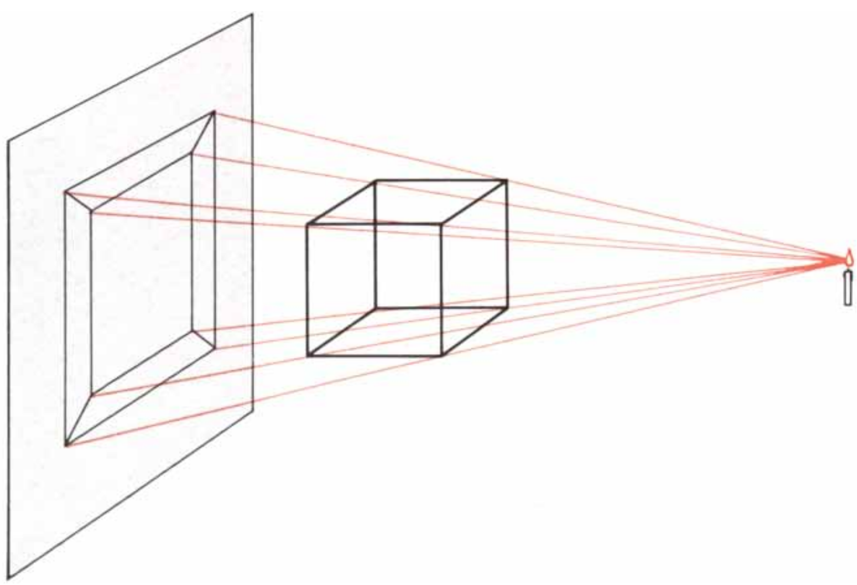
n-SPACE	POINTS	LINES	SQUARES	CUBES	TESSERACTS
0	1	0	0	0	0
1	2	1	0	0	0
2	4	4	1	0	0
3	8	12	6	1	0
4	16	32	24	8	1

Elements of structures analogous to the cube in various dimensions

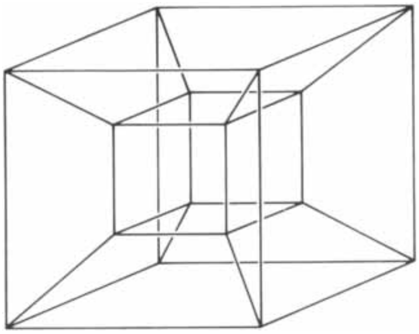
The chart above gives the number of elements in "cubes" of spaces one through four. There is a simple, surprising trick by which this chart can be extended downward to higher n-cubes. Think of the nth line as an expansion of the binomial $(2x + 1)^n$. For example, the line segment of one-space has two points and one line. Write this as $2x + 1$ and multiply it by itself:

$$\begin{array}{r} 2x + 1 \\ 2x + 1 \\ \hline 4x^2 + 2x \quad\;\; \\ 2x + 1 \\ \hline 4x^2 + 4x + 1 \end{array}$$

Note that the coefficients of the answer correspond to the chart's third line. Indeed, each line of the chart,



Projection of the cube in two-space



Projection of the tesseract in three-space

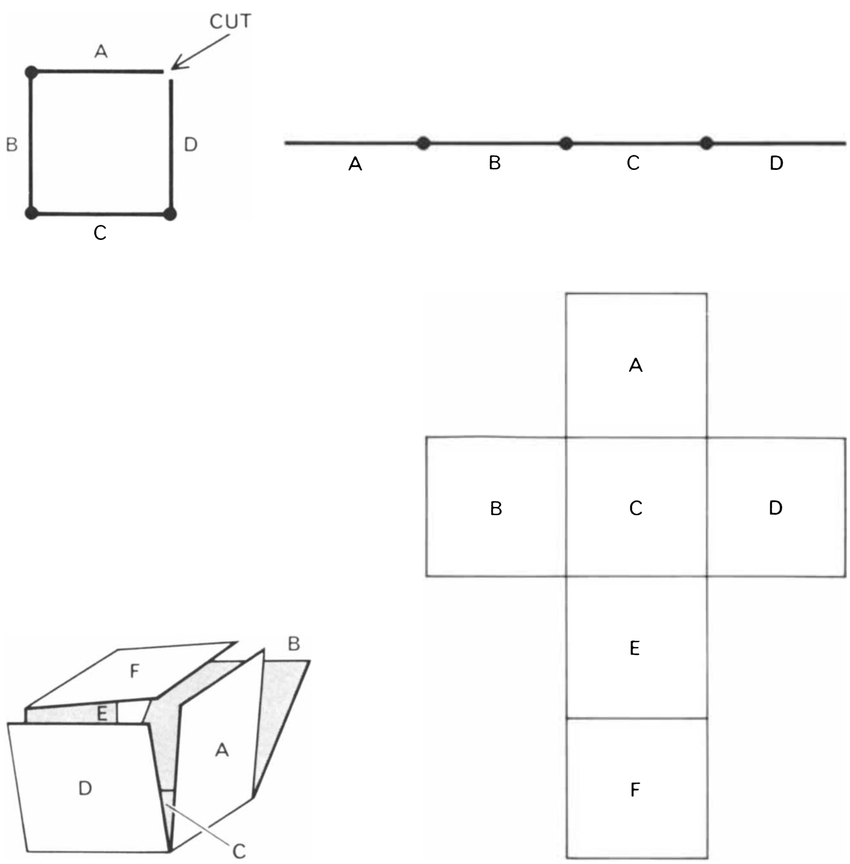
written as a polynomial and multiplied by $2x + 1$, gives the next line. What are the elements of a five-space cube? Write the tesseract's line as a fourth-power polynomial and multiply it by $2x + 1$:

$$\begin{array}{r} 16x^4 + 32x^3 + 24x^2 + 8x + 1 \\ 2x + 1 \\ \hline 32x^5 + 64x^4 + 48x^3 + 16x^2 + 2x \qquad\qquad \\ 16x^4 + 32x^3 + 24x^2 + 8x + 1 \\ \hline 32x^5 + 80x^4 + 80x^3 + 40x^2 + 10x + 1 \end{array}$$

The coefficients give the fifth line of the chart. The five-space cube has 32 points, 80 lines, 80 squares, 40 cubes, 10 tesseracts and one five-space cube.

If you hold a wire skeleton of a cube so that light casts its shadow on a plane, you can turn it to produce different shadow patterns. If the light comes from a point close to the cube and the cube is held a certain way, you obtain the projection shown in the bottom illustration on the preceding page. The network of this flat pattern has all the topological properties of the cube's skeleton. For example, a fly cannot walk along all the edges of a cube in a continuous path without going over an edge twice, nor can it do this on the projected flat network.

The illustration at the top of this page is the analogous projection in three-space of the edges of a tesseract; more accurately, it is a plane projection of a three-dimensional model that is in turn a projection of the hypercube. All the elements of the tesseract given by the chart are easily identified in the model, although six of the eight cubes suffer perspective distortions just as four of the cube's square faces are distorted in its projection on the plane. The eight cubes are the large cube, the small interior cube and the six hexahedrons surrounding the small cube. (Readers should also try to find the eight cubes in the drawing at *d* on page 138—a projection of the tesseract, from a different angle, into another three-space model.) Here again the topological properties of both models are the same as those of the edges of the tesseract. In this case a fly *can* walk along all the edges without traversing any edge twice. (In general the fly can do this only on hypercubes in even spaces, because only in even spaces do an even number of edges meet at each vertex.)



Unfolding a square (top) *and a cube*

Many properties of unit hypercubes can be expressed in simple formulas that apply to hypercubes of all dimensions. For example, the diagonal of a unit square has a length of $\sqrt{2}$. The longest diagonals on the unit cube have a length of $\sqrt{3}$. In general a diagonal from corner to opposite corner on a unit cube in n-space is $\sqrt{n}$.

A square of side x has an area of x^2 and a perimeter of $4x$. What size square has an area equal to its perimeter? The equation $x^2 = 4x$ gives x a value of 4. The unique answer is therefore a square of side 4. What size cube has a volume equal to its surface area? After the reader has answered this easy question he should have no difficulty answering two more: (1) What size hypercube has a hypervolume (measured by unit hypercubes) equal to the volume (measured by unit cubes) of its hypersurface? (2) What is the formula for the edge of an n-cube whose n-volume is equal to the $(n - 1)$-volume of its "surface"?

Puzzle books often ask questions about cubes that are easily asked about the tesseract but not so easily answered. Consider the longest line that will fit inside a unit square. It is obviously the diagonal, with a length of $\sqrt{2}$. What is the largest square that will fit inside a unit cube? If the reader succeeds in answering this rather tricky question, and if he learns his way around in four-space, he might try the more difficult problem of finding the largest cube that can be fitted into a unit tesseract. Next month I shall give the answer for the square-in-cube (as well as for the two questions in the preceding paragraph), but I do not know the answer for the cube-in-hypercube.

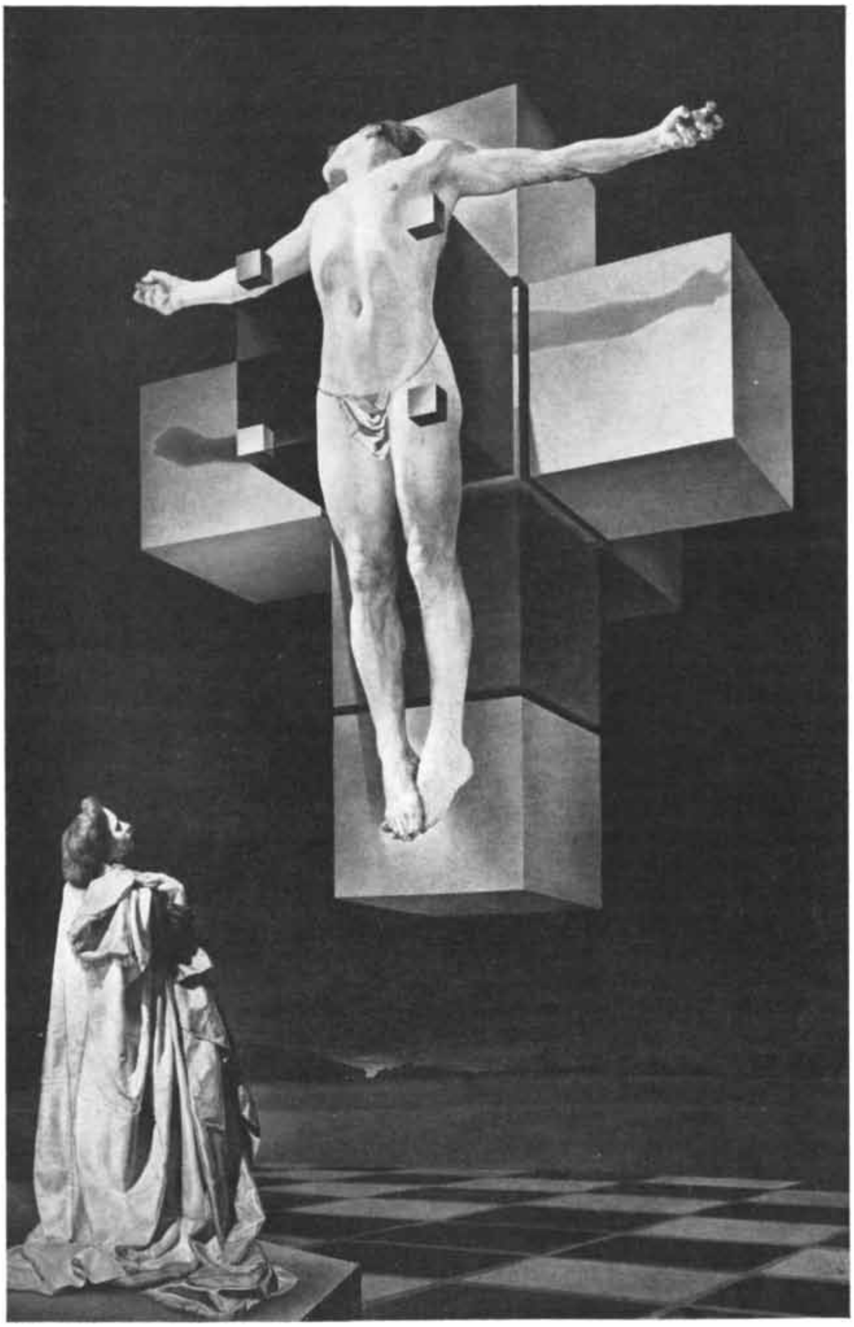
An interesting combinatorial problem involving the tesseract is best approached, as usual, by first considering the analogous problems for the square and cube. Cut open one corner of a square [*see top drawing in bottom illustration on opposite page*] and its four lines can be unfolded as shown to form a one-dimensional figure. Each line rotates around a point until all are in the same one-space. To unfold a cube, think of it as formed of squares joined at their edges; cut seven edges and the squares can be unfolded [*bottom drawing*] until they all lie in two-space to form a hexomino (six unit squares joined at their edges). In this case each square rotates around an edge. By cutting different edges one can unfold the cube to make different hexomino shapes. Assuming that an asymmetric hexomino and its mirror image are the same, how many different hexominoes can be formed by unfolding a cube? (This question will be answered next month.)

The eight cubes that form the exterior surface of the tesseract can be cut and unfolded in similar fashion. It is impossible to visualize how a four-space person might "see" (with three-dimensional retinas?) the hollow tesseract. Nevertheless, the eight cubes that bound it are true surfaces in the sense that the hyperperson can touch any point inside any cube with the point of a hyperpin without the pin's passing through any other point in the cube, just as we, with a pin, can touch any point inside any square face of a cube without the pin's going through any other point on that face. Points are "inside" a cube only to *us*. To a hyperperson every point in each cubical "face" of a tesseract is directly exposed to his vision as he turns the tesseract in his hyperfingers.

Even harder to imagine is the fact that a cube in four-space will rotate around any of its *faces*. The eight cubes that bound the tesseract are joined at their faces. Indeed, each of the 24 squares in the tesseract is a joining spot for two cubes, as can easily be verified by studying the three-space models. If 17 of these 24 squares are cut, separating the pair of cubes attached at that spot, and if these cuts are made at the right places, the eight cubes will be free to rotate around the seven uncut squares where they remain attached until all eight are in the same three-space. They will then form an order-8 polycube (eight cubes joined at their faces).

Salvador Dali's painting "Corpus Hypercubus" [*right*] shows a hypercube unfolded to form a cross-shaped polycube analogous to the cross-shaped hexomino. Observe how Dali has emphasized the contrast between two-space and three-space by suspending his polycube above a checkerboard and by having a distant light cast shadows of Christ's arms. By making the cross an unfolded tesseract Dali symbolizes the orthodox Christian belief that the death of Christ was a metahistorical event, taking place in a region transcendent to our time and three-space and seen, so to speak, only in a crude, "unfolded" way by our limited vision. The use of Euclidean four-space as a symbol of the "wholly other" world has long been a favorite theme of occultists such as P. D. Ouspensky as well as of several leading Protestant theologians, notably the German theologian Karl Heim.

On a more mundane level the unfolded hypercube provides the gimmick for Robert A. Heinlein's wild story "—And He Built a Crooked House," which can be found in Clifton Fadiman's anthology *Fantasia Mathematica*. A California architect builds a house in the form of an unfolded hypercube, an upside-down version of Dali's polycube. When an earthquake jars the house, it folds itself up into a hollow tesseract. It appears as a single cube because it rests in our space on its cubical face just as a folded cardboard cube, standing on a plane, would appear to Flatlanders as a square. There



Salvador Dali's "Corpus Hypercubus," 1954

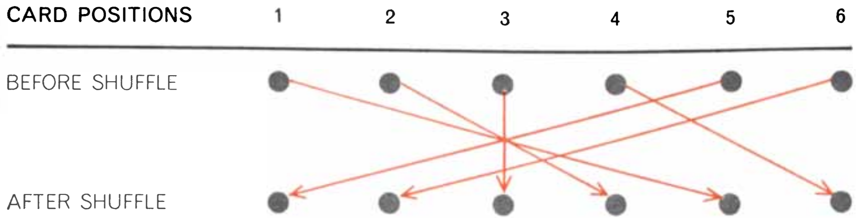


Diagram of a random shuffle of six cards

are some remarkable adventures inside the tesseract and some unearthly views through its windows before the house, jarred by another earthquake, falls out of our space altogether.

The notion that part of our universe might fall out of three-space is not so crazy as it sounds. The eminent American physicist J. A. Wheeler has a perfectly respectable "dropout" theory to explain the enormous energies that emanate from quasi-stellar radio sources, or quasars. When a giant star undergoes gravitational collapse, perhaps a central mass is formed of such incredible density that it puckers space-time into a blister. If the curvature is great enough, the blister could pinch together at its neck and the mass fall out of space-time, releasing energy as it vanishes.

But back to hypercubes and one final question that will also not be answered next month because I do not know the answer. How many different order-8 polycubes can be produced by unfolding a hollow hypercube into three-space?

Readers were asked last month to determine the longest possible cycle for a shuffle of 52 cards; that is, assuming that a shuffle pattern is repeated exactly each time, what is the maximum number of iterations that can be made before the deck returns to its original order?

This is best answered by first considering the random shuffle of six cards diagrammed above. Examine it closely and you will see that it can be broken into subsets, each with its individual cycle. The card in position 3 goes to position 3, and so it forms a subset of one card with a cycle of 1. Cards 1 and 5 interchange, forming a subset of two cards that return to their original positions after a two-shuffle cycle. Cards 2, 4 and 6 are in a subset that returns to the initial order after three shuffles. We thus have three cycles of lengths 1, 2 and 3. It is obvious that the entire deck of six cards will return to its initial order after a number of shuffles equal to the LCM (lowest common multiple) of 1, 2 and 3, which is 6. All decks, when a shuffle is iterated, subdivide into such subsets, each of which has a cycle equal to its number of cards. To find the longest cycle for an entire deck of n cards, we test every possible partition of n into subsets to see which partition gives sets with the *highest* LCM. In the case of six cards there are 11 different partitions:

1 1 1 1 1 1
1 1 1 1 2
1 1 2 2
2 2 2
1 1 1 3
1 2 3
3 3
1 1 4
2 4
1 5
6

The subsets with the highest LCM's are the 1, 2, 3 set and the 6 set, both of which have 6 as the LCM. We conclude that no shuffle of six cards, exactly repeated, can have a cycle longer than 6 before the original order is restored.

A deck of 52 cards has so many different partitions that one must use shortcuts to find those partitions whose sets have the highest LCM. There is not space to go into this here; I can only refer the reader to W. H. Hudson's article in the *Educational Times Reprints: Volume II* (1865), page 105, where the problem seems first to have been solved. No partition of 52 has an LCM higher than 180,180; therefore no shuffle for 52 cards can have a cycle longer than 180,180. An example of such a partition is 1, 1, 1, 4, 5, 7, 9, 11, 13. The reader should have no difficulty diagramming a 52-card shuffle, with subsets corresponding to the numbers in the partition, that will not return a deck to its original order until the shuffle has been repeated 180,180 times.

Oct. 31 = Dec. 25 if "Oct." and "Dec." are taken as abbreviations for the octal and decimal systems. The number 31, in a system based on 8, is written 25 in a system based on 10.

THE AMATEUR SCIENTIST

Two devices for electric welding, one using a carbon arc torch and the other a rattrap

Conducted by C. L. Stong

Many experiments require the joining of metal parts to form a strong bond. In some cases the parts can be soldered. If the joint is intended for use inside an evacuated vessel, however, the relatively high vapor pressure of lead-tin solder cannot be tolerated. There are also joints that must carry loads beyond the breaking strength of solder or that must operate at temperatures above its melting point. Such bonds are most frequently made by brazing or welding.

Brazing is essentially a form of soldering. In brazing a comparatively infusible alloy such as brass is substituted for the conventional alloy used in soldering. The brazing alloy must have a melting point lower than that of the metal being bonded but higher than the melting point of solder.

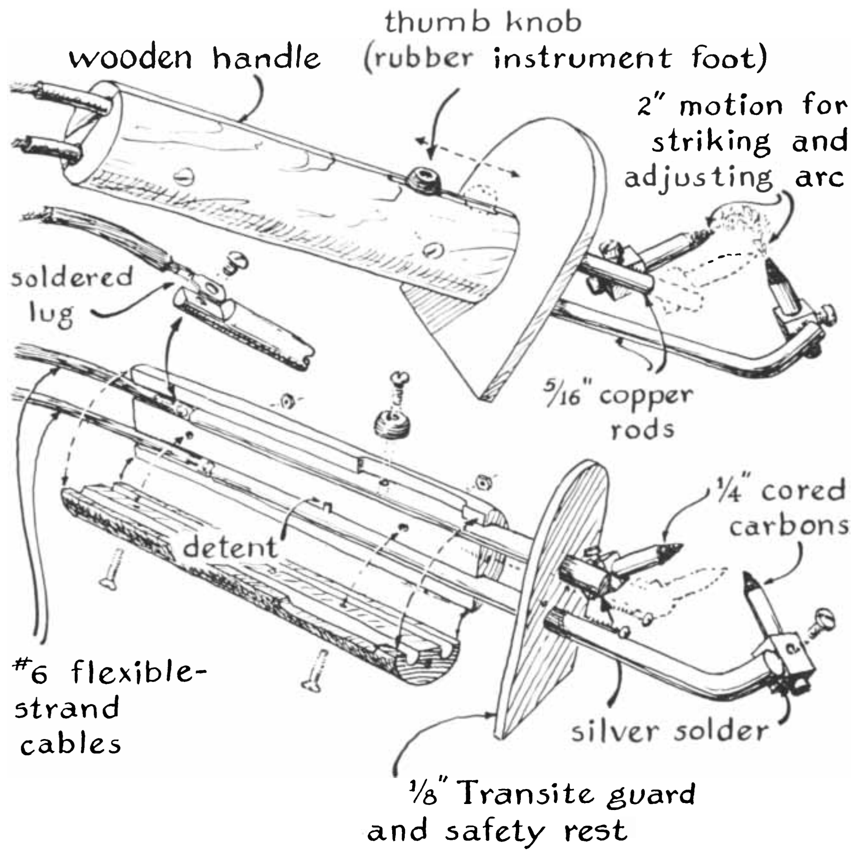
Welds are made by fusing the metal at the site of the bond. Generally the process requires the addition of metal, which must be the same as the metal being bonded. Both brazing and welding are done at temperatures much higher than those developed by soldering irons and blowtorches. Special torches that attain the necessary temperatures cost more than the average layman is willing to spend in view of the limited use he is likely to make of the equipment.

The problem of cost appears to have been solved by Robert Cushman of Princeton Junction, N.J. He is a specialist in metal bonding. Cushman recently improvised a torch in the form of an electric arc. The device can weld steel plates up to a quarter of an inch thick. It can be made easily at home. Cushman writes: "Although the twin-electrode arc torch has been around for many years, it has never received the attention it merits. When properly used, it is astonishingly effective.

"Essentially the device consists of a pair of carbon rods that meet at an angle of about 45 degrees. When the carbons are supplied with an appropriate electric current, touched together momentarily and then separated, an electric arc appears in the form of a V-shaped flame that is much hotter than the melting point of any metal. The carbons are supported by a pair of copper rods clamped in a wooden handle [*see illustration at left*]. The lower rod is fixed in the handle; the upper one can be moved in or out by a knob. Movement of the rod facilitates striking and adjusting the arc. By means of the handle the arc can be manipulated much like the flame of an oxyacetylene torch.

"The arc operates on 120 volts at currents ranging from three to 60 amperes, depending on the amount of heat wanted. I use carbon electrodes as small as 1/16 inch in diameter and as large as 1/2 inch. The size depends on the amount of heat needed and on the thickness of the material to be bonded.

"Welding carbons differ from conventional carbon electrodes in two respects. First, they are coated with a film of copper to minimize the change in resistance that would otherwise result as the carbon burns away. Second, the center of each electrode is filled with a core of rare-earth material. The core tends to sustain the arc during the portion of



The twin-electrode torch designed by Robert Cushman each cycle when the voltage falls to zero.

"The torch can be operated on either alternating current or direct current. When it is operated on direct current, one electrode burns away more rapidly than the other. Special welding carbons are available from dealers in welding supplies and from the larger mail-order houses. They cost between 25 cents and $1, depending on the size. The carbons last for many hours of welding and so are relatively inexpensive. Flux must be applied in brazing or welding just as in soldering. A can of general-purpose flux should be bought along with the electrodes.

"Power is supplied to the arc through a network of eight resistors. Parts of the network can be switched in and out of the circuit for regulating the current. The network consists of 1,000-watt Nichrome heating elements, which are available in most hardware stores. The resistors are interconnected by toggle switches rated at 10 amperes. One of the switches is of the double-pole, double-throw type. The others are of the single-pole, single-throw type. Suitable switches can be bought for about 60 cents each at radio supply houses.

"The switching scheme enables the experimenter to connect two resistors in series, use a single resistor or, in six steps, progressively connect all eight resistors in parallel. Current is thereby controlled in steps ranging from three to 60 amperes. If the house wiring is fused for a maximum of 15 amperes, all except the first two resistors of the network (and their companion switches) can be eliminated. In such a case the torch will be less useful, but it will still find many applications that involve metals up to about an eighth of an inch in thickness.

"The resistance elements of the network are supported by ceramic insulators fixed to a base of Transite, which is a stiff board of asbestos composition. It is available from dealers in building supplies. The ceramic insulators, known as nail-and-knob insulators, can be bought from dealers in electrical supplies. The nail and the leather washer that come with the insulator are replaced by a machine screw and a spring washer. The toggle switches are also mounted on the Transite base [*see illustration on next page*].

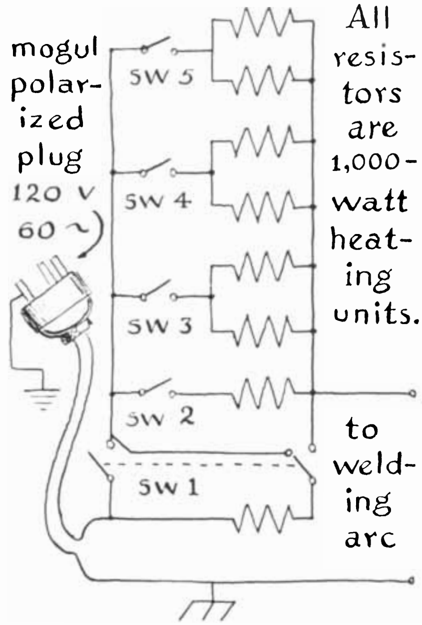
"Electrical connections between the heating elements and the switches are best made by straightening a few turns of the coiled wire at the ends and twisting the ends together. Additional connecting wire can be obtained by straightening an extra heating element. A stud bolt equipped with seven pairs of nuts can be used as a bus bar for interconnecting the common end of all heating elements. Clamp between the nuts the leads to be connected. Do not use copper wire for interconnecting the unit. Copper will oxidize rapidly at the temperature reached by the heating elements.

"The Transite base rests at the sides on brackets of angle iron attached every six inches by machine screws. A cover of perforated steel or expanded metal that shields the heating elements can be attached to the angle brackets. The angle brackets should be joined on the bottom by two or more lengths of strap iron. The installation of the strap iron gives you an excellent opportunity to make your first braze. The completed metalwork should be connected electrically to the grounded lead of the torch.

"An electrical outlet of the 'mogul' type, rated at 60 amperes, should be installed near the location at which the welder will be used. Identify the grounded lead of the power line and make sure the polarized plug of the welder is connected so that the upper electrode of the torch is at ground potential. It is possible, of course, to connect the apparatus directly to the main circuit of the fuse box by means of storage-battery clips, thus avoiding the expense of installing the special outlet. The reader is advised against adopting this expedient, which is not only hazardous but also illegal in most communities.

"Because the arc emits intense radiation in both the ultraviolet and the infrared portions of the spectrum, a protective face mask fitted with dark glasses must be worn. Moreover, the experimenter must protect his skin with opaque covering. Neglect of these precautions invites radiation burns. Face masks designed for arc welding cost about $10. An adequate mask can be made of fiberboard and equipped with welding goggles of dark glass. The goggles cost $3.50.

"The selection of carbon electrodes and the optimum current for a given job of welding or brazing must be determined by experiment. In general electrodes 1/8 inch in diameter operated at a current of three to five amperes are appropriate for joining wires up to 1/16 inch in diameter and for bonding even smaller wires to metallic foils. Steel plates 1/4 inch in diameter require 1/2-



Circuitry of the torch

TOGGLE SWITCHES CLOSED	⅛" ELECTRODE SPACING (~15 VOLTS ACROSS ARC)	1" ELECTRODE SPACING (~60 VOLTS ACROSS ARC)
SW 2	3.7 AMP.	2.1 AMP.
SW 1	7.3 AMP.	4.2 AMP.
SW 1 SW 2	14.6 AMP.	8.3 AMP.
SW 1 SW 2 SW 3	29.2 AMP.	16.7 AMP.
SW 1 SW 2 SW 3 SW 4	43.8 AMP.	25.0 AMP.
ALL	58.4 AMP.	33.4 AMP.

Table of arc currents

inch electrodes and a current of 60 amperes.

"The operating procedure is simple. Set the switches for a current of 15 amperes. Check to make sure your clothing is buttoned, then don the face mask and a pair of gloves that cover your wrists. Move the electrodes together slowly, by means of the slide button, until the tips just touch. After one or two seconds a glow will appear at the point of contact. When the glow is well developed, slowly move the electrodes apart about a sixteenth of an inch and let the arc operate for five seconds. The electrode separation should then be increased until the arc emits a soft hum. Normally the sound will develop at a separation of about a quarter of an inch.

"The heat generated by the arc increases with its length. This is a desirable characteristic not shared by most arc-welding equipment. The arc starts easily and is stable in operation. Both characteristics derive from the substitution of resistors for the special transformer commonly used in welding equipment of other types. Because resistors are used for limiting the current, full-line voltage exists across the electrodes at the moment the arc is struck. Once the arc has become established, the current can be increased or decreased by operating the switches. Usually the arc cannot be struck unless the switches are set for a current of about 15 amperes.

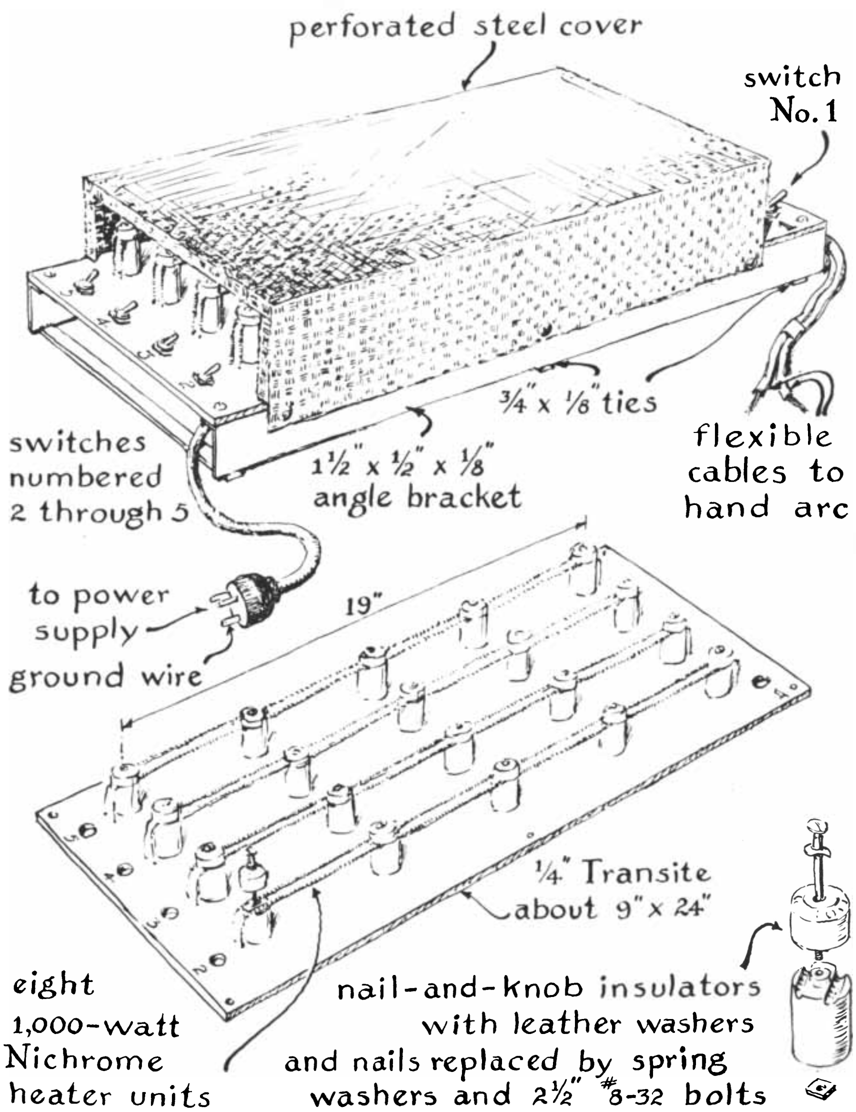
"Welding is an art and its mastery comes only with practice. Beginners will doubtless discover that the most successful initial bonds are made by brazing. I find brazing at least 100 times easier than welding. Moreover, a good braze is usually far stronger than a poor weld. In general when two parts are welded, at least one of the metals must be heated to its melting point, whereas in brazing neither part need be heated to more than a few hundred degrees below its melting point. The brazing alloys become fluid at these temperatures and form smooth joints with a pleasing appearance, much like a conventional solder connection. The parts to be brazed, as well as the brazing alloy, must be coated with an appropriate flux. The brazing temperature is not particularly critical.

"In contrast, any perceptible variation from optimum temperature in the case of a weld results in either a poor bond or damage to the metals that are being joined. The artisan must create a pool of molten material bounded by the solid metal. The material must reach the fluid state or a poor bond results. On the other hand, if all the metal becomes molten, the material flows out of control and the work is damaged. For this reason thick pieces are much simpler to weld than thin ones. Before attempting to weld thin wires and foils the beginner should consult one of the references listed in the bibliography [*page 160*].

"The resistance network can also be used for making bonds by means of a single metal electrode. In this method of welding the arc is struck between the electrode and the workpiece, which has been connected to the grounded lead. I do not recommend the technique, particularly for beginners.

"A tool of the suggested design can be assembled for about $30, a modest figure compared with the cost of commercial welders of equal performance. On the other hand, the apparatus is grossly inefficient in its consumption of power. At least 50 percent of the energy is lost in heating the resistors, compared with about 5 percent in commercial equipment that uses transformers and inductors for limiting the current. Power is cheap, however. At the rate at which the average amateur makes welds a lifetime of use would be required for the low efficiency to offset the saving in first cost."

Experimenters often have occasion to bond wires and sheet metal less than .040 inch thick, particularly when making electrode assemblies for use in gas-discharge tubes and similar apparatus. With practice such welds can be made in a matter of minutes using the apparatus described by Cushman. A spot-welding machine can join thin materials in seconds and its operation



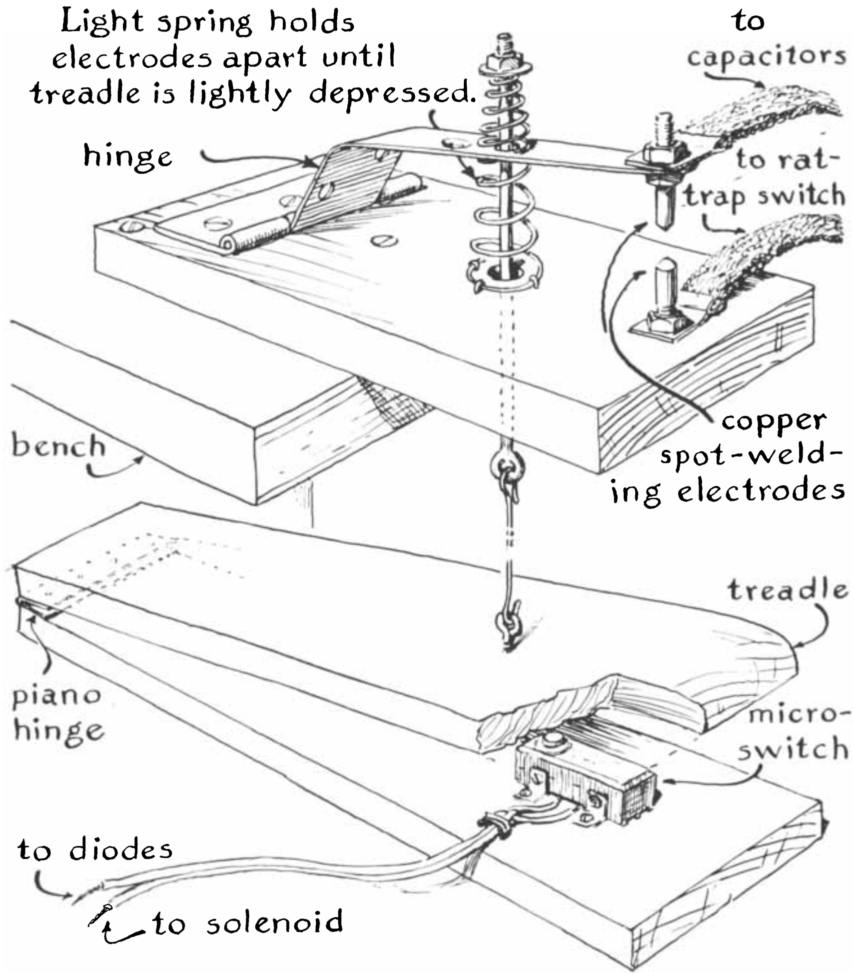
Details of the resistor network

makes little demand on craftsmanship. The parts to be joined are first clamped between a pair of copper jaws. An electric current is passed through the small area where the pieces make contact. The zone of contact acts as an electrical resistance that converts the current into heat. The heat melts the surfaces. They fuse, forming the bond. A successful bond results only when the proper amount of current is applied for a proper interval to surfaces of proper resistance. The spot-welding machine is designed to take these three variables into account.

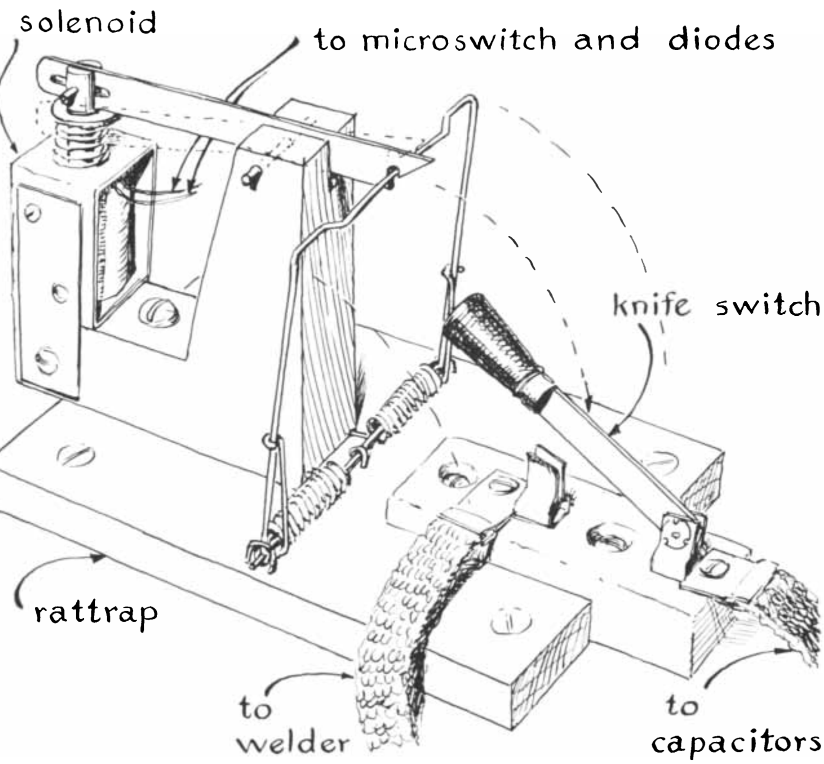
The editor of this department improvised a satisfactory spot-welder about a year ago, largely from the contents of his scrap box. My improvisation made use of such items as an old rattrap, a knife switch and a hinge from a barn door. The essential component consists of a set of four electrolytic capacitors connected in parallel by copper bars. They are also connected to a pair of copper jaws by flexible storage-battery cable of the kind used in automobiles. A quick-acting knife switch closes the circuit automatically when the metal parts to be welded have been clamped between the jaws. The charged capacitors send a pulsed current through the jaws; the current makes the weld. Accessory components include circuits for charging the capacitors with an appropriate amount of energy and for the operation of the jaws and switch.

Spot-welders of this type were made possible by the development of electrolytic capacitors. The energy stored by a capacitor is equal (in watt-seconds) to half the product of the capacity in farads multiplied by the square of the voltage to which the capacitor is charged. When connected in parallel, the four electrolytic capacitors of my unit total 6,800 microfarads, or .0068 farad. They can be charged to a maximum potential of 180 volts. At this potential the stored energy amounts to $180 \times 180 \times .0068/2$, or 100 watt-seconds. I bought the capacitors from Barry Electronics Mail Order Corporation, 512 Broadway, New York, N.Y. 10012. They cost $2.25 each. Capacitors with different voltage and capacitance ratings can be substituted if they are capable of storing about 100 watt-seconds of energy.

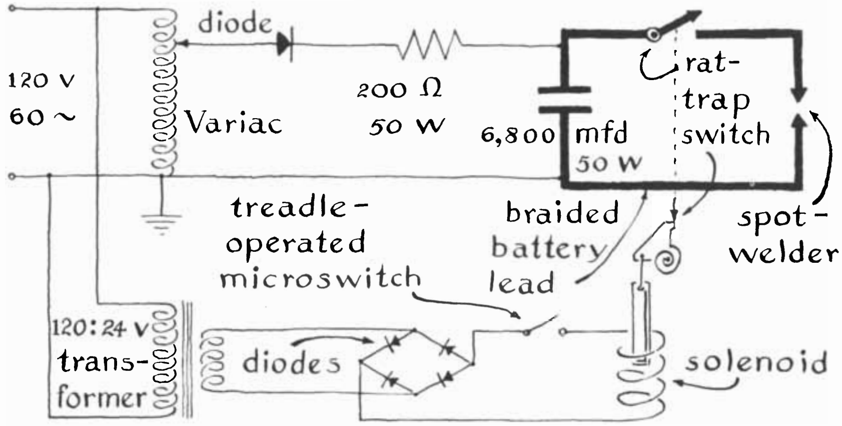
The welding fixture consists of a pair of threaded copper rods supported in vertical alignment by the hinge and a wooden base [*see top illustration at right*]. When the hinge is lowered, the



Some components of the spot-welder



Design of the rattrap switch

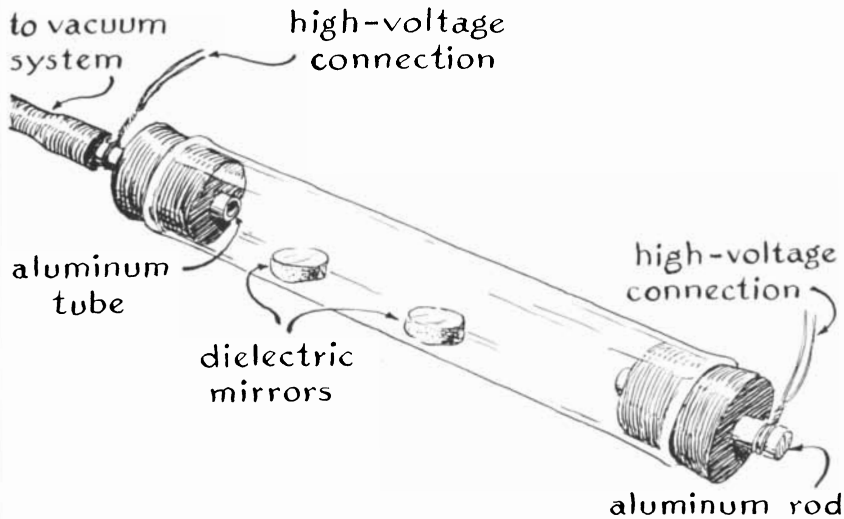


Circuitry of the spot-welder

tips of the copper rods meet and clamp the metal to be joined. The hinge is operated by a treadle that applies force on the workpieces through a spring. The amount of force can be adjusted by altering the position of a nut that controls the compression of the spring and also by substituting weaker or stronger springs. The electrical resistance of the contact between the workpieces to be joined varies with the applied pressure. Hence the adjustment of the spring partly determines the extent to which the current will heat the metal. At the lower limit of its travel the treadle activates a small switch. This switch in turn trips a knife switch that discharges the capacitors. In this way the operator can use both hands to manipulate the pieces to be welded.

The knife switch must be closed quickly to prevent the blade from welding to its seat at the point of initial contact. Any fast-acting device can be used to close the blade. I used a rattrap that is tripped by a solenoid [*see bottom illustration on preceding page*]. Although resetting the trap is inconvenient, the alternative is to pay about $65 for a quick-acting, automatically resetting contactor of the kind used in commercial spot-welders. The rattrap gadget can be built for less than $5.

The temperature developed in the weld is determined in part by the amount of stored energy; this quantity depends in turn on the voltage to which the capacitors are charged. The voltage can be varied as desired by inserting either a potentiometer or a variable-voltage transformer in the circuit ahead of the diode that provides direct current for charging the capacitors. All diodes can be 1N1763 or the equivalent. The solenoid is a Guardian Type 11 that operates on 24 volts (direct current) and develops a pull of 21 ounces. This unit is available from Allied Radio, 100



Carl Fromer's device for cleaning laser mirrors

North Western Avenue, Chicago, Ill. 60680, as are equivalent solenoids that operate directly on 120 volts (alternating current). To minimize the hazard of accidental shock an isolation transformer was inserted between the power line and the power supply. Equivalent isolation can be provided inexpensively by interconnecting the secondary windings of two filament transformers and using the primary winding of one as the input and the primary winding of the other as the output.

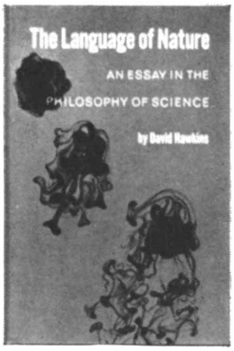
The optimum force with which to clamp the parts to be welded and the optimum voltage to which the capacitors should be charged must be determined experimentally for each kind and size of weld. In general both the clamping force and the voltage increase with the size of the weld. A record should be made of the proper settings established for each kind of weld. The record will serve as a rough guide to the best trial settings for similar welds.

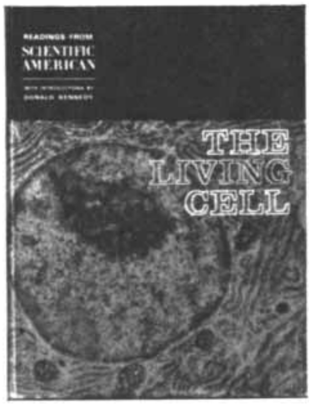
Carl Fromer, a high school student in Staten Island, N.Y., has hit on an effective method of cleaning the soft-coated dielectric mirrors used in continuous lasers of the helium-neon type. The coatings accumulate a film of grime after some weeks of exposure to the air. The film seriously reduces their reflectivity. Any chemical treatment that dissolves the grime destroys the coatings.

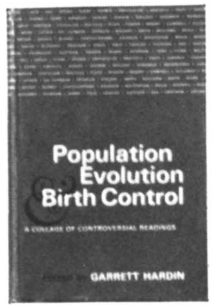
Fromer removes the grime by electronic bombardment. He inserts the soiled mirrors face up in a simple gas-discharge tube, exhausts the tube to a pressure of about one torr, backfills with argon or with a 7 : 1 helium-neon mixture to a pressure of 10 torr and operates the tube for one minute at a current of 60 milliamperes [*see bottom illustration on opposite page*]. The mirrors emerge looking like new.

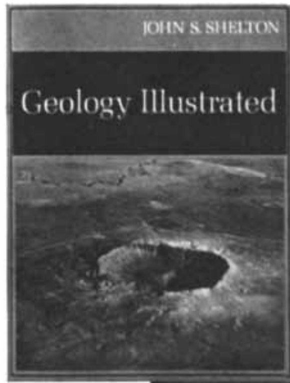
In addition to grime, the coatings are vulnerable to moisture. Hence the mirrors should be stored in a dry place. A good place is an airtight four-ounce jar. Put an ounce of anhydrous calcium sulfate on the bottom and then add a layer of absorbent cotton.

Sam Epstein of Los Angeles, who designed the spectrograph described in this department in September, calls attention to the fact that the instrument was designed for a diffraction grating with a focal length of 53 centimeters. If a grating of differing focal length is substituted, appropriate changes must be made in the dimensions of the instrument.









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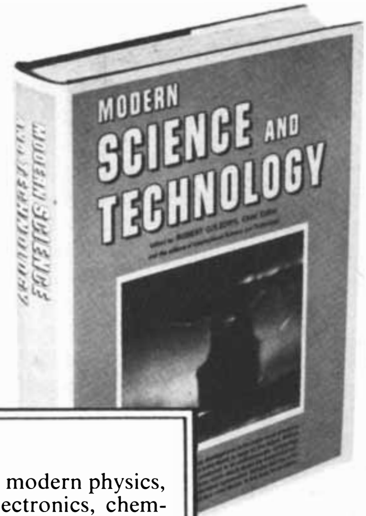

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BOOKS

George Ellery Hale, the master promoter of American astronomy

by Harlow Shapley

Explorer of the Universe: A Biography of George Ellery Hale, by Helen Wright. E. P. Dutton & Co., Inc. ($10).

George Ellery Hale, whose name is perhaps best known to a younger generation in its association with the 200-inch Hale telescope on Palomar Mountain, was a great organizer of American science. He had a full life—full of triumphs and also of illness and frustration. In writing the story of Hale's origins, career and bequest to posterity Helen Wright has richly served her fellow astronomers. No one else could have done so well. Her account preserves an admirable balance in presenting Hale not only as a doer but also as a dreamer.

Hale was born in Chicago in 1868. His family was idealistic and decently ambitious. His father, a manufacturer, was well-to-do but not rich. Both his father and his mother recognized early that their son was highly talented. Other members of the family were also impressed with him. His younger brother William and younger sister Martha were his happy slaves.

It is of interest to speculate on which of Hale's many outstanding contributions will be most enduring in the years to come. To the scientifically minded public it may be the 200-inch telescope or the California Institute of Technology, the formation and growth of which Hale guided over many years. One might choose the 40-inch telescope at the Yerkes Observatory, the largest telescope of its time and still the largest refractor. But if we limit our appreciation to instruments, we must put at the top of the list the rich equipment on Mount Wilson: the solar telescopes that for many years have dominated research on the sun, and the superb reflectors that for half a century have made history in the study of stars and galaxies.

Several of us who worked on Mount Wilson in the days before the 100-inch reflector was built earnestly believed the two most effective instrumental interpreters of the universe had been Galileo's "optic tube" and the Mount Wilson 60-inch reflector. Discoveries to be credited to Galileo's instruments are the moons of Jupiter, the resolution of the Milky Way into stars and the fact that Venus has phases like the moon's. Credited to the 60-inch on Mount Wilson are many revelations about the larger universe, including the period-luminosity relation of pulsating stars and numerous facts about the structure of the galaxy.

Several ingenious colleagues developed and used the Mount Wilson telescopes, but Hale for many years supplied a major part of the driving inspiration. The series of four epoch-making telescopes (the 40-inch, the 60-inch, the 100-inch and the 200-inch) was preceded by Hale's private refractor in Chicago ("a childhood adventure"), and that was preceded by various astronomical cameras at the Harvard Observatory. These he was privileged to use while he was an undergraduate at the Massachusetts Institute of Technology.

Hale's skill in promoting the construction of instruments was matched by his skill in organizing scientific institutions. We are largely indebted to him for the National Research Council, *The Proceedings of the National Academy of Sciences, The Astrophysical Journal* and the International Astronomical Union. How could he find time for so much? And for his family, to which he was devoted? Perhaps personal efficiency is the inadequate answer.

Half a dozen obituary accounts have been written about Hale since his death in 1938, and Miss Wright's excellent biography covers the highlights of his career. I should enjoy adding to her account some personal recollections. They should assist in interpreting the temperamental life of this very human and admirable American.

As a typically ambitious young scientist I decided early in my university career to make the Mount Wilson Observatory my goal. My teachers at the University of Missouri and at Princeton agreed that research rather than college teaching was something to which I could hopefully aspire. That meant turning my attention toward the California observatories. While at Princeton I had done my graduate work on eclipsing double stars, and under the guidance of Henry Norris Russell I had published a few small papers. Soon I could pretend to competence in the field and was rewarded with a doctor's degree. Russell and Frederick Seares suggested that I try for Mount Wilson, and toward that end Seares arranged a breakfast meeting at the Commodore Hotel in New York. Both he and Hale would be stopping there on the way to Europe.

Needless to say, this was for me an exciting moment. To be sure of being alert for the confrontation, I went up to New York from Princeton the night before the interview. I prepared further by going to the opera—to hear Caruso in *Pagliacci*.

In the morning, nervous and stuffed with lore on eclipsing binaries, I faced the great and genial George Ellery Hale. I was expecting to give him a modest glimpse of my wit and wisdom in matters astronomical. Hale told a story or two, and was interested to hear that I had gone to a favorite opera of his. Not a word did he say of astronomy. There was no exploration of my stellar tastes, of my binary theories or of my arithmetic.

"I must go now," he said, and without further conversation departed for a Cunard pier. I was dismayed. All that preparation and my only return was some scrambled eggs. I asked Seares what it all meant. He only smiled at my discomfiture. In a few days, however, a letter came saying that the job was mine. It had even been mailed in New York. I resolved then that if and when my time came to employ others, I should not be cruel and quiz them about *Pagliacci*.

Miss Wright describes Hale's wide interests: Egyptology, astrophysics, music, education, philanthropy. She tells how keenly he regretted the fact that his activities were limited by his health; throughout his life he suffered from stomach trouble and back pain, perhaps resulting from his highly anxious and nervous nature. In the seven years of my association with the Mount Wilson Observatory I had fewer than a dozen interviews with him. Ferdinand Ellerman, Seares, Walter Adams and Adrian van Maanen were his natural associates in later years. His health could not stand the pressure of scientific arguments, so we regretfully spared him. One day, however, he asked that I come and do him a service.

"You know all the young men at the observatory. Perhaps you would know if any are in financial distress. I should like to help them, but anonymously." Soon I was able to write him that one able youngster needed emergency help or he would have to drop out. Conditions promptly altered for that young man. He is now a member of the National Academy of Sciences and has received national awards. I never knew how much he had been helped. I do know, however, how much someone else was helped. Some years later Hale arranged a public debate between Heber D. Curtis and me on the scale of the universe. I needed money to travel from California to Washington for the debate, and in my mail was an anonymous $200.

Hale liked to be considered an amateur, which indeed he was if we use the term literally—a lover of his subject. He believed we should recognize popular astronomy and its devotees. He once asked me to go with him to Oceanside, or some similar watering place down San Diego way, to meet with another believer in popular science, namely E. W. Scripps, the important newspaper tycoon. Scripps announced that he would like to establish an institution for the popularization of current scientific discoveries. I was asked to join the conference because I was known to have had a little newspaper experience. It was not much experience, but it did give me a brief and pleasant association with a skillful operator. Before long there was a Scripps Foundation for Journalism, and Science Service was born. It operates under a board of 15 members, three each from the National Academy, the National Research Council, the American Association for the Advancement of Science, the Scripps estate and the journalistic profession. It has been a very effective organization that has played an important role in science reporting in this country.

Miss Wright's book is highly authentic, thanks to two circumstances. Hale was a prolific writer of letters, and among his numerous collaborators were intimate friends who were similarly prolific. It is our good fortune that in their college days at M.I.T. Harry Goodwin and George Hale became lifelong friends. They shared joys and sorrows as Goodwin rose to be a distinguished dean at his alma mater and Hale to be America's most famous promoter of scientific and scholarly research.

Among Hale's earliest astronomical co-workers and correspondents were most of the big-name American astronomers of the time: Edward C. Pickering of Harvard, Simon Newcomb of the Naval Observatory, Lewis Boss of Albany, James E. Keeler of the Lick Observatory, Walter Adams of Mount Wilson, Charles A. Young of Princeton, C. G. Abbot of the Smithsonian and John A. Brashear of Pittsburgh. He was also close to the physicists Henry A. Rowland, A. A. Michelson, Sir William Huggins, Sir Robert Ball and some of the eminent scientists of the Continent: Antonio Abetti of Florence, H. Kayser and Karl Runge and others of Germany and A. A. Belopolski of Russia. Hale, while still a very young man, was known to all of them. He was elected to high honors while still in his 20's. His interest in spectroscopes, diffraction gratings, solar optics and other gadgets was practically a passion.

One of Hale's deepest nonastronomical interests was Egypt as interpreted by his University of Chicago colleague James H. Breasted. Still, his first devotion in the necessary escape from too much astronomy—escape from the great telescopes and the problems of the National Academy of Sciences—was Pasadena's Huntington Library and Art Gallery. Pasadena, he argued, was a most appropriate region for the blossoming of the humanities. The coming to California of Robert A. Millikan and Arthur A. Noyes had made Cal Tech a haven for the natural sciences. The humanities, properly promoted, would bring a richness that half a dozen Nobel prize winners could not provide. In the 1920's Hale turned his diplomatic skill to the establishment in the suburb of San Marino of the utmost in art and literature. As Cal Tech and the great telescopes would bring prestige to Pasadena, so would the Huntington Library and Art Gallery bring it for art.

George Hale died at the age of 70. What he might have accomplished if he had had another decade stimulates the imagination. This reviewer's conclusion is that every graduate student, at least in the sciences, should be required to read thoughtfully this story of a very modest man who reached outward into the universe, conferring with this planet on the way.

Short Reviews

PARTICLES IN THE ATMOSPHERE AND SPACE, by Richard D. Cadle. Reinhold Publishing Corporation ($10). The particles discussed here range in size from a tenth of the wavelength of light up to a centimeter. Such particles are of widespread importance to practical affairs and to scientific knowledge. It is evident that in a universe of gas, a universe that we on the solid earth study so much with visible light, particles will be important. On the one hand, gas cannot condense without nucleation somehow into droplets or crystallites. On the other hand, subdivided matter is optically conspicuous far beyond its equivalent mass in bulk. And it is chemically more active.

Here we read of all such dusts and grains and fogs. The unresting sea sends fine particles of solid sea salt into the entire atmosphere. They are produced not by the spray—spray particles are too heavy to float far from their point of origin—but by a thin surface film and by the bursting of fine bubbles on the surface, which produces a microscopic jet. Both of these evaporate to tiny salt crystals, which are carried on the winds to all the continents. The sea-salt grains may nucleate rain formation from those clouds that do not contain ice. The trigger of nucleation is much studied as a means of forecasting and modifying the weather.

Smog is part of the story. The old-fashioned sooty fog of London is of course no longer the smog prototype. That is now the hazier, more reactive assemblage of particles familiar in coal-free Los Angeles. It is fed by all organic combustion, in cars, trash burners, industrial furnaces and trees. It is trapped by inversion in the bowl of the city. It is activated from the hydrocarbons, the carbon monoxide and the nitrogen oxides of the combustion products into ozone and other such irritating radicals by the ultraviolet of the bright sun. Why it is particulate is still unclear.

Radioactive fallout is another modern addition to natural history. The hot radioactive gases nucleate out either on the airborne particles already present or on the copious dust thrown up in the explosion. Blowing in the wind at low levels, it falls out downstream nearby. Some of it may enter the high air; small enough particles even persist for years. Marked with the brand of nuclear instability, they have revealed the history of the rain and the snow they contaminate.

There are beautiful dusts too. Consider the light blue clouds seen at summer twilight in high latitudes. These "noctilucent" clouds apparently form at an altitude of 50 miles, and they resemble a glowing sea surface. They shine in the sunlight coming over the pole long after the ground is dark. Rocket sampling suggests, but does not yet prove, that they consist of ice crystals formed on nuclei of meteoritic dusts. There is the zodiacal light, a column of light extending up from the horizon for a few hours after sundown or before sunrise. It supplies up to a third of the total light of a clear moonless night sky. That it shows no parallax proves its astronomical distance from us, and its symmetry about the orbital plane of Jupiter (rather than the orbital plane of the earth) suggests it is under long-range control by the sun and the solar system. Some of it is light scattered by the electrons of the solar corona, some by dust in space. The latest measures of polarization incriminate the interplanetary dust, which may indeed feed the earth with magnetic spherules found in the deep sea, the antarctic ice—anywhere undisturbed and iron-free sediment can be studied.

Finally there are two chapters on the moon, the planets and the galaxy. It is now clear that the moon is a dusty place. The moon chapter of this book is remarkable for the ingenuity of the conflicting theories of the moon's surface that are outlined. The author is much more successful in carrying a thread of argument through a gantlet of inconsistent papers in the chapters on earthly dusts, where he himself has done distinguished work, than he is in these remoter regions. The entire volume is review, in which rather complicated matters are handled by very concise extracts. The result is readable wherever some of Cadle's assessment is implied; it is less so elsewhere. He has done a service in organizing so large a field of modern natural history; the final treatise on particles is still in the future.

THE HUMAN BODY IN EQUIPMENT DESIGN, by Albert Damon, Howard W. Stoudt and Ross A. McFarland. Harvard University Press ($11.95). "Design error may in fact be responsible for a substantial fraction of aircraft and automobile accidents now ascribed to human failure." So writes this Harvard team of applied physical anthropologists. It is a book full of tables and line drawings, a reference text for designers and students of engineering design. How far can a man reach to his left to pull a brake lever? It of course depends on whether he is a small man dressed in bulky arctic gear or a rangy driver in undershirt and shorts. The book draws heavily on the military for its data: its aircraft and trucks have had rational design, and Detroit data are almost absent from the compilations. The average value is of little use: very few operators are of average height. The *sine qua non* of a machine that, if not every man, many men can operate is to provide devices adjustable over a small range to accommodate 90 or 95 percent of the candidates. This work tabulates for many groups such characteristics as height, shoulder depth and breadth, grasping reach and size of the hand. There is a faint suggestion that the data are not new, many depending on World War II statistics. The data are not all for static packaging. There is material on center of gravity and moment of inertia, on lifting, gripping and pushing. There is reaction speed and knob-setting performance. A rather grim chapter on resistance to acceleration and to blows closes the portion on data. The book ends with a summary chapter of design recommendations that pleads for much more data still, particularly data beyond the mere static sizes.

The tables—about 150 of them—and text are full of curiosities. The tallest men mentioned were a group of workers in the wood-pulp industry, 1 percent of them over six feet four. The average adult loses about .95 inch of height during the day by compression of the intervertebral disks. A group of "powerfully built Englishmen," working from a flat seat with a backrest, averaged a maximum pedal pressure of 845 pounds! Reaction and movement times are fastest at an age of about 20. They slow down with the years, which is no surprise, but 24 vigorous oldsters from 62 to 86 had lost only 11 percent to a control group of young voters. Center of gravity, moment of inertia, impact resistance and a number of similar matters are best known by measurements on the cadaver and its portions. Fracture occurs in long bones mainly from tensile stress, with static bending from 1,000 to 2,000 pounds, depending on position. The brave crash measurements of Colonel John Paul Stapp and his co-workers are presented graphically. The scalp, a soft "helmet" less than a quarter inch thick, absorbs about 90 percent of the force impinging on the head. (The authors may mean not force but energy transfer.) A normal automobile stop is an acceleration of about .25 times gravity for some six seconds; a quick stop, .45 *g* for four seconds; an emergency stop, brakes jammed on, about .7 *g* for three seconds; a crash, some 20 to 100 *g* for .1 second or less. Such a crash is fully survivable with good design.

Finally, as a measure suited to the economics of an earlier age, the maximum individual load carried in the hand by a handgrip should be 60 pounds for short distances, 35 pounds for longer ones. By muscle power a normal man can do lifting work of half a million joules per day. That is about 15 cents per month at the rate of your electricity bill. In Madras, for example, not a few people still work all day as pumps in the paddy.

The Invention of the Aeroplane (1799–1909), by Charles H. Gibbs-Smith. Taplinger Publishing Co. ($14.95). The brothers Wright made the first genuine powered flight at Kill Devil Hills in December, 1903. Throughout the early years of flying they were never bested in duration of flight until the great Reims meet of 1909, when half a million thrilled watchers became aware that the rickety kites of the daring sportsmen had grown into a new and practical means of transport in war and in peace. In 1909 you could buy a production-model Wright Flyer for about $5,000. It would carry you—and a Wright-trained pilot—reliably for a couple of hours in fully maneuverable flight at an altitude of a few hundred feet and a speed of 40 miles per hour. Sitting next to you would be a Wright-built four-cylinder water-cooled engine, turning out 30 horsepower with its 200 aluminum-free pounds. There were by the end of this period several worthy competitors in the U.S. and in France, selling box-kite biplanes of the Flyer kind as well as the cheaper and more elegant monoplanes.

This is a fine-grained history—and prehistory—of powered flight up to its time of practicality. The text is both precise and delighted, with thorough and painstaking documentation and judicious analysis. The photographs and drawings sum up to a complete period piece, an accurate complement to that fine, funny, romantic film *Those Magnificent Men in Their Flying Machines.*

Gibbs-Smith is a scholarly historian of aviation who does not allow his passion for accurate detail to blow him away in a whirlwind of trivia. He convincingly demonstrates the Wrights' priority and power, flowing from their careful experiments and deep thought. They were true "airmen," he says, who viewed the task as one of controlled motion in a new medium and a new dimension. Too many of their contemporaries were mere "chauffeurs," driving by brute force a kind of motorcar with wings a little way above the road. The airmen succeeded, even though they made mistakes. The Wrights believed so much in control that they required it of the pilot constantly and built no inherent stability into their machines. They were "incomparably the greatest men in aviation." By the end of 1909 airplanes were proved. Then theory entered, engineers and factories appeared, and the industry had begun to leave the pioneers behind by the eve of World War II. This volume recounts the work of George Cayley, who lived a century too early for success, briefly surveys the 19th century, then covers the pioneer years with high resolution.

The Reims meet, in those innocent years, was largely sponsored by the champagne industry. Military observers were there. The future was to trade the *ambiance* of sportsmanship and bubbles for the slaughter bench of history.

THE PHYSICS OF MUSICAL SOUNDS, by C. A. Taylor. American Elsevier Publishing Company, Inc. ($9.50). Many physicists are, like Professor Taylor, musicians. His is a fresh and attractive addition to the corpus of works aimed at those "fascinated by the relationship between physics and music." He writes a clear, up-to-date and agreeable kind of introduction to the physics of music. On an underlying (but not much used) framework of setting himself and the reader the task of designing a new type of musical instrument, he builds the familiar story of vibration and waves. More than the author of any other introductory treatment, he pays central attention to the physics of complex sound, that is, to the quality of sound. This is the most original and successful portion of the book; he manages to make real the description of patterns in time by their frequency content—the Fourier transform—essentially without resorting to mathematical formulas. Physicists (although not enough of their students) and a vanishing fraction of the musical public understand this crucial language in something like the qualitative form he has given here. About a fifth of the book is mathematical—branded with an asterisk for the timid—and there the formal treatment is given. Armed with the Fourier weapon, Taylor can make reasonable the key role of transients, of beats, of phase and of combination tones. He discusses energy transfer in the same lucid style. The intricacies of the ear and a brief discussion of high fidelity come in for a good chapter, and there is a crisp account of the physics of strings, woods and brasses. Several novel instruments (even the Hammond organ) are considered in the final chapter, but not that new instrument of his early hinting. A 45-r.p.m. disk accompanies the book, with recorded illustrations of many of the points described. Lying between an introductory text and a serious if popular treatment, this good book would have gained by greater length. This is not blame but praise.

THE CONCRETE ARCHITECTURE OF RICCARDO MORANDI, by Giorgio Boaga and Benito Boni. Frederic A. Praeger, Inc. ($20). The arches and shells of Pier Nervi soar familiarly in many buildings, now almost commonplaces of our visual surroundings. Concrete and its invisible reinforcing mesh is shaped in the form of bubbles. This book is a reminder that it is not the only way. Riccardo Morandi is another brilliant Roman designer in reinforced concrete. Master of prestressing, follower of Robert Maillart and Eugène Freyssinet, he designs and builds with a purity and coolness of line, expressed in ribs and girders and clean trusses, that deserve the description "classical" compared with the romantic structures of Nervi. This book is handsome with photographs of Morandi's work, and fascinating for the care with which it shows the stages of construction, sometimes step by step from drawing and model to the precarious erection of a towering hinged bridge. The Storms River bridge in South Africa floats 400 feet across the gorge with Greek simplicity and Newtonian necessity. Morandi's big Venezuela causeway looks like a model in the photographs, so simply and originally is it built, even in detail.

A HISTORY OF RECREATION, by Foster Rhea Dulles. Appleton-Century-Crofts ($6.95). When the formidable Cotton Mather fell into Spy Pond on a weekday, he had been fishing. The austere leaders of Puritanism permitted only those sports, other than well-licensed drinking, that earned some useful product. The people lagged in their austerity, but 17th-century America was sternly ruled, even by the Anglican power in Virginia. Tombs were visited by the pious, but the theater was out. At Harvard College in 1760 a student actor in the scarcely frivolous drama *Tancred and Sigismonda* wrote: "We are likely to be prosecuted." Perhaps he was overanxious.

The theater grew as an aristocracy of means and manners came to rule, and the frontiersman escaped entirely the severity of the old settlements. By 1800 the cities knew theater in full bloom, with famous stars, a "road" and an iron-voiced repertory. The backwoodsmen wrestled and competed in their rough way and also held revival meetings, where from time to time the crowd was seized by "the jerks," or set to barking like spaniels.

As the cities grew to industry's call, spectator sports replaced the games and field sports, no longer accessible in a time without transportation or public parks. This is the origin of the great American watcher. A sort of Grand Prix was run on foot through New York streets in 1835 for a purse of $1,000 to any man who could run a 10-mile course in less than an hour. These were famous professional runners, called "peds"; one Henry Stannard claimed the prize. Boats and horses raced too, and the prizefight flourished underground.

By the middle of the century the cities were restless and teeming. Phineas T. Barnum came on the scene, with a genuine mix of media. From Jenny Lind, around whose hotel 30,000 people gathered in greeting, to the white-washed Siamese elephants, Barnum's promotion fitted precisely the Victorian scene. He expurgated Shakespeare; he made circusgoing seem like self-improvement.

Baseball (Professor Dulles deflates Cooperstown) slowly arose, and in 1842 it was being played well at the Elysian Fields in Hoboken. Roller skates and bicycles were the first machine-age contributions to participant sport, and with croquet they were attractive to men and women alike. The Victorian repression, like the Puritan, was weakening.

The automobile entered from above, the sport of the rich. Films began at the bottom, the nickelodeon magnates aiming directly at the factory laborers, largely immigrants, of the steel towns and the fur and garment centers.

Finally we survey the American recreational scene today. The last fourth of the book is up to date, redone on the structure of the earlier part, which first appeared in 1940. Here one sees the rise of the films, of television, and above all of the automobile and the highways and parks it implied. The complexity of modern life extends even to spectator sport: kayaking, automobile demolition, skiing, tennis, golf, drag racing—all appearing on television. Participant sport, with numberless quieter diversions outdoors and in, has grown even more. Americans have finally learned how to play.

It is hard to put down this lively and detailed book without a sense that in recreation the forces of the economy are shown plain. The Puritans could not afford amusement; they had to lay up capital in a new land. So it was again when industry grew. Now we have a different way of making a living.

THE SCIENTIFIC PAPERS OF JAMES CLERK MAXWELL, edited by W. D. Niven. Dover Publications, Inc. ($12.50). The two volumes of the 1890 memorial edition of the works of the incomparable Maxwell are hardbound into one thick, attractive, photographically reduced book. The papers begin with his schoolboy publication generalizing the scheme of drawing an ellipse by using thread wrapped around pins to construct ovals of many foci. They end with his reviews and encyclopedia articles, which sum up 19th-century physics in terms a serious lay reader can grasp. The *Encyclopaedia Britannica* piece on "Atom" is particularly modern, with its concern for the facts of genetics and its wonder at the identity of atoms. The kinetic theory is here, both in theory and in experiment, and the foundations of Maxwell's electromagnetic work, both at the deep level of the original papers. Physics libraries should have this book, as should anyone with a concern for the history of modern physics. Maxwell's clarity and completeness fit some of his papers for the modern graduate student.

The *Treatise on Electricity and Magnetism*, his marvelous but difficult masterpiece, is not here, but it is available at a great bargain in two paperback volumes from the same publisher.

PESTICIDES IN THE ENVIRONMENT AND THEIR EFFECTS ON WILDLIFE, edited by N. W. Moore. Blackwell Scientific Publications ($12). A paperback account of a meeting of experts on this gloomy subject held in England in the summer of 1965. It was sponsored by NATO, but the scientists were invited as and spoke as individuals, not as representatives. Some 40 papers span analytic methods, species from partridge to perch and seals, and statistical techniques. Detectable amounts of DDT, for example, are present in the fatty tissues of Adélie penguins, thousands of miles from the nearest farm. Traces of mercury and copper from fungicides are found in French and Swedish owls, hawks and foxes, at lethal levels in some cases. A full assessment is complex, like the long story of radioactive fallout. The editor concludes cautiously that "pesticides are a most important feature of modern life but they have undoubtedly done some harm to wildlife. The extent and the nature of damage are still largely unknown." As usual, he urges only much research and study. Multinational economic measures, subsidizing specific pesticides and penalizing more harmful ones, seem warranted by the present level of both knowledge and hazard.

CIVILIZATIONS OF THE INDUS VALLEY AND BEYOND, by Sir Mortimer Wheeler. McGraw-Hill Book Company ($5.50). In 1961 the London firm Thames and Hudson produced a splendid book—thick, high, broad and dear. Called *The Dawn of Civilization,* it contained 10 essays by leading British archaeologists, one on each of the great ancient cultures of Asia, Europe and America. The book had 1,000 illustrations, scores in color; in both text and picture it was superb. The text appeared on two levels: a rather simple, brief caption story and a serious, half-technical narrative by an authoritative and devoted scholar. The present series, of which this volume is a glowing example, distributes the older work in short hand- and mind-sized takes.

Sir Mortimer here reworks his worthy essay, and the designers have given it to us in a slender book with half again as many illustrations as the first version. The great theme of the book, the rise and fall of Mohenjo-daro in the Indus Valley, is seen as the result of several causes: conquest, flood and denudation. The skeletons of a fleeing family of ivoryworkers, found a couple of years ago, bear witness to attack, probably by the Aryan worshipers of Indra, the god who "rends forts as age consumes a garment." The beautiful seals are here, carved with those great oxen and the still wholly undeciphered pictographs. These represent a third system of writing, neither hieroglyph nor cuneiform, yet born with the others within a remarkably short span of time and space.

Five other titles of the series are also in print; all of them can be called excellent, and some are outstanding. The volume on the American cultures is not yet out; it is worth waiting for.

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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.

TECHNOLOGY IN CHINA

ECONOMIC PROBLEMS OF RED CHINA. Jin Xiong Bai. Jiji Press, Tokyo. (Available in Japanese only.)

SCIENTIFIC AND ENGINEERING MANPOWER IN COMMUNIST CHINA, 1949–1963. Chu-yuan Cheng. National Science Foundation (NSF 65–14). U.S. Government Printing Office, 1965.

HOMO ERECTUS

MANKIND IN THE MAKING. William W. Howells. Doubleday & Company, Inc., revised edition in press.

THE NOMENCLATURE OF THE HOMINIDAE. Bernard G. Campbell. Occasional Paper No. 22, Royal Anthropological Institute of Great Britain and Ireland, 1965.

THE TAXONOMIC EVOLUTION OF FOSSIL HOMINIDS. Ernst Mayr in *Classification and Human Evolution,* edited by Sherwood L. Washburn. Viking Fund Publications in Anthropology, No. 37, 1963.

MAGNETIC FIELDS ON THE QUIET SUN

SOLAR AND INTERPLANETARY MAGNETIC FIELDS. John M. Wilcox in *Science,* Vol. 152, No. 3719, pages 161–172; April 8, 1966.

SOLAR MAGNETIC FIELDS. V. Bumba and Robert Howard in *Science,* Vol 149, No. 3690, pages 1331–1337; September 17, 1965.

THE TOPOLOGY OF THE SUN'S MAGNETIC FIELD AND THE 22-YEAR CYCLE. H. W. Babcock in *The Astrophysical Journal,* Vol. 133, No. 2, pages 572–587; March, 1961.

TRANSPORT OF MAGNETIC FIELDS ON THE SUN. Robert B. Leighton in *The Astrophysical Journal,* Vol. 140, No. 4, pages 1547–1562; November 15, 1964.

THE THREE-DIMENSIONAL STRUCTURE OF AN ENZYME MOLECULE

BIOSYNTHESIS OF MACROMOLECULES. Vernon M. Ingram. W. A. Benjamin, Inc., 1965.

INTRODUCTION TO MOLECULAR BIOLOGY. G. H. Haggis, D. Michie, A. R. Muir, K. B. Roberts and P. M. B. Walker. John Wiley & Sons, Inc., 1964.

THE MOLECULAR BIOLOGY OF THE GENE. J. D. Watson. W. A. Benjamin, Inc., 1965.

PROTEIN AND NUCLEIC ACIDS: STRUCTURE AND FUNCTION. M. F. Perutz. American Elsevier Publishing Company, Inc., 1962.

STRUCTURE OF HEN EGG-WHITE LYSOZYME: A THREE-DIMENSIONAL FOURIER SYNTHESIS AT 2 A. RESOLUTION. C. C. F. Blake, D. F. Koenig, G. A. Mair, A. C. T. North, D. C. Phillips and V. R. Sarma in *Nature,* Vol. 206, No. 4986, pages 757–763; May 22, 1965.

THE AGING GREAT LAKES

EUTROPHICATION OF THE ST. LAWRENCE GREAT LAKES. Alfred M. Beeton in *Limnology and Oceanography,* Vol. 10, No. 2, pages 240–254; April, 1965.

GEOLOGY OF THE GREAT LAKES. Jack L. Hough. University of Illinois Press, 1958.

GREAT LAKES BASIN. Edited by Howard J. Pincus. American Association for the Advancement of Science, Publication No. 71. The Horn-Shafer Company, 1962.

GREAT LAKES: SPORT FISHING FRONTIER. Howard A. Tanner in *Michigan Conservation,* Vol. 34, No. 6, pages 2–9; November–December, 1965.

THE ST. LAWRENCE GREAT LAKES. Alfred M. Beeton and David C. Chandler in *Limnology in North America,* edited by David G. Frey. The University of Wisconsin Press, 1963.

PARTICLE STORAGE RINGS

ADONE, THE FRASCATI 1.5 GEV ELECTRON-POSITRON STORAGE RING. F. Amman. Laboratori Nucleare di Frascati, August, 1965.

THE STORAGE-RING SYNCHROTRON. G. K. O'Neill in *CERN Symposium on High Energy Accelerators and Pion Physics.* CERN, June, 1956.

THEORETICAL ASPECTS OF COLLIDING BEAM EXPERIMENTS. R. Gatto in *Electron and Photon Interactions at High Energies,* edited by G. Höhler. Springer-Verlag, 1965.

ACETABULARIA: A USEFUL GIANT CELL

DETERMINATION AND REALIZATION OF MORPHOGENESIS IN ACETABULARIA. Günther Werz in *Brookhaven Symposia in Biology,* No. 18, pages 185–203; Brookhaven National Laboratory, 931 (C-44), 1965.

ENDOGENOUS CIRCADIAN RHYTHM IN CYTOPLASM OF ACETABULARIA: INFLUENCE OF THE NUCLEUS. E. Schweiger, H. G. Wallraff, H. G. Schweiger in *Science,* Vol. 146, No. 3644, pages 658–659; October 30, 1964.

NUCLEO-CYTOPLASMIC INTERACTIONS. J. Hämmerling in *Annual Review of Plant Physiology: Vol. XIV.* Annual Reviews, Inc., 1963.

NUCLEOCYTOPLASMIC INTERACTIONS IN UNICELLULAR ORGANISMS. J. Brachet in *The Cell, Vol. II: Cells and Their Component Parts,* edited by Jean Brachet and Alfred E. Mirsky. Academic Press, 1961.

SURVIVING CYTOPLASTS IN VITRO. Aharon Gibor in *Proceedings of the National Academy of Sciences,* Vol. 54, No. 6, pages 1527–1531; December, 1965.

ANALGESIC DRUGS

ANALGESIA AND ADDICTION. L. B. Mellett and L. A. Woods in *Progress in Drug Research,* Vol. 5, pages 155–267; 1963.

THE CHEMISTRY OF THE MORPHINE ALKALOIDS. K. W. Bentley. Oxford University Press, 1954.

NARCOTIC ANTAGONISTS. Sydney Archer and L. S. Harris in *Progress in Drug Research,* Vol. 8, pages 261–320; 1965.

THE OPIUM ALKALOIDS. David Ginsburg. Interscience Publishers, 1962.

MATHEMATICAL GAMES

THE FOURTH DIMENSION. E. H. Neville. Cambridge University Press, 1921.

GEOMETRY OF FOUR DIMENSIONS. Henry Parker Manning. Dover Publications, Inc., 1956.

AN INTRODUCTION TO THE GEOMETRY OF *N* DIMENSIONS. D. M. Y. Sommerville. Dover Publications, Inc., 1958.

REGULAR POLYTOPES. H. S. M. Coxeter. The Macmillan Company, 1963.

THE AMATEUR SCIENTIST

WELDING FOR ENGINEERS. Harry Udin, Edward R. Funk and John Wulff. John Wiley & Sons, Inc., 1954.

THE WELDING OF NON-FERROUS METALS. E. G. West. John Wiley & Sons, Inc., 1952.

"He who makes two blades of grass grow in place of one renders a service..."
Voltaire

One of the contributions of chemical research today is making things grow.

Sometimes figuratively, as when a chemical innovation brings an entirely new business enterprise into being.

Sometimes literally, as when a potent new chemical fertilizer helps meet the need of an exploding population for increased soil productivity.

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