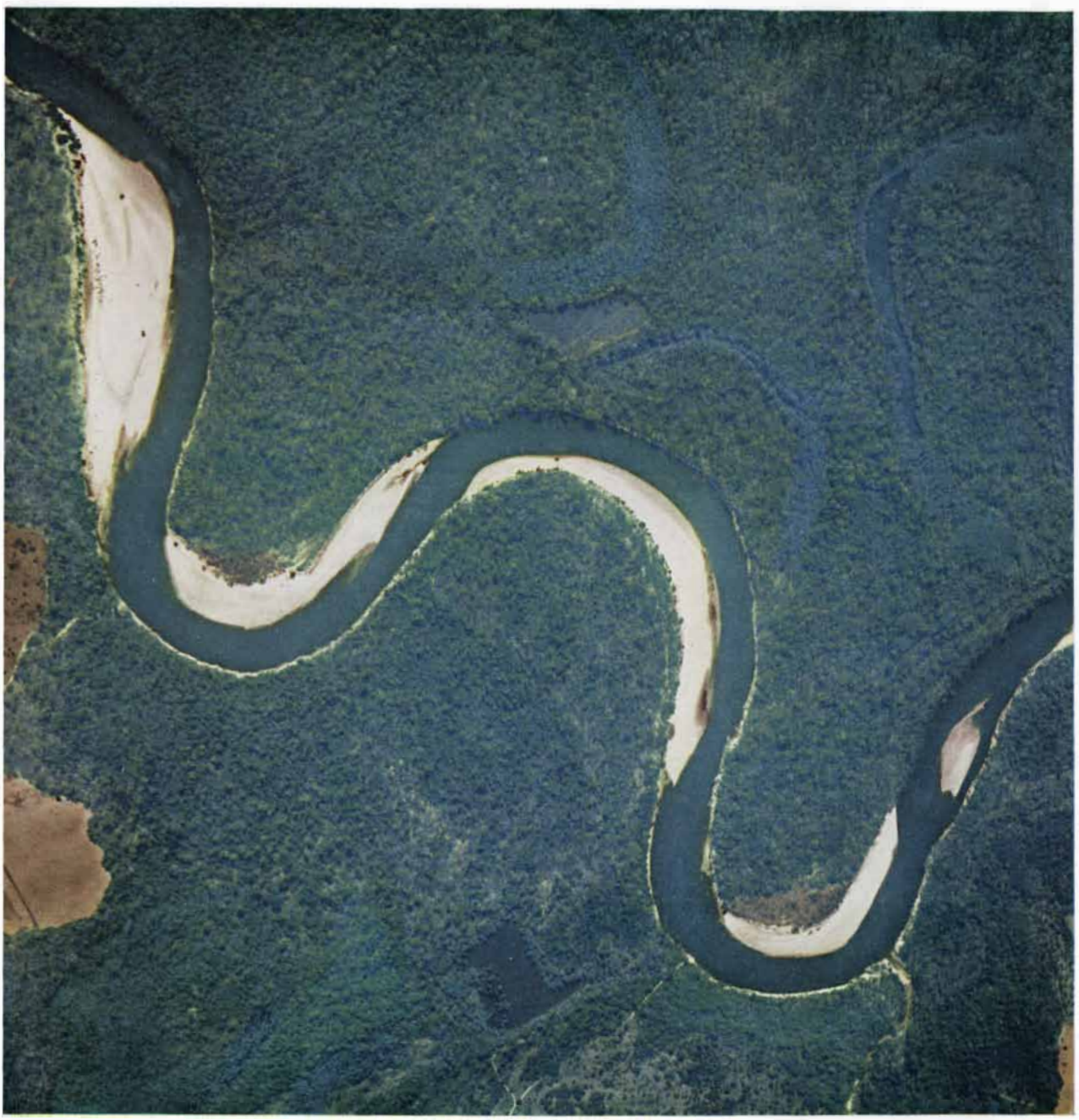
SCIENTIFIC AMERICAN



MEANDERING RIVER

SIXTY CENTS

June 1966

Rust, barnacle, stain, stress...old enemies meet new defenses

Problems that have bothered men for decades are being solved by engineers and scientists at M&T.

Barnacles, for example. In coping with this problem, copper-based antifouling paints can create another... galvanic corrosion. With paints containing organometallic bioMeT* antifoulant from M&T, though, there's neither corrosion nor barnacles.

Corrosion has been a lifelong enemy for metal water pipes. Now coming into increasing use is noncorrosive vinyl plastic pipe produced with a Thermolite* stabilizer to protect it against degradation from heat and light, both during manufacture and in actual use.

Physical working of metal sets up internal stress. Not with M&T's electro-chemical machining process. It removes metal, however hard, cleanly and without residual stress.

Some organic finishes succumb to a simple thing like food stain. Not M&T-created vinyl plastisols which resist food acids, alkalies, alcohols and other chemicals.

For more information, write M&T Chemicals Inc., General Offices: Rahway, New Jersey 07065.

M&T Chemicals Inc.

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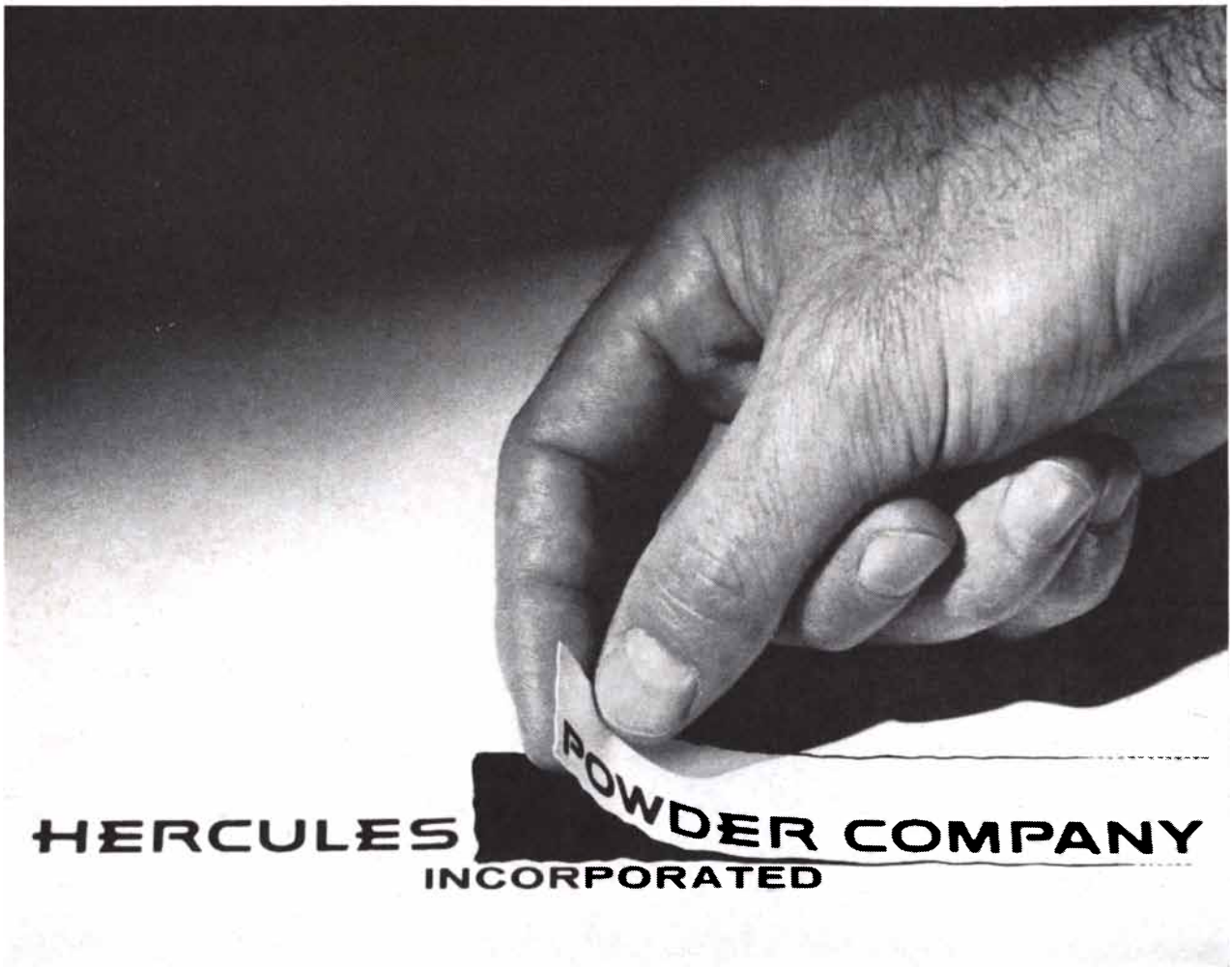

A SHORTER NAME

AND THE REASONS FOR IT

WHY A CHANGE OF NAME? During the past half-century, Hercules Powder Company has grown and diversified from powder to protective coatings, to plastics, to proteins, to plasma chemistry. During that same half-century, as one of the top ten chemical companies of the United States, Hercules has become known to customers, competitors, and the public at large as a major producer of agricultural chemicals (including plant foods, herbicides, and insecticides), of solid propellant rocket engines, and of olefin film and fiber. The fiber, sold under the trade name Herculon®, is increasingly being used in fabrics, pile lining, and especially in carpets. The company also markets plastic milk bottles and specially designed machinery for the packaging industry.

The increasing diversification of the company's interests, both in production and research, resulted in the need for a nonspecific name retaining the 54-year-old identity of Hercules as a symbol of the highest quality materials coupled with technical skills providing the ultimate in customer service.

For these reasons, and because the types of products for which the company was named in 1912 now constitute less than ten percent of Hercules' sales, the corporate name "Hercules Powder Company" henceforth belongs to history and is replaced by "Hercules Incorporated." NA66-1

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Wilmington, Delaware 19899

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(The second most important family for the man who wants to know everything about his business, everyday.)

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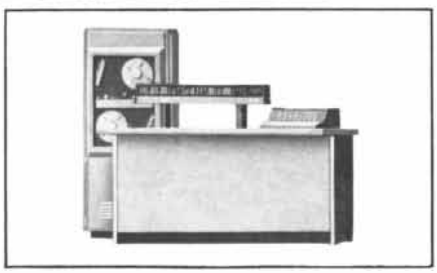
NCR



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Established 1845 **SCIENTIFIC AMERICAN** June 1966 Volume 214 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The aerial photograph on the cover shows a series of meanders, or bends, of the Tombigbee River in Alabama. The regular geometric curve that closely approximates that of the meanders is called a sine-generated curve; this means that the angular direction of the channel at any point with respect to the mean down-valley direction (*toward the lower right in the photograph*) is a sine function of the distance measured along the channel. This curve represents the form in which a river does the least work in turning; hence it is the most probable form a river can take (see "River Meanders," page 60). Material is continuously eroded from the concave banks of the meanders; it is then transported downstream and deposited on the convex banks, or bars (*light areas in the photograph*). As the meanders migrate laterally across the valley, the channel occasionally breaks through the narrow neck of land in a loop, creating an isolated "oxbow" lake; the scars of three such lakes are discernible as bluish crescents at upper right. Photograph was made from an altitude of 12,000 feet.

THE ILLUSTRATIONS

Cover photograph by Edward J. Blood

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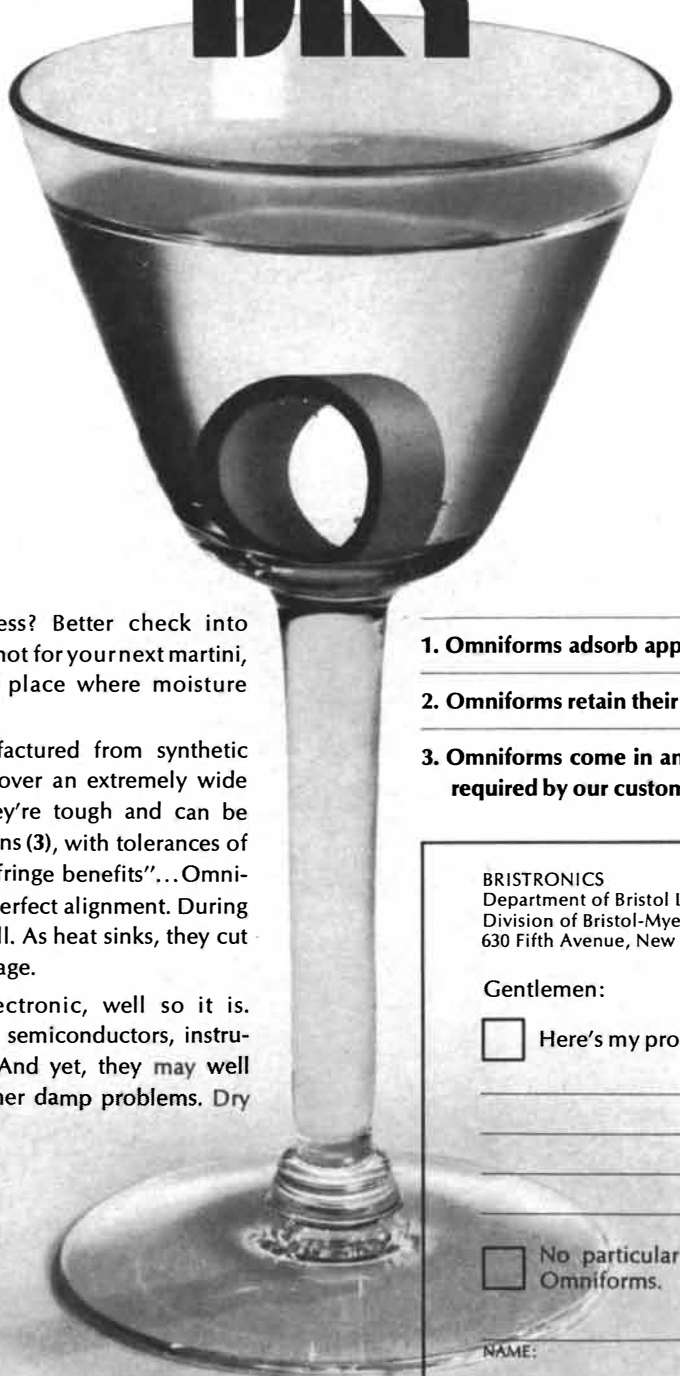
KEEP IT DRY



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☐ Here's my problem. Can you help?

☐ No particular problem, but I'd like more data on Omniforms.

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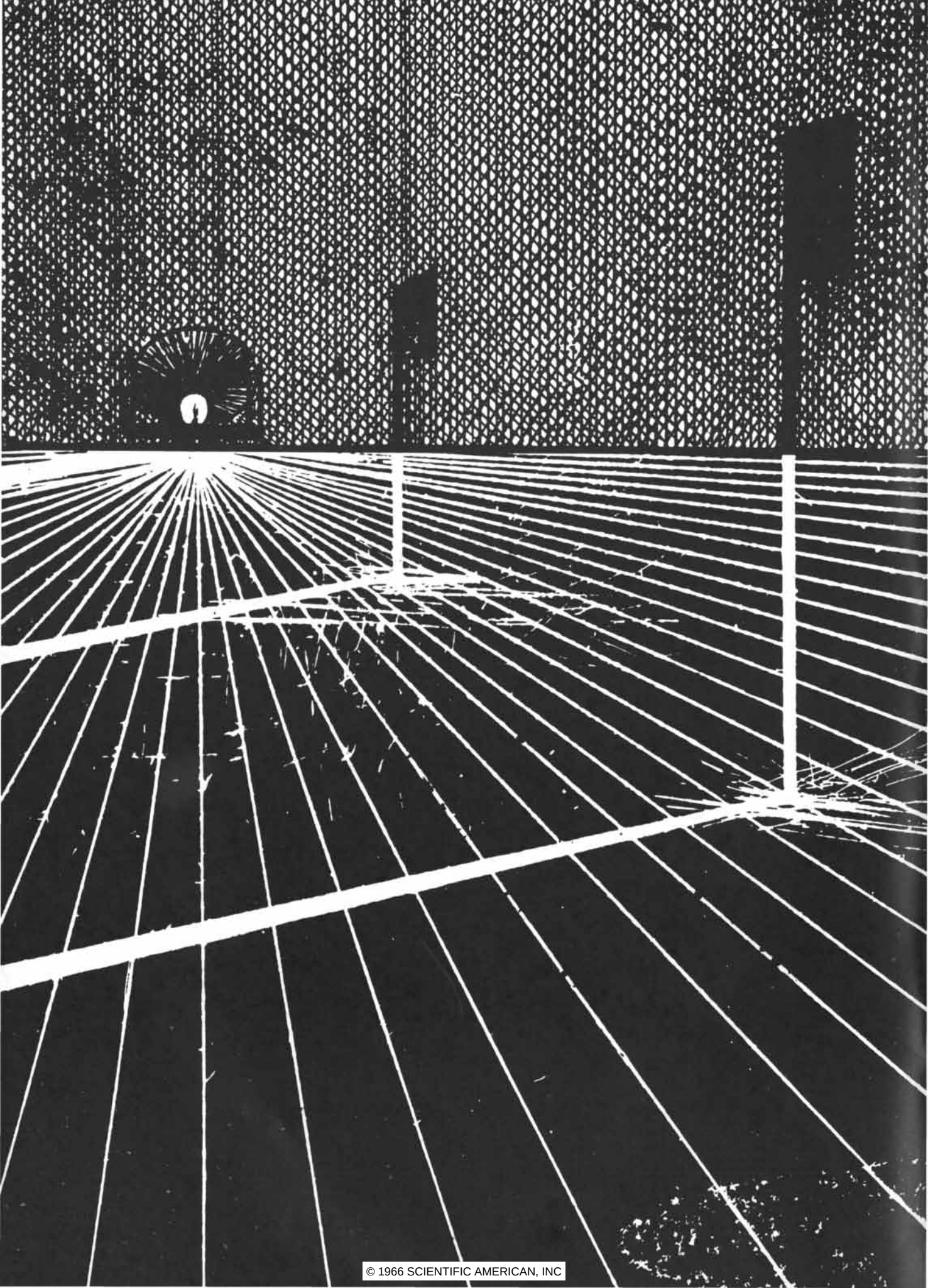

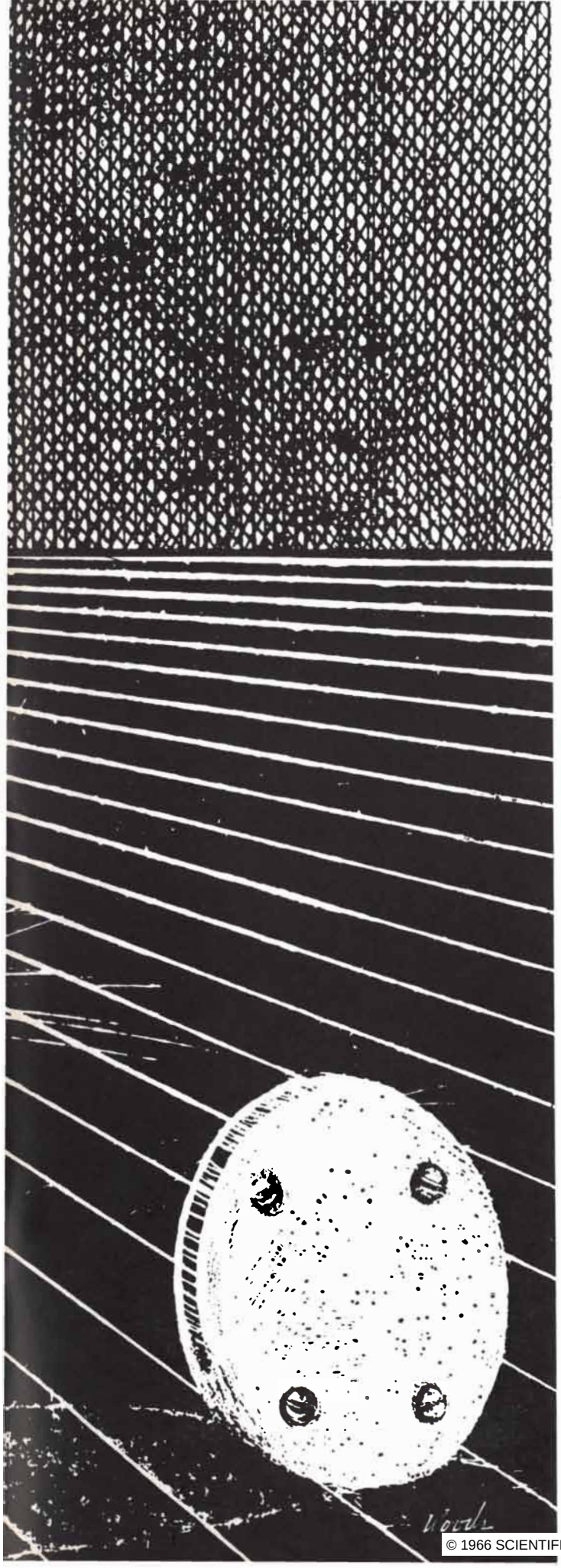

The candle is 3 miles away. Detect its heat.

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This rare material was chosen because it is the only one that can transmit radiation of wavelengths 0.3 to 1,000 microns with any degree of linearity. The windows weigh about 1¾ carats, are slightly wedge-shaped, with plane surfaces inclined at an angle to each other.

This avoids the "thin film" effect in the long wavelengths that causes soap bubbles to reflect blues, greens, yellows or red selectively from white light.

But don't think that diamonds are good only for exotic uses like this. On the contrary, De Beers natural and synthetic diamonds are now being used routinely for a variety of jobs in optics, ceramics, metalworking and road-building.

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LETTERS

Sirs:

Mr. N. W. Pirie's review of J. D. Bernal's *Science in History* [SCIENTIFIC AMERICAN, March] demands some comment, as it is both inaccurate and misleading to a degree that does a disservice to the readers of *Scientific American*. In spite of Mr. Pirie's repetition of the phrase that *Science in History* is not a history of science, it is and deserves to be judged as such. This is particularly true since Bernal repeats standard and hoary clichés that are now so out of date as to be laughable if they were not taken so seriously by practicing scientists whose knowledge of the history of science rarely rises above the level of the anecdotal.

Before getting to the major errors committed by Bernal, may I point out an original one introduced by Pirie, who gives credit to Alexander the Great for founding the museum of Alexandria. This is merely an error of fact; Bernal's are errors of omission and interpretation. For example, Bernal's discussion of Harvey's work and Pirie's discussion of it are hopelessly out of date. No mention is made of Harvey's work on embryology, which is permeated with Aristotelianism. Nor is there any discussion of the link between the natural motion of the Aristotelian quintessence and the blood that reveals the essential unity of Harvey's thought. All of this is old stuff in the history of science but clearly unknown to both the author and the reviewer. Similarly, Bernal's discussion of Galileo and Pirie's remarks on it show no evidence of any contact with recent (that is, past 30 years) Galilean scholarship. Galileo's greatness as an experimenter still remains to be established, and the remark that "the Middle Ages still enmeshed him" since "he did experiments to convince others on matters about which reason had already made him certain" merely shows that Mr. Pirie has swallowed whole the definition of science that is implicit in Bernal's work. Mr. Pirie might like to try out this remark on P. A. M. Dirac, who, although he is many things, can hardly be accused of being a leftover from the medieval period.

Such examples of uncritical acceptance by the reviewer of Bernal's special pleading could be multiplied almost at will. They will serve, I trust, to focus attention on my main point, which is that the history of science is a professional and rigorous discipline demanding the same level of skills and scholarship as any other scholarly field. It is time for the scientist to realize that he studies nature and others study him. He is no more nor no less competent to comment on his own activities and the activities of his fellow scientists than is the politician. Critical political history is rarely written by the politician and the same is true of the history of science. In this case it should be recognized that Bernal has created a majestic myth; it is unfortunate that the reviewer took it for reality.

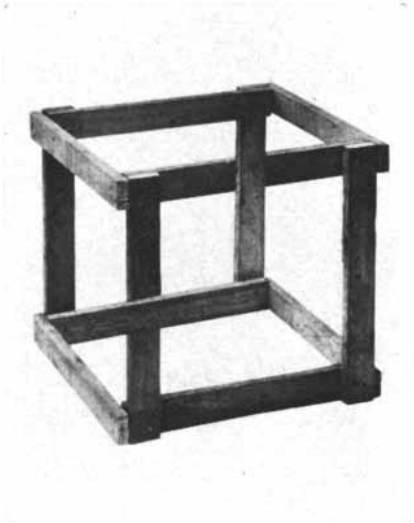
L. PEARCE WILLIAMS

Professor of the History
of Science
Department of History
Cornell University
Ithaca, N.Y.

Sirs:

I was very pleased to read the article on Maurits C. Escher in Martin Gardner's "Mathematical Games" [SCIENTIFIC AMERICAN, April]. I was particularly impressed by the "impossible box" held by the boy in the reproduction of "Belvedere."

This box is, as Mr. Gardner points out, not realizable in three-space. Two-space is of course another matter, whether in one of Mr. Escher's lithographs or in a photograph. Not long ago I made a photograph showing a near relative of this box; I have exhibited the photograph under the title "Freemish Crate" [*see illustration above*]. They tell us the camera does not lie, but as much cannot be said for photographers. My explanation is that the crate was built for the shipment of optical illusions in quantity and I simply took a snapshot of it.



"Freemish Crate"

C. F. COCHRAN

Chicago, Ill.

ADDENDUM AND ERRATA

The illustration on page 83 of "The Hagfish" (SCIENTIFIC AMERICAN, February) is based on the work of Ronald Strahan of the University of New South Wales. This work is published in the chapter "The Behavior of Myxine and Other Myxinoids" of the book *The Biology of Myxine*, edited by Alf Brodal and Ragnar Fänge (Universitetsforlaget, Oslo, 1963).

The two illustrations on page 96 of "The Muonium Atom" (SCIENTIFIC AMERICAN, April) were inadvertently transposed. Also transposed in that issue were two labels in the illustration on page 28 of "The Economics of Technological Change." The labels were "Materials inputs" and "Chemical inputs."

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ALLOY STEELS

The interaction of solute elements, their thermodynamic relationships with each other and with iron... how these interactions control subsequent solid state transformations to produce a microconstituent which determines the properties of the alloy.

by James Smith

Alloy steel studies were once measured in terms of "the state of the art." Not so now. Steel research activity is moving forward so rapidly it now includes such sophisticated concepts as atomic scale interactions, solid state reactions and micron scale defect measurements.

This rapid advance in alloy steel development can be attributed to the interaction of physicists, chemists and engineers—often working as a team. Separately as well as together, they make careful studies of the intimate structure of metals and the mechanisms by which the structure controls engineering properties of steel, such as strength, toughness, ductility and joinability.

True, iron is the backbone of steel. But it is only that until researchers work to develop in it properties many times superior to those inherent in iron. Strength is an important example. The yield strength of iron is approximately 4,000 psi. But research has developed commercial steels with strengths two orders of magnitude greater.

Research studies begin with the periodic table. Here is where the researcher makes a finite choice of those elements that may be alloyed with iron.

The treatment the alloy then receives ultimately determines what engineering properties the steel will develop.

Alloy studies delve into the interaction of these (alloying) solute elements. Their thermodynamic relationships with each other, as well as with the iron are investigated. These interactions control subsequent solid state transformations to produce a microconstituent which can enhance the properties of steel. These transformations are also studied. The internal structure or atom array within the microconstituent is examined by electron microscopy, electron and/or X-ray diffraction and by microstraining techniques. This examination can reveal the presence of dislocation networks which determine the deformation characteristics of the alloy steel.

These tools are useful in observing the contribution made by the clustering of solute atoms. Also, the precipitation of intermetallic compounds to the strengthening by coherency binding and strain hardening mechanisms.

Through these observations, new concepts are being introduced. Concepts such as the interaction of precipitates or foreign particles with dislocation structures and vacancy concentrations. These new concepts permit the interpretation of why and how steels can be made tougher, stronger and more ductile. The way these mechanisms operate to form the microconstituents which comprise the composite microstructure determines the engineering properties of the steel.

Just as chemistry determines what is to be alloyed with the steel, the treatments which can be given to the steel are determined by the variables of pressure, temperature and time. These alter the thermodynamics and kinetics of the solid state transformations in alloy steels.

Every time steel is heated or cooled, compressed or stretched, squeezed or expanded, its properties are changed. Science and engineering are combined to exercise a control over these variables under conditions where the research investigator can examine the contribution of each variable. And where he can optimize the combination of variables to produce steels with superior properties.

Recently this type of investigation has resulted in a physical simulation of hot rolling steel through experiments in the laboratory – experiments in which the steel is not even rolled!

Greatly enhanced thermal transfer systems used in cooling steels provide an excellent example of advances in engineering. This kind of advancement has enabled steel production to make use of the thermal-mechanical treatments. Previously, this treatment could be performed only in the laboratory.

Alloy steels which take advantage of these increased capabilities are now evolving. Concepts are developing from a combination of chemistry, physics and engineering, and will produce the engineering properties required by an advancing technological age.

This article gives you a glimpse of just a few developments in alloying steels. It's only a small part of the continuing, widespread research effort that is going on 24 hours a day at Youngstown's research center. If you think our researchers might be able to help you, just give us a call or write Department 251B6.

Nothing forced us to redesign the popular Bulletin 609 manual starter – but,

This is what is really "New" about the new Bulletin 609 line!

1 Bulletin 609, Size 0, Size 1, and Size 1P—all use the same size enclosure, not only in NEMA Type 1, but also for NEMA Type 4 and NEMA Type 7-9 service.

2 Bulletin 609, Size 0, Size 1, and Size 1P starters in NEMA Type 1 enclosure are available in either START-STOP push button or START-STOP toggle lever operation. Also true of "non-enclosed" construction.

3 Third overload relay can now be furnished without any increase in dimensions of the new Bulletin 609—non-enclosed, NEMA Type 1, NEMA Type 4, and NEMA Type 7-9 starters.

4 NEMA Type 1 enclosure designed to harmonize with corresponding NEMA Type 1 enclosure for Bulletin 709 magnetic starters.

5 Easy to add Pilot Light in NEMA Type 1 enclosure.

6 All Bulletin 609 Starters, non-enclosed and in NEMA Type 1, NEMA Type 4, and NEMA Type 7-9 enclosures can be padlocked in STOP position.

7 A clearly visible "Indicator" shows when an overload relay has operated to trip the Bulletin 609 starter.

New Bulletin 609 manual starters in NEMA Type 1 enclosures. Size 0, 1, and 1P all fit into same compact enclosure.

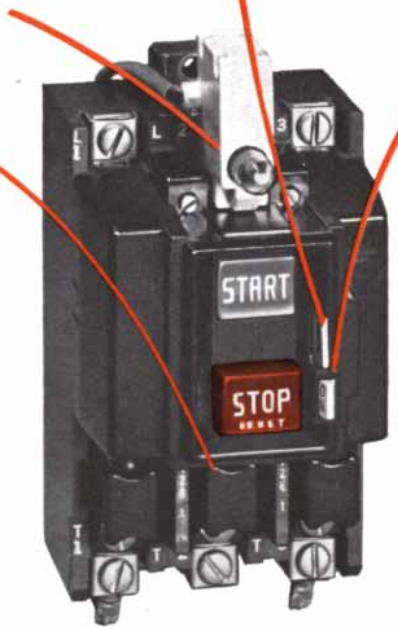
we owed this to you because – we could give you more value for your money

new easy-to-add pilot light

This can be done in the field. Nothing could be simpler. To accept the pilot light housing, a slot has been molded into the top of the starter mechanism cover. Slide the pilot light molding into position and wire the two attached leads. There's an easily removable knockout in the NEMA Type 1 cover underneath the A-B trademark. Use a small screwdriver to push out the trademark and the knockout will drop out with it, making a hole for the pilot light lens. The entire installation takes but a few seconds. The pilot light kit is listed as a separate item.

new safety lock

Bulletin 609 starters can be instantly locked in the STOP position. Pull out the locking latch—shown in the "locked" position in the toggle operated switch picture on the left-hand page—and the switch is locked. It cannot be forcibly operated. The lock can only be released by pushing downward on the locking latch. The hole in the top of the locking latch will accept a padlock for locking the starter in the "STOP" position. For added safety, all types of enclosures can also be padlocked.



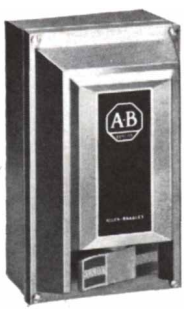
the third overload relay

Can be furnished on the Size 0 and Size 1, 3-phase Bulletin 609 with no increase in space requirements. These overload relays provide reliable and permanently accurate protection against overloads irrespective of frequency of operation or the surrounding atmospheric conditions. Furthermore, they cannot be held closed against a sustained overload. After the relay has been tripped, pressing the STOP button resets the relay and the motor can be restarted.

positive contact position indicator

On the right side, adjacent to the starter, is a white tab. It indicates whether the starter contacts are either open or closed. When the contacts are closed, this white tab extends beyond the operator housing and is clearly marked ON. The indicator tab operates directly from the contact crossbar and is independent of the switch mechanism, in order to assure that it provides a positive indication of contact position. Likewise, **OVERLOAD RELAY TRIPPING** is immediately apparent—there's no guesswork. When an overload relay trips, it opens the contacts, and the white contact position indicator drops into its OFF position. Thus, the operator can tell immediately that the operation of an overload relay has tripped the starter to its OFF position.

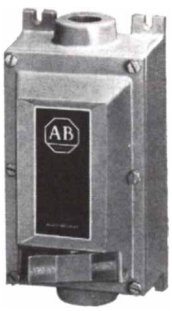
NEMA Type 4



new NEMA Type 4 watertight and corrosion-resistant enclosures

The enclosure base and cover are molded from a high impact material, which is completely inert to attack by corrosive atmospheres. A synthetic rubber gasket between cover and base seals out moisture and corrosive atmospheres. In addition, the stainless steel shaft for the operator has a tight O-ring seal.

new NEMA Type 7-9 cast aluminum enclosures for hazardous locations and also the NEMA Type 4 enclosures have their operating levers recessed below the cover of the enclosure, where they are protected from mechanical damage. Furthermore, since the hole for the shaft of the operating lever is located in a downward direction, water cannot collect. This minimizes, if not virtually eliminates, all danger of having this shaft "freeze" tight, when these starters might be used in below freezing temperatures.



NEMA Type 7-9

466-6KD

The important features of this new Bulletin 609 line justifies your immediate investigation. Please write: Allen-Bradley Co., 1204 South Third St., Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Limited. Export Office: 630 Third Ave., New York, N.Y. U.S.A. 10017.

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SCIENTIFIC AMERICAN

JUNE, 1916: "The world's altitude record was broken on April 26 when Harry G. Hawker flew to a height of 24,408 feet in an aeroplane at Brooklands, England, according to an announcement made by the Royal Aero Club. Although Heinrich Hoelerich, a German aviator, attained a height of 25,756 feet in 1914, this feat has not been recognized by the Royal Aero Club."

"Plans for the utilization of the tidal currents in the Bay of Fundy are now being studied. This bay is about 150 miles long, and for a large portion of its length it is about 40 miles wide. The tide rises 50 feet at the head of the bay and in the main body from 28 to 30 feet. In the middle of the bay the current flow is from one to two knots, and in the Digby Gut on the Nova Scotia coast it rises to four knots; but in the Minas Channel a rate of from eight to 10 knots exists, and it is here that it is proposed to establish a power station. This location is also desirable as the possibilities of disposing of power in this neighborhood are particularly good. Special motors will have to be devised for this use of the tidal current; and probably some system of storage reservoirs will also have to be provided to cover periods of the day when there is no tidal flow."

"In answer to a newspaper correspondent's request for an opinion concerning the German Fokker monoplanes, of which so much has been heard of late, M. Blériot, the aviation pioneer, replied: 'It is a very greatly overrated aeroplane and no better than the aeroplane we have had in France for a long time. I refer to Morane-Saulnier. The German machines are without doubt inferior to ours or yours, but they have an engine, the Mercedes, which is as good as, but no better than, the French engines. Never for a moment has Germany had mastery of the air, and now that we have this machine we have established a lead which will never be wrested from us.' The new machine referred to is called the 'Spad' and has a speed in excess of 125 miles per hour."

"At a recent meeting of the Royal Institution in London, Sir James Dewar exhibited a remarkable soap bubble that he had blown a month before and which was still as perfect as when formed. It is described as a glowing sphere of iridescent color, showing no signs of 'blackness,' which is the prelude of collapse. The longevity of the bubble is described by Lord Rayleigh as a case of suspended gravitation, which is due to the fact that it was blown in and with clean air, free from motes, which appear to be the seeds of decay."

Scientific American.

JUNE, 1866: "The idea of the possible exhaustion of the coal fields of England is a subject that now excites apprehension in the minds of English statesmen and manufacturers. The Right Hon. J. Stuart Mill, the able writer on political economy, in a recent speech in the House of Commons, the delivery of which occasioned great interest, spoke as follows upon this subject:—'The termination of our coal supplies, though always certain, has always, until lately, appeared so distant that it appeared quite unnecessary for the present generation to occupy itself with the question. The cause of that was that we had calculated upon the then rate of consumption; but the fact now is that our consumption of coal increases with such extraordinary rapidity from year to year that the probable exhaustion of our supplies is no longer a question of centuries but of generations. If the present rate of consumption continues, three generations at the most, or very possibly a much shorter period, will leave no workable coal nearer to the surface than 4,000 feet in depth; and that depth will entirely put it out of the power of the country to compete in manufactures with the richer coal fields of other countries. I think, then, if there be any one in this house or out of it who knows anything that will invalidate these conclusions, it will be right of him to come forward and make it known.'"

"At a meeting of the Massachusetts Institute of Technology the atmospheric resistance to railroad trains was shown. A set of cars made of pasteboard with the engine of the usual form and shape was placed upon a horizontally revolving cam attached to a vertical shaft driven round by the force of a given weight; the time of the revolutions was measured by an instrument beating seconds. Then the proposed improved form of car and engine (which improvement consisted in the conical shape given to the front part of the engine, the same shape also to the rear end of the last car, the spaces between the cars covered with canvas, with some other lesser changes from the common form) was placed upon the same rotating arm. The result showed, with the same power applied and the same weight of cars and engine, a saving of 25 per cent in speed, which is of course equal to a gain of 25 per cent of running expense—certainly a most important item for railroad directors and railroad stockholders to inquire into. The same has also been tried by the same parties with hand cars upon some of the roads in Massachusetts, with equally favorable results."

"In our last number we alluded to the *Aereon*, then under construction in New York by Dr. Andrews. On May 26th the aerial ship was launched for a trial trip, ascending to a considerable elevation, apparently for a time under the perfect control of the aeranaut, rising but slowly and going rapidly forward at an angle of less than 45 degrees in the direction of Westchester County. Having reached somewhere about Harlem, the *Aereon* seemed to be less under control than before, being drifted forward in the direction in which the wind was blowing, following in that course till she was lost sight of. On gaining an open space the *Aereon* was allowed to descend, and the party finally alighted in a field near Astoria. The gas was permitted to escape, and the apparatus was brought back to the city. It appears that it had been the intention of Dr. Andrews to sail against the wind, but this was found to be impracticable from the fact of the rudder's not being sufficiently large and strong. The ship was turned three times head to wind, but she could not be held in that position. The inventor and his friends express themselves well satisfied with the results of the trip and feel assured that when a few more improvements have been perfected they will be enabled to navigate the air with as much certainty and also more safety than we now navigate the waters."

Report from

BELL LABORATORIES

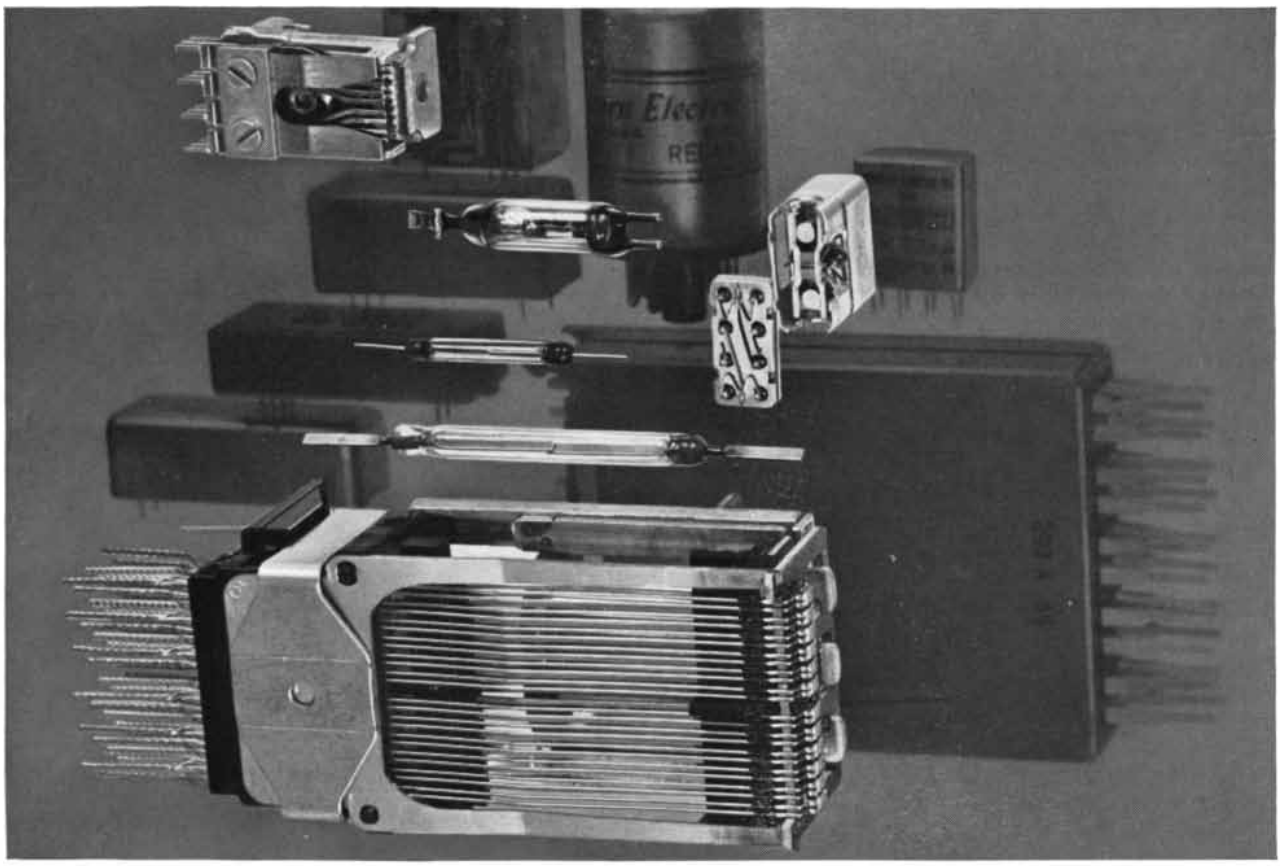
A relay for every communications need

The average modern telephone office uses 50,000 or more relays, and an average telephone call involves 1000 relay operations and 7000 electrical contacts. Furthermore, a telephone relay is typically expected to operate with not more than one failure in 5 million operations—the equivalent of 40 years of service life.

The jobs assigned to relays range from simple switch closures to the computer-like functions of counting, machine memory, and number and code translation. These call for a variety of relay types, many of them tailored for use in electronic switching systems, data systems, and submarine cable amplifiers.

Therefore, Bell Telephone Laboratories maintains a continuing program of designing and developing reliable and economical relays to meet the ever-expanding needs of modern communications.

Bell Telephone Laboratories
Research and Development Unit of the Bell System



Some electromechanical relays developed at Bell Telephone Laboratories:

The large unit at the bottom foreground is the wire-spring relay, the switching "workhorse" of the Bell System. It takes many forms, with many contact arrangements and such special features as magnetic latching.

Upper left is a rugged miniature relay. It can be mounted directly on a printed-circuit board or in a socket. In this type, each pair of precious-metal contacts is closed by its own pretensioned springs. Thus, contact force remains constant for millions of operations and is essentially unaffected by wear.

Right center are two subassemblies of a "crystal can" relay, especially designed to withstand extreme environments. It went into space in the TELSTAR® I and II satellites and will be in the ocean in submarine cable amplifiers. This relay's moving masses are balanced and are therefore virtually immune to vibration and shock. And, because the coil is sealed and because the moving parts contain no organic materials, it is highly resistant to internal deterioration.

The three units at the center are glass-sealed reed contacts; they are unaffected by the external atmosphere. The topmost of the three, a mercury-wetted reed, is chatter-proof; its contacts stay closed without "bouncing." This is accomplished by feeding liquid mercury—sealed within the glass envelope—to the contacts by capillary action. A fast-acting device, it has the highest current-carrying capacity of any communications-type switch element. Also, it has the longest life, often up to 1 billion operations.

The two remaining units are sealed dry reeds. They can make contact in less than 1/1000 second. Relays containing such dry-reed contacts and associated operating coils may have one or many contacts in an apparatus unit. Ferreed switches, for example, used in the Bell Laboratories-developed Electronic Switching System, have as many as 256 contacts in one unit. A dry-reed type relay also replaces five larger relays in a translator, which control a ten-digit indicator tube.

Typical enclosures are seen in background. All units are shown about 4/5 actual size.

Chase Manhattan's approach to multinational banking

A joint statement to multinational companies by Chairman Champion and President Rockefeller

Were we to select one phrase to sum up our responsibility to a customer operating multinationally it would be "The best job that can be done, with whatever facilities are necessary to do it."

What this comes down to is flexibility.

We know from appraising the present, probing into the future and drawing on more than a hundred past years of worldwide banking experience that no pat operational plan is adequate for all customers' needs.

Sometimes the Open Sesame to a customer's multinational requirements is a correspondent bank in a remote corner of the world. Another time the best place to turn might be to one of our overseas branches or representatives. And there are our affiliates—indigenous and established banking organizations strategically selected for their importance to the world's most thriving trade areas.

These are the ways we accomplish multinational business matters today. We will continue to seek affiliations where appropriate. Our relationship with correspondent banks all over the world will be strengthened. Our branches outside the United States will continue to multiply. And, we will undoubtedly add more representative offices.

Flexibility requires all of these operational factors in increasing abundance.

In 1962 in Brazil we affiliated with Banco Lar Brasileiro. One of Brazil's progressive banks, Banco Lar has 33 offices in key cities throughout all of Brazil. In the same year in Venezuela, we formed an affiliation with Banco Mercantil y Agricola. A leading Caracas bank, Banco Mercantil offered us, through affiliation, 17 branches in Venezuela. Last year we affiliated with one of Peru's largest commercial banks, Banco Continental, with 42 offices in the Lima-Callao area. In 1965 we extended our associations to the hundred-year-old Standard Bank to join in serving seventeen African countries through 1,104 branch offices. And this year we have expanded even further by entering into an agreement with Banque de Bruxelles, Belgium's second largest bank, to jointly own Banque de Commerce with offices in Brussels and Antwerp.

By working together with established banking organizations like these the world over we can give multinational customers the area savvy of the indigenous banker. For added strength and the American touch we have ranking Chase men working side-by-side with affiliate management.

And affiliation offers our customers another major advantage.

The deposits of our affiliates are in local currency. Therefore, we can better serve our customers seeking to expand to countries where these affiliations are located.

This, then, is our approach:

To offer multinational business a service flexibility that uses, according to the dictates of advantage, the separate or collective capacities of our affiliates, our overseas correspondent banks, our offices in major trade centers, our representatives in key cities the world over and the services of our home based World Wide Projects Division.

* * *

In short, we propose to do the best job for multinational companies with whatever facilities are necessary to do it. And we've chosen flexibility as the way to serve you best wherever you have a multinational need.

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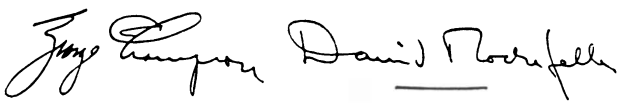

CHAIRMAN OF THE BOARD — PRESIDENT

THE AUTHORS

FORREST E. LINDER ("The Health of the American People") is director of the National Center for Health Statistics, a unit of the U.S. Public Health Service. The center's responsibility is to provide the factual basis for the planning and evaluation of public health programs. Linder was graduated from the State University of Iowa in 1930 and received a Ph.D. there two years later. Since then he has been involved in statistical work relating to demographic and public health subjects. He has served in the U.S. Bureau of the Census, the Navy's Bureau of Medicine and Surgery and the United Nations as well as the Public Health Service. Although his concern is with statistics of health, he believes that "the major emerging problems of the present generation are not related to health statistics in the more traditional sense but to national and international crises that will arise out of rapid population growth." Linder wishes to call attention to the fact that he wrote his article in a private capacity and that no official support or endorsement by the U.S. Public Health Service is intended or should be inferred.

R. W. CLARKE ("Locating Radio Sources with the Moon") is a research scientist with the Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization of Australia. He was graduated from the University of Cambridge in 1959 and obtained a Ph.D. there in 1963. In the same year he took up his present work. He describes his principal research interest as "extragalactic radio sources, with particular reference to the detailed structure of the sources and to the cosmological significance of radio-source observations."

CYRUS LEVINTHAL ("Molecular Model-building by Computer") is professor of biophysics at the Massachusetts Institute of Technology. His original bent was toward physics; he took a Ph.D. in nuclear physics at the University of California at Berkeley in 1950 and spent seven years in the physics department of the University of Michigan, starting as instructor and leaving as associate professor. In 1957 he began his present work in the biology department of M.I.T. Levinthal did his undergraduate work at Swarthmore College, from which he received a bachelor's degree in 1943.

LUNA B. LEOPOLD and W. B. LANGBEIN ("River Meanders") are respectively chief hydrologist and research hydrologist of the U.S. Geological Survey. Leopold was graduated from the University of Wisconsin in 1936 with a degree in civil engineering. In 1944, while he was teaching meteorology to Air Corps cadets, he completed work for a master's degree in physics-meteorology at the University of California at Los Angeles. He obtained a doctorate in geology at Harvard University in 1950. Leopold joined the Geological Survey in 1950, after three years as head of the department of meteorology at the Pineapple Research Institute in Hawaii; he became chief hydrologist of the Geological Survey in 1957. Langbein was graduated from Cooper Union in New York in 1931. He spent four years as a construction engineer in New York before joining the Geological Survey.

PATRICK ECHLIN ("The Blue-Green Algae") is senior assistant in research in the School of Botany of the University of Cambridge. He is also in charge of electron microscopy at the school. Echlin obtained a teacher's certificate from Goldsmiths' College of the University of London in 1954 and a bachelor's degree from University College London in 1957. For the next five years he was at the University of Pennsylvania School of Medicine, where he obtained a Ph.D. in medical microbiology in 1961. His research interests include not only algae but also the fine structure and development of pollen. Outside of his work his interests include photography, gourmet cooking, gardening and the camping variety of travel.

IMANTS REBA ("Applications of the Coanda Effect") is a research engineer at the IIT Research Institute, which is associated with the Illinois Institute of Technology. He was born in Latvia and lived there until he was 18 years old, moving to Germany in 1944 and to the U.S. five years later. In 1951 he entered the Polytechnic Institute of Brooklyn, where he obtained bachelor's and master's degrees. He is now completing work for a doctorate in mechanical and aerospace engineering at the Illinois Institute of Technology. Reba's research activities have included the study of combustion instabilities in liquid-propellant motors and the development of an experimental liquid-propellant rocket system. More recently he has investigated new combustion concepts and also has studied conventional combustion methods in the course of an effort to reduce corrosion on turbine blades and in boiler tubes.

LEO K. BUSTAD ("Pigs in the Laboratory") is director of the radiobiology laboratory and professor of radiation biology in the School of Veterinary Medicine of the University of California at Davis. His degrees include a doctorate in veterinary medicine, which he obtained from Washington State University, and a Ph.D. in physiology from the University of Washington School of Medicine. Before taking his present position he was with the Hanford Laboratories (now the Batelle-Northwest Laboratory), which operate under the sponsorship of the U.S. Atomic Energy Commission. Bustad writes: "Outside of science I am sort of an amateur theologian and am involved locally in a philosophical discussion group and nationally in a retreat center called Holden Village, where I will be the scientist in residence for a short time this summer, addressing the general subject of science and faith. Additionally I have been a member of the board of directors of a social agency concerned with a home for unwed mothers, foster-home care and an adoptive agency. I am also a very amateur bird watcher and gardener."

C. VANCE HAYNES, JR. ("Elephant-hunting in North America"), is director of the radiocarbon laboratory in the geochronology laboratories at the University of Arizona. He writes: "My father, Major General C. V. Haynes, was a pioneer in military aviation. My youth was spent on military posts in Virginia, Alabama, Kansas, Puerto Rico, New York and Newfoundland. After graduation from the Hill School in Pennsylvania I attended Johns Hopkins University, the Colorado School of Mines and the University of Arizona." Haynes reports that he is working at present on "fundamental problems of alluvial deposition, erosion and soil formation in relation to the climates of the Ice Age."

MARSHALL D. SAHLINS, who in this issue reviews *Structural Anthropology*, by Claude Lévi-Strauss, is professor of anthropology at the University of Michigan.

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High Energy for Space: A report from General Dynamics

How can you add calories and not gain weight?

The question, only rueful to waistline worriers, is vital to space flight. Calories are energy that has to be unlocked from fuel. The fuels that now lift relatively large payloads into earth orbit are not really efficient to take them all the way to the moon. Something with more "calories" to the ounce is needed.

The theoretical answer has been known for years—hydrogen.

Hydrogen contains more heat units to the pound than any carbon-derived power source. It burns explosively when mixed with oxygen. Under proper control, it would be ideal.

Enigmas of ultra-cold:

Hydrogen, existing naturally as a gas, is unnoticeable under everyday conditions. To be used as a practical space fuel, it must be carried in the vehicle as a liquid. In that form it is one of the coldest things in existence, 420° below zero Fahrenheit.

In this world of ultra-cold, most materials become as brittle as thin glass. Should the temperature rise only a few degrees, liquid hydrogen "boils" into a rapidly expanding gas that could burst through a sealed container.

Could liquid hydrogen be contained within a vehicle light enough for space flight? Could it be kept cold enough? Be controlled so precisely that its reaction with oxygen would give exactly the amount of thrust needed?

Today, hydrogen has been tamed. When the National Aeronautics and Space Administration's Surveyor lands on the moon, it will have been put on its way by Centaur, the first space vehicle fueled by high-energy liquid hydrogen.

Centaur was originally started by General Dynamics as a research project for the Department of Defense to test the feasibility of hydrogen as a fuel. Now operational for NASA, Centaur is the most powerful upper-stage space vehicle for its size and weight available. In nature the most efficient container in terms of weight to strength is considered the shell of an egg. Centaur, which needs only 1/35th of a pound of tank for each pound of propellant carried, is three times more efficient.

But before Centaur became operational, major problems had to be solved.

Early hurdles...

On the ground liquid hydrogen must be stored in large stainless steel tanks with double walls filled with insulation and evacuated to a high vacuum. Similar permanent insulation would mean a substantial weight penalty for a space vehicle.

With the best available insulation, relatively high external air temperatures on earth and the friction heat generated during booster flight cause some boil-off, creating the danger of constantly increasing gas pressure inside a tank. Liquid oxygen must be carried in the vehicle to react with the hydrogen. Lox is pretty cold itself at −297° F., but "hot" enough to make hydrogen boil.

Centaur's stainless steel tank, which is also the external skin of the vehicle, is only one-third the thickness of a dime. The extreme cold initially created microscopic cracks, visible only under magnification, in the stainless steel around some welds. Such cracks could cause structural weakness—and leaks, since hydrogen, the smallest of atoms, can seep through openings that will hold back everything else.

...and answers:

For external insulation Centaur is wrapped with 1,200 pounds of inch-thick glass fiber panels filled with plastic foam. Just before the upper stage separates from its booster, the panels, which have served their purpose, are forced away by explosive charges. Now Centaur is free to reach its required speed at a minimum insulation-weight penalty to the mission.

To control boil-off, venting systems bleed off hydrogen gas during propellant loading and until launch at 18 pounds per minute. Excessive pressure is prevented from developing inside the tank, yet the gas is sufficiently diffused that it can be fed into the atmosphere without danger of explosion. During booster flight, venting continues until the vehicle enters the frictionless cold

Atlas-Centaur launches a payload.

How Centaur works as a space vehicle

Space flight requires both muscle and speed. Whether the payload is a grapefruit-sized satellite or a manned capsule, it must be pushed to a speed of 25,300 feet per second to reach a 160-mile high orbit around the earth. To go to the moon, it must hit 36,000 f.p.s.

The muscle is supplied by a launch vehicle whose initial push, defined in pounds of thrust, must be sufficiently greater than the total weight of the vehicle, fuel and payload to overcome the pull of gravity.

The heavier the combination, the more thrust is needed to get it started against the pull of gravity and to keep it moving fast enough to reach its destination.

Just adding more propellant to a single stage vehicle would ultimately make the propellant containers so heavy that the vehicle could not reach the necessary velocity.

So for speed, a second stage is used.

This tandem combination can be compared to a sports car being pushed by a truck. The truck goes as far and as fast as it can. When both vehicles reach the top speed of the truck, the fully fueled sports car starts, adding its own acceleration to carry its driver farther and faster.

Centaur's "truck" so far has been an Atlas, the same General Dynamics' launch vehicle that boosted the first American astronauts into orbit.

Fully fueled on the ground, Atlas, Centaur and a two-ton payload weigh a total 303,000 pounds. Atlas' 380,000 pounds of thrust, provided by a kerosene-derived fuel, push the combined vehicles to 91 miles and a speed of 12,700 f.p.s. before it drops off and Centaur's hydrogen fueled engines take over.

The high energy of the smaller Centaur now need push only the 36,500 pounds of itself and the payload against less gravitational effect and without the resistance of the atmosphere. After 440 seconds of firing, Centaur is traveling at 36,000 f.p.s., fast enough to send its payload along its orbit to the moon.

of space, when the bleed drops to a half-pound per minute.

One step in the elimination of microcracks was to thicken the original skin of Centaur a bare .004 inch to its current .014 inch. To reduce them further, all the vehicle's 162,000 spot-welds are X-ray inspected, and any imperfect welds are repaired before assembly continues.

Extra chores:

In addition to its fuel energy, the hydrogen even helps itself work.

The ultra-cold actually solves one insulation problem. Oxygen and hydrogen tanks are separated by less than one-third of an inch, but the liquid hydrogen freezes air between the tanks into a solid, creating a narrow vacuum that minimizes the passage of heat.

The thrust chamber—where the fuel is burned—develops temperatures of some 5,500° F. Such heat could quickly bring the cryogenic propellants to the explosion point.

On its way to be "burned," liquid hydrogen is first pumped through a cooling jacket surrounding the thrust chamber, separating the very hot from the very cold areas.

In absorbing the engine heat the liquid expands to a turbulent gas to be used for the energy reaction. But some is temporarily diverted to drive turbopumps that feed the propellants in required amounts to the engines. Without this technique, propellants would have to be force-fed to the engines under high gas pressure, requiring thicker tank walls and greater weight.

Slimming down more:

Centaur, for its size, is the most efficient single vehicle in operation today. Its fuel is the most efficient currently available for space use.

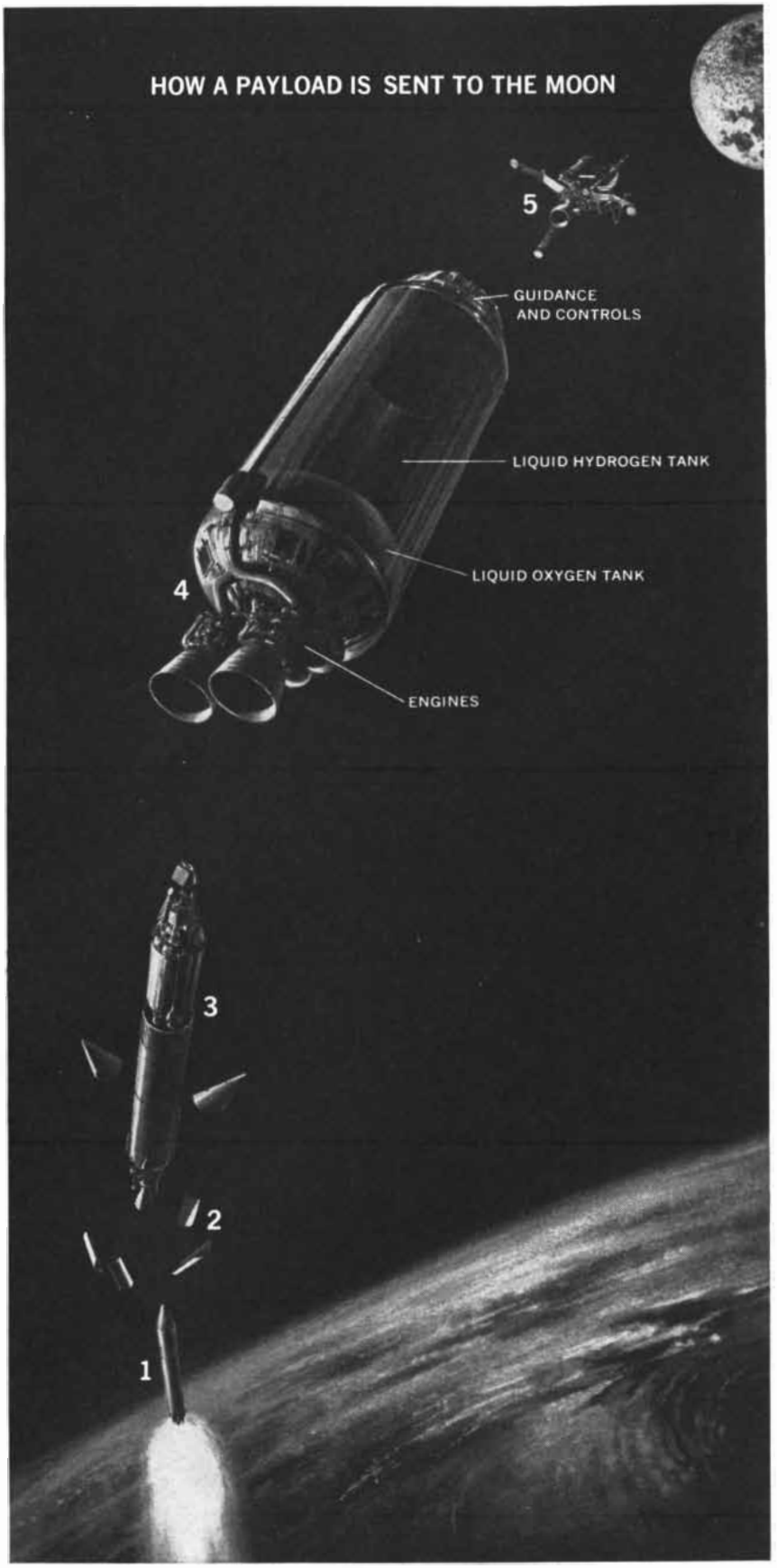
Yet further improvements are being worked on by General Dynamics: metals equally strong and possibly lighter; "super-insulations"; uprated engines, advanced control systems and fuel additives to increase performance.

As Centaur matures, it's going to take on even more calories—and probably lose more weight in the process.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communication systems; machinery; building supplies; coal, gases.

GENERAL DYNAMICS

One Rockefeller Plaza, New York, New York 10020



1—Atlas starts Centaur and its payload on their flight. **2**—Shortly before Atlas and Centaur have separated, insulation panels and then nose fairings have been jettisoned. **3**—Atlas separates and Centaur and payload start their phase of journey. **4**—Centaur has completed firing and separated from payload. **5**—Payload continues along its orbit to the moon.

Sylvania ECG finds the way to "dig a hole" for destructive electrical surges.

Numerous protective devices have been developed for momentarily "grounding" electrical lines subjected to extreme voltage surges. The problem has been to devise a method that would shunt repeated high energy surges to ground instantaneously without damage to the protective device itself.

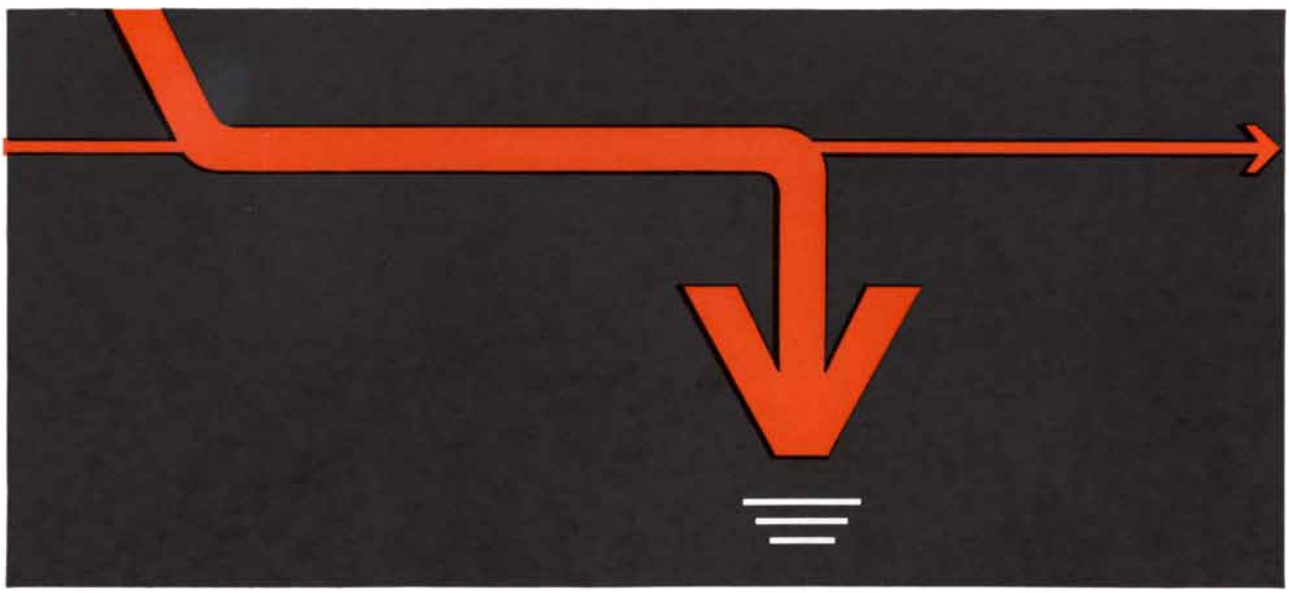
The Sylvania Electronic Components Group solved the problem through the development of an electronic surge arrestor capable of dissipating natural and man-made electro-magnetic impulses with energies as high as 110 coulombs—greater than the surge of an average lightning bolt!

Basic to the device is Sylvania's new Type SG-1360 spark gap composed of three metal alloy electrodes hermetically sealed in a ceramic and metal package back-filled with an inert gas. Under normal conditions, it presents a virtual open circuit between both sides of a communication line. In the presence of a voltage surge, it fires instantly, and bypasses the surge to ground, then restores itself to the open circuit condition.

When used as a primary protective device in communications and control equipment for industrial and military use, the Sylvania electronic surge arrestor is capable of reducing high transient energy from whatever source to a safe level for secondary protectors in applications such as solid-state power supplies and computers. And does so repeatedly without suffering damage or deterioration.

"Digging a hole" for destructive electrical surges is another example of advanced component design resulting from Sylvania ECG *unified* research and engineering. And a way to find the answers to your problems in system design.

Sylvania Electronic Components Group, Sylvania Electric Products Inc., Seneca Falls, New York 13148.



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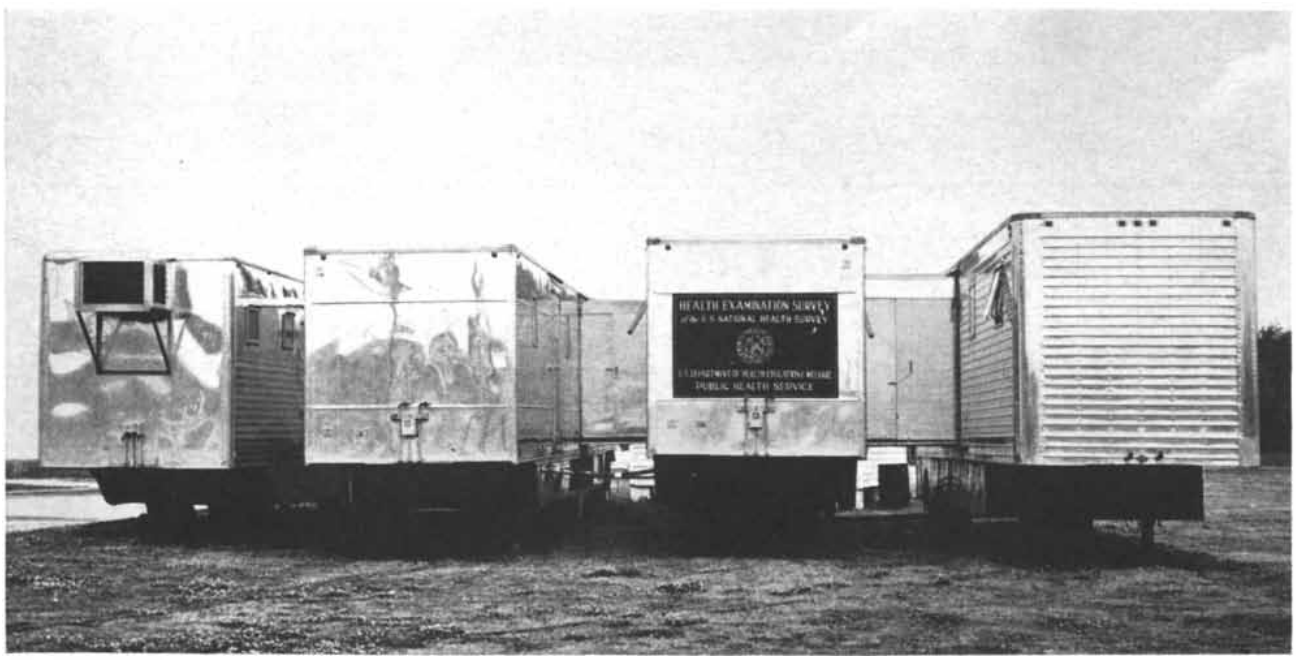
The Health of the American People

The death rate is no longer an adequate index of a population's health. New techniques have been developed with which to assess the nation's health problems and plan for improved medical care

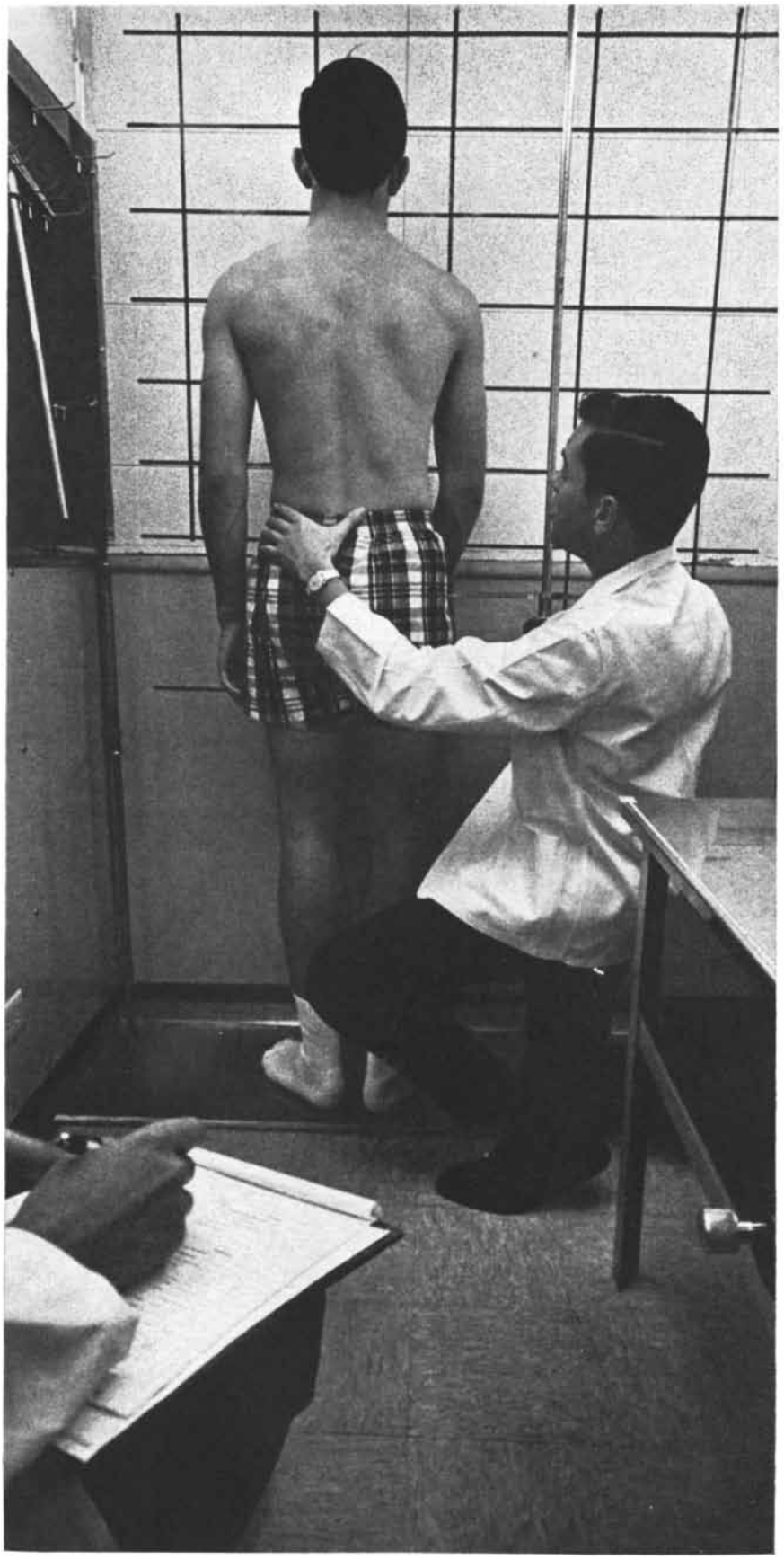
by Forrest E. Linder

The health of a country's people has traditionally been measured by the rate at which they die: a decreasing death rate is taken as an indication of increasing health. In recent years, however, the concept of health has undergone significant changes. There is a new interest in the total quality of life rather than merely the length of life, in the positive elements of good health rather than merely the absence of disease and infirmity. As medical science advances, moreover, it becomes increasingly pertinent to know the extent and degree to which new knowledge and techniques are being applied throughout the population. The death rate, and indeed the entire battery of vital statistics that have long been collected by the states and the Federal Government, no longer yield enough information on which to base a sound national health policy.

How, then, can the health status of an entire population be calibrated so that goals can be set and progress toward those goals can be gauged? The annual U.S. investment in health and medical care is now $35 billion, or 5 percent of the country's total gross



HEALTH-EXAMINATION SURVEY, one of the major activities of the National Health Survey, is conducted in mobile centers. Here one of the trailer caravans is seen in Charleston, S.C., where examinations were under way for children aged 12 through 17.



PHYSICAL EXAMINATION conducted in the mobile center takes three and a half hours. It includes, in addition to the usual components of a routine health checkup, a dental examination, psychological testing and precise body measurements of the kind shown here.

national product. By what standards can one judge whether or not the investment is being allocated efficiently? These are the questions with which public health officials were faced when Congress in 1956 established the National Health Survey and charged it with laying the factual foundation for new thinking about national health problems and the level and extent of medical care.

The major problem in developing the National Health Survey was methodological: my colleagues and I at the National Center for Health Statistics had to design, test and install novel data-collecting systems and statistical treatments. Our approach has been to rely on the powerful technique of population sampling and to project the results of our detailed studies in order to obtain information on the U.S. population and its various segments. The purpose of this article is to explain the methods we have developed and report on some findings of the past 10 years.

Statistics are the underpinning for programs of action in almost any area of human activity, and as a society assumes greater responsibility for the well-being of its members one of the chief difficulties has been the lag in social statistics. Economists do such things better. Their body of generalized economic theory has enabled them to devise such sensitive probes of economic activity as the input-output matrixes and such overall indexes as the gross national product, which blends a great number of disparate elements into a single figure that measures the economic state of the nation.

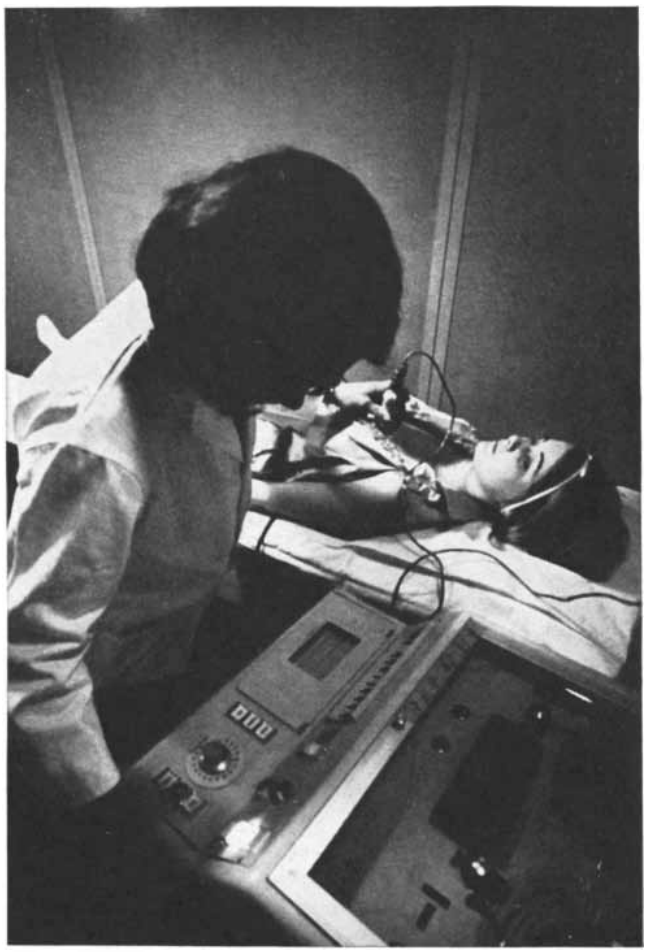
Perhaps it will someday be possible to develop a GNP-like health index—perhaps a "gross national health deficit" (GNHD) that could blend together in one number the days of healthful living lost each year by the chronically and acutely ill, the days of life lost through death that comes too soon and all the impairment suffered for lack of medical treatment and advice. Even if it were logically possible to construct a GNHD, it might not meet all needs because it would still stress, as conventional health statistics do, the negative aspects of health. The fact is, however, that the health sciences still lack the unifying theory and the unit of convertibility (such as the economists' dollar) that might permit the construction of a single index in health. Experimental and theoretical efforts are being directed toward solving the problem, but for some time

the health of a population will have to be measured in bits and pieces, each having at best a specialized and fragmented meaning.

In deciding what bits and pieces should be sought after it is necessary to take into account the varying needs of different elements in the heterogeneous health establishment of the U.S. There are national, state and local health departments; government, voluntary (nonprofit) and private hospitals; teaching and research institutions and professional groups in medicine, dentistry and nursing; economists and sociologists interested in health problems; health and life insurance companies, and the gamut of commercial organizations that make and distribute instruments and equipment, drugs, books, appliances and all manner of other health products. Each of these elements sees the health and illness of the population from its own point of view and seeks specific information with which to reinforce or modify its activities.

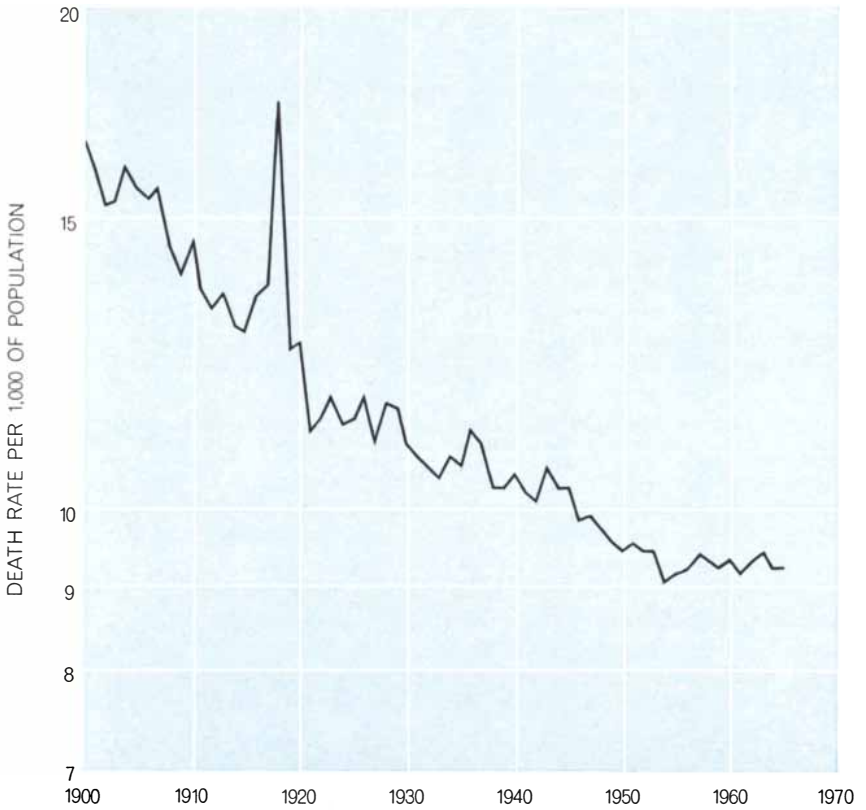
Among them these varied interest groups want a broad range of data on the physical condition of the population—on the average measurements and standards as well as on diseases and accidents and the conditions under which they occur. It is important to know the impact of illness and injury on the lives of people. How much disability, either temporary or lasting, does ill health cause and to what degree does the disability restrict normal activities? Beyond the fact of illness and its impact one wants to know what people have done to seek relief and how successful they have been. What is the availability of medical and dental care and of hospital inpatient and clinic facilities? How adequate are health and disability insurance and other means of coping with the economic impact of illness? Finally, all such data are much more valuable if they are classified according to a large number of demographic, social and economic characteristics. How do the facts vary with race, age, sex, education, income and so on? What is the situation with regard to the residents of cities, of suburbs or of farms, or to different components of the working force, or to veterans or schoolchildren? What are the figures not only for the U.S. as a whole but also for each region, state and major city?

Before 1956 material of this kind was simply not available in adequate detail. The U.S. had, to be sure, a long-established and efficient system of recording birth and death statistics. In addition, records have long been kept of the annual incidence of a large number of diseases and the death rate from each. These records are derived, however, from the reports of individual states, which in turn depend on the completeness and accuracy of reports from individual hospitals and physicians. The many special studies that accumulate detailed information on specific diseases and conditions and establish standards for everything from height and weight to cholesterol level, blood pressure and



HEART SOUNDS are recorded on tape. The recording is part of the subject's record and may also provide material for studies of the way in which different physicians interpret heart sounds.

AUDIOMETRIC TEST is administered to a 16-year-old girl in a soundproof compartment of one of the health-center trailers. The test measures the threshold of hearing at a number of frequencies.



U.S. DEATH RATE declined rapidly in the first half of the century as infectious diseases were controlled, but it has remained almost constant since 1950. The death rate can no longer serve as an adequate measure of progress toward better health in a broad sense.

the prevalence of tooth decay are based on selected groups that are in most cases quite arbitrary and therefore not necessarily representative of the population as a whole.

When the National Health Survey was set up as a continuing activity, we soon decided that if we wanted to know about people's health, we would have to go to those people. Not even the most careful compiling and tabulating of data about people from physicians' or hospitals' case records would do. For one thing, such records have no standard content or level of detail. For another, any one person may seek care in the course of a year from a number of physicians, hospitals and clinics; their treatments of his conditions may overlap, and so will their records. Finally, even if all the technical difficulties could be corrected for, a major drawback would remain: medical records relate only to illness for which medical attention is sought, and there is a great deal of poor health that never comes to the attention of a physician or hospital.

Clearly the individual person is the only focus for all information about that person's life. It is only the individual himself who knows the total of his medical experiences: the illnesses, chronic conditions and injuries, the effect they have had on his life, and the places where he has sought treatment or preventive care. The major investigations of the National Health Survey are therefore designed with the individual person as the unit of study. There are two principal types of survey; in one information is collected by means of interviews, in the other the method is direct physical examination. It would of course be too expensive, in time as well as dollars, to interview in every household and to examine every person. Nor, of course, can one survey just the people in one city or county or even in a few convenient localities and hope that their health data will reflect accurately the health of the population as a whole. Modern sampling theory, however, provides techniques that ensure that every person in a large population has a known chance of being included in a small sample, that every stratum and significant class and subclass of the population will be represented in proportion to their share of the total population and—perhaps most remarkable—that the precision of the survey (insofar as the effects of sampling are concerned) can be assessed from examination of the very data collected in the survey. In fact, evidence from a well-drawn sample survey can be even more reliable than figures from a complete enumeration of the population, simply because the limited survey can be kept under closer control.

The Health Interview Survey is based on interviews conducted in a sample of households all over the U.S. It began in 1957 and is a continuous operation, with data being collected week after week and with the questionnaires revised every year so that information on new health topics can be compiled as the need arises. About 42,000 interviews are conducted each year, covering about 134,000 individuals—a total to date of 313,000 interviews, yielding material on more than a million people. The data from these surveys measure the social rather than the physiological dimensions of health: the total amount of illness, how it affects people's lives, what action they take to prevent or cure illness and what the relation of health and medical care is to a wide variety of social, economic and demographic variables.

The Health Examination Survey, on the other hand, collects precise physiological and diagnostic data by means of comprehensive clinical examinations with objective measurements and tests. It too is a continuing operation. The first cycle, completed in 1962, involved the examination of 6,672 people, a representative population sample of U.S. adults from 18 through 79. The second cycle, completed last year, collected data on a national sample of more than 7,000 children aged six through 11. Right now examinations are being conducted for children aged 12 through 17. The survey is conducted from mobile examination centers: caravans of four large trailers that together provide facilities for a complete three-and-a-half-hour medical examination and for laboratory procedures. Each such center, staffed by a trained team of medical specialists, nurses and technicians, moves about the country on a route predetermined by the sampling plan, which also selects the specific dwelling units in each community whose residents are to be examined.

Although surveys of people are the principal tools of the National Health Survey, there remains a need for certain information that is best collected from health institutions themselves. This includes, for example, information about the services hospitals and other insti-

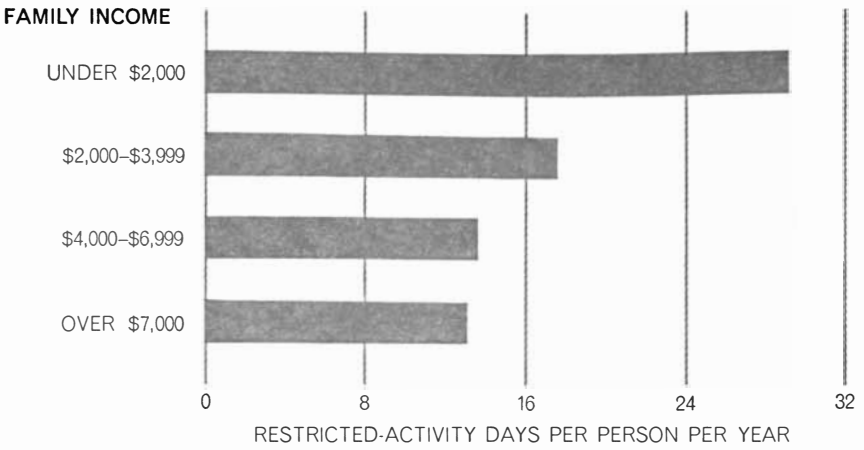
tutions perform, the nature of their facilities and their average bed-occupancy rate; the number of patients and their average stay; the cost of hospitalization and the extent of insurance coverage. Soon it will be important to measure the impact on hospitals of the new Federal "medicare" program. The Health Records Survey compiles material of this kind by examining (again with a sampling technique) the records of hospitals, nursing homes and other institutions.

In 10 years the interview, examination and records surveys have compiled hundreds of thousands of new facts, which have been tabulated, analyzed and published in some 120 scientific reports. Here I can only hope to give some idea of the range of material that has been developed.

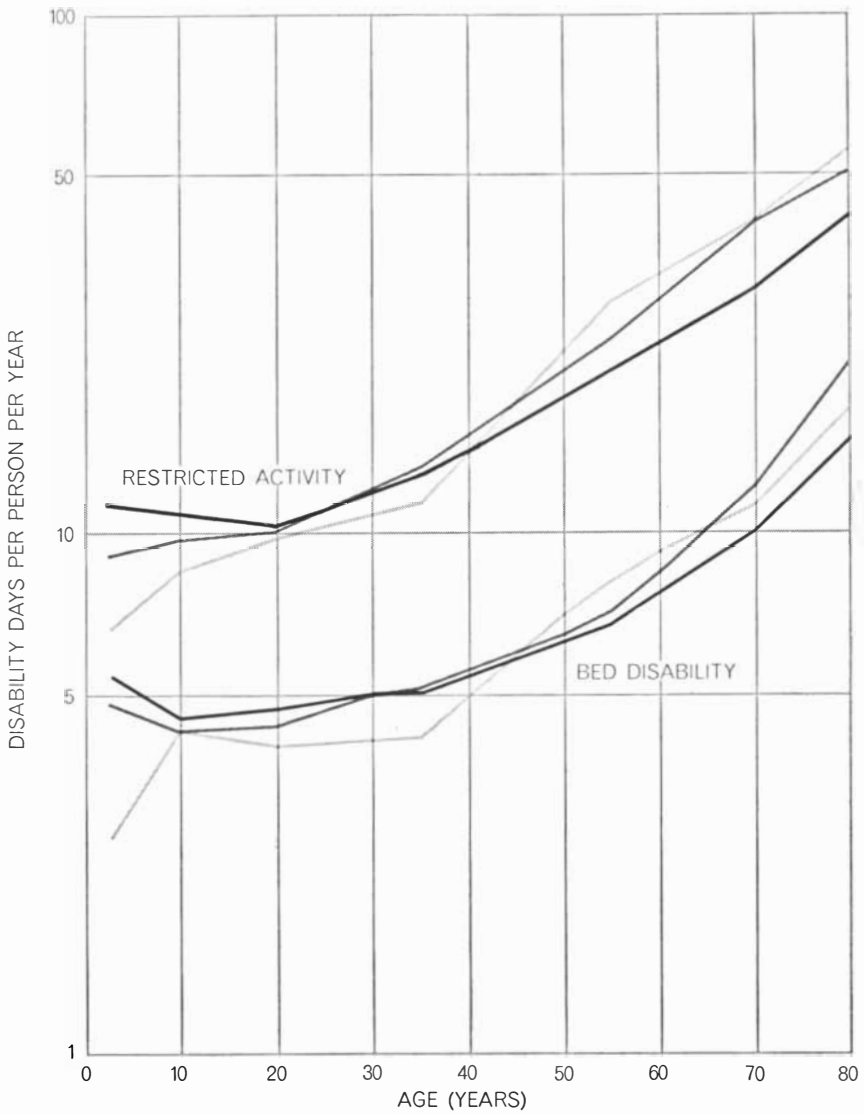
The total amount of illness in a population can be measured in many ways and for many different purposes. One of the most useful concepts is the amount of disability a population suffers during a given period. This concept measures the total weight of illnesses striking the general population and gives some indication of the cost of poor health in terms of economic loss and personal suffering. Disability can be measured in various categories, the most comprehensive of which is "number of days of restricted activity."

In 1964 the civilian noninstitutional population of the U.S. experienced more than three billion days of restricted activity due to illness or injury. This figure may be translated into more than 16 days of such disability for each man, woman and child. The three billion days of restricted activity included more than a billion days of confinement to bed, 385 million days lost from work and more than 200 million days lost from school. It remains for the economist to convert such figures into a dollar cost to the U.S. economy, but even casual computation makes it clear that the economic cost of this loss of productive life is enormous—to say nothing of the human cost.

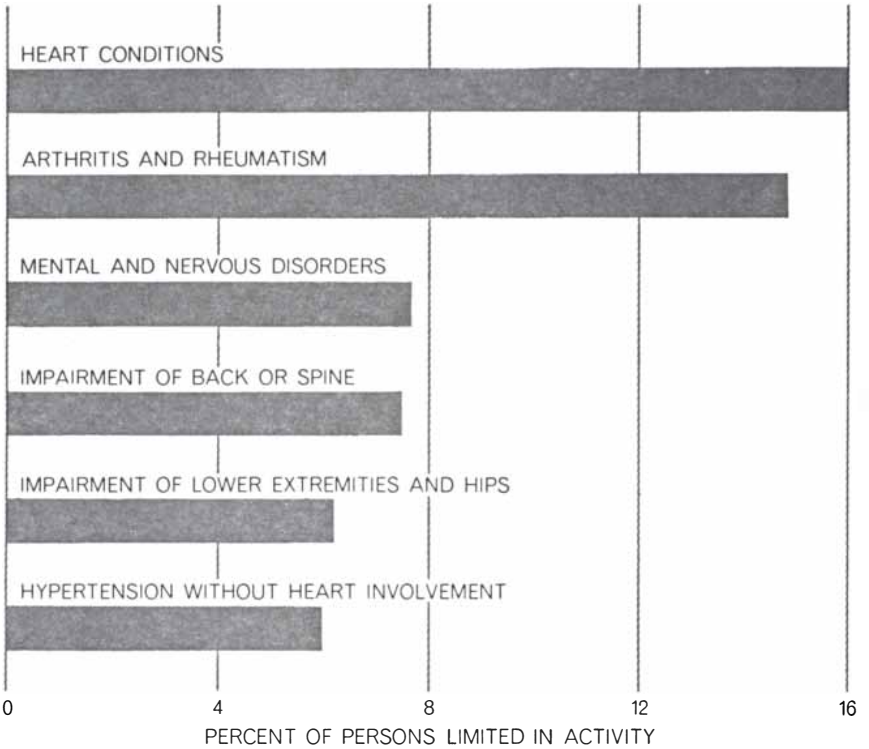
There were more than 844 million visits to physicians, 294 million dental appointments and more than 23 million admissions or discharges from general hospitals in 1964. That is, on the average each person in the U.S. saw a physician 4.5 times and a dentist 1.6 times, and about 128 people in every 1,000 were admitted to and discharged from a general hospital. (Such averages, as we shall see, vary substantially from



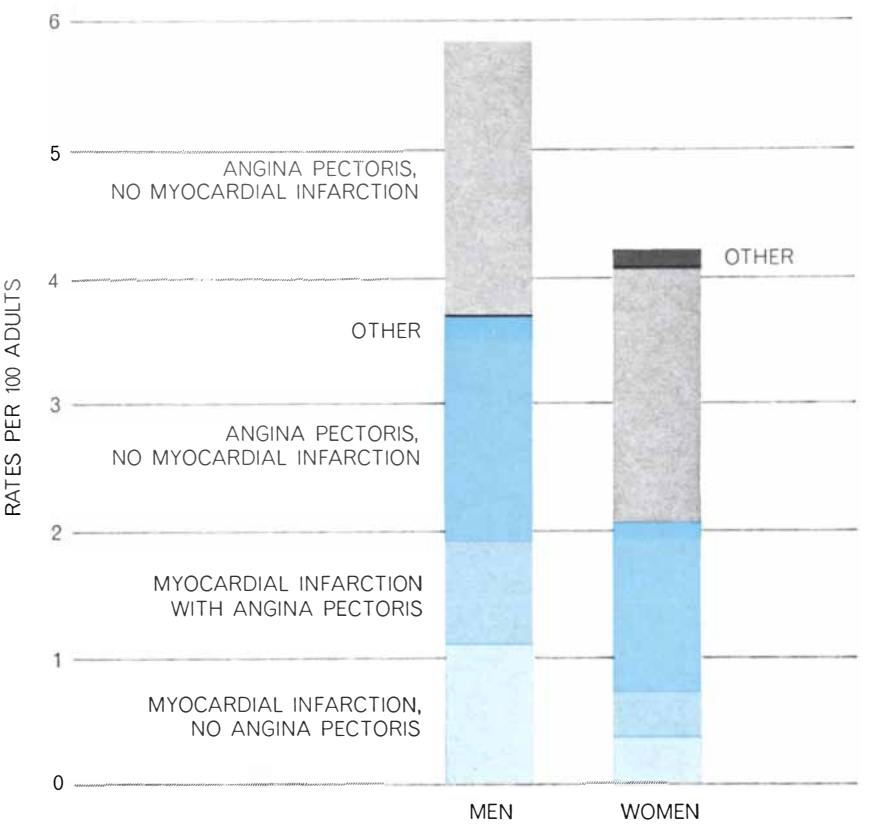
TOTAL IMPACT OF ILLNESS is measured by the number of days on which people missed work or school or otherwise had to reduce their usual activities. The chart, based on the interview survey, shows that lower-income people have more "restricted-activity days."



PLACE OF RESIDENCE has an effect on the number of disability days that varies with age. Children and young adults living in metropolitan areas (*black lines*) have more illness than those outside metropolitan areas, either on farms (*light gray lines*) or elsewhere (*dark gray lines*). People who live in the rural areas lose their advantage in later life, however.



CHRONIC CONDITIONS limit in varying degrees the activities of about 22 million Americans. The chart, based on data from the interview survey, shows what percentage of these people attribute their disability to each of six categories of diseases and other impairments.



HEART DISEASE is a widespread U.S. health problem. The chart shows the incidence of definite (*color*) and suspected (*gray*) coronary heart disease among adults aged 18 through 79. It was established on the basis of physical examination of a sample of the population.

region to region, between urban and rural areas and by age, sex, income and other economic, social and demographic characteristics.) Most of these services were for the diagnosis and treatment of some medical condition. Some 80 percent of all visits to physicians were for these purposes; 4 percent were for prenatal or postnatal care, 8 percent for "general checkups" and 5 percent for preventive services such as immunization. More than 70 percent of the population were covered by some form of hospital insurance and more than 65 percent had surgical insurance.

What specific conditions and diseases contribute to poor health in the U.S.? The diagnostic information compiled by the surveys varies widely in quality and must be interpreted with some care. From interviews one can learn the health history of a household at a level of detail and accuracy that necessarily depends on the person being interviewed. The physical examination reveals chronic conditions with a high degree of accuracy, but its definitions and criteria must necessarily differ from those of more conventional medical practice.

On the basis of interviews we know that in the 12 months ending in June, 1964, Americans suffered from more than 380 million acute illnesses serious enough to require medical attention or at least cause limitation of the patient's normal activities. Some 200 million of these illnesses were respiratory conditions, including the common cold. In addition there were more than 55 million cases of nonrespiratory infectious disease (including the common childhood diseases), about the same number of injuries from accidents and some 20 million illnesses of the digestive system. Collectively these acute conditions accounted for well over half of the bed-disability days that year and of the time lost from work.

Although acute illness and injury loom large in the statistics, chronic conditions often have greater impact on individuals and, because of their continuing character, exact a greater social cost. Of the population surveyed by sampling in 1962–1963 some 80 million suffered from one chronic condition or more. Of these 80 million 58 million experienced no resulting limitation of activities; four million were sufficiently disabled so that they could not work, keep house or go to school; 12 million could engage in these "major activities" only to a restricted extent and six mil-

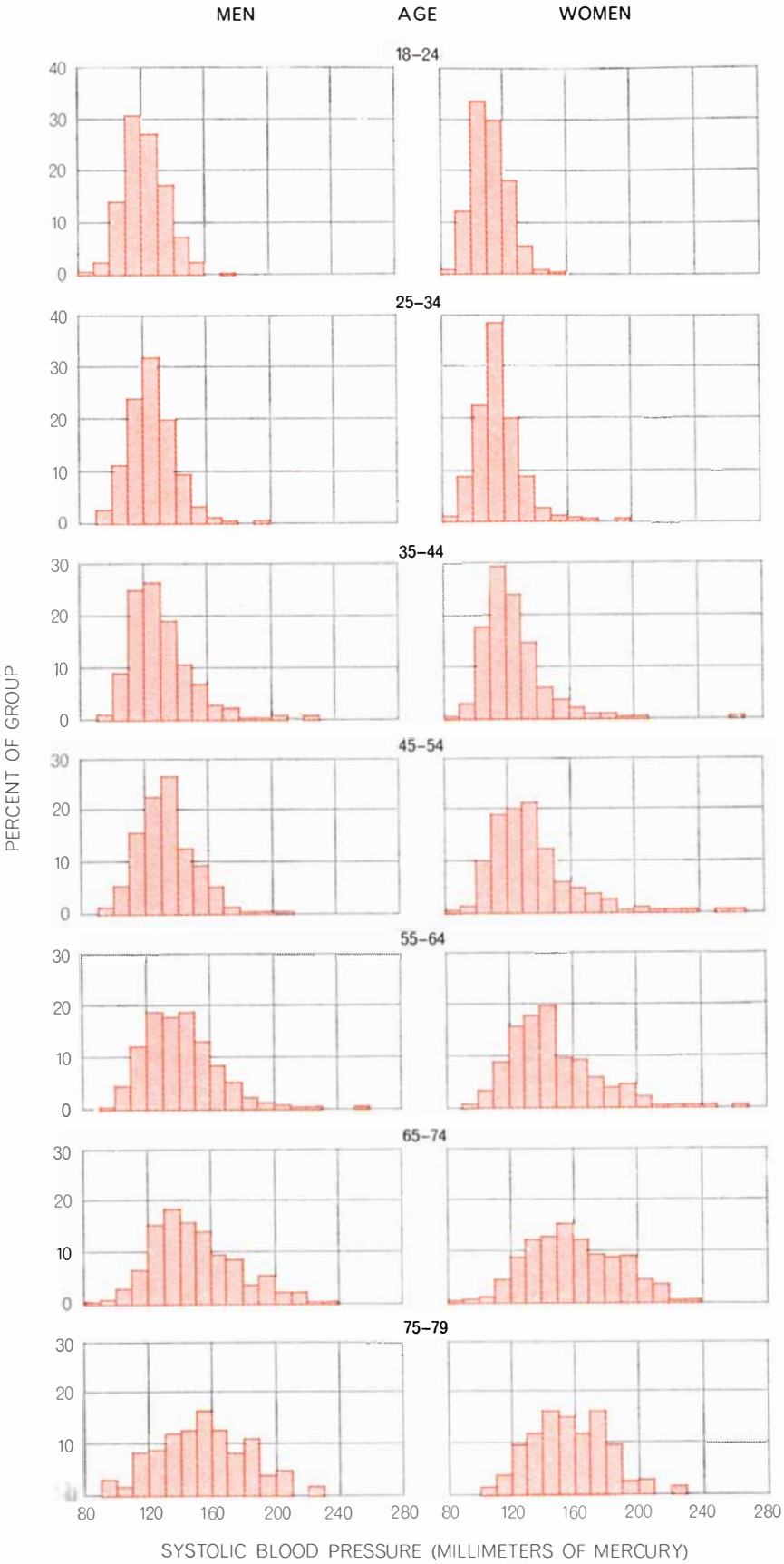
lion, although able to do their basic work, were limited in other activities.

The Health Examination Survey has turned up valuable diagnoses of some of the major chronic diseases. One of its most important findings has been the extent of "unknown diabetes" in the population. The physical examinations indicated that about two million people in the U.S. have diabetes and are aware of it. They also showed that a substantially larger number of people have what are generally considered to be symptoms of diabetes even though the disease had not been previously diagnosed.

The large dimensions of the heart-disease problem in the U.S. have also become apparent as a result of the examination survey: about one adult in every four has cause to be concerned about a heart condition. The survey established, on the basis of firm diagnostic procedures, that more than 14 million adults definitely have some form of heart disease, and that three million of them have coronary heart disease. On the basis of less conclusive symptoms, almost 13 million more adults have "suspect heart disease."

The unique value of such figures as these is that they are based for the first time on a carefully drawn statistical sample of the population and can be accepted with some confidence as being representative of the U.S. population as a whole. Specific symptoms can now be related on a truly national basis to age, sex, body dimensions, blood pressure, cholesterol level and other physical measurements. In addition to providing data on these interrelations the examination survey is establishing basic physiological standards, in terms of averages and frequency distributions, for a number of physiological and medical measurements. Such basic standards will have a permanent value as base-line criteria for future medical observations and research.

The aggregate representations of illness and physical condition are interesting in themselves, but they mean more when they are related to some of the major social problems that concern the American people today. The various measures of general health and health services can be studied in the context of such issues as the war on poverty, problems of urbanization, racial justice and health care for the aged. In relation to such major policy problems as these the National Health Survey can reveal the basic facts of health and



EXAMINATION SURVEY is establishing average levels and distributions of physiological and physical variables based for the first time on a sample of the entire population. These histograms show the wide variation and dispersion in the measurement of blood pressure.

clarify some of their interrelations and associations, thus providing the factual basis for the formulation of policy and subsequent legislative and administrative action.

The findings of the survey, for example, confirm clearly and in quantitative terms the generally accepted idea that there is a positive relation between poor health and low income. Consider the per capita number of restricted-activity days for different income classes of the population. For people in families with a total income of less than $2,000 a year there were (in 1961) 29 days of restricted activity per year per person. For those with a family income in the $2,000-to-$4,000 range the number of disability days dropped to 18, and in families with an income of more than $4,000 the number was 13.

It is true that to some extent income may be low because of illness; furthermore, older people are more likely to be both ill and in the less productive stages of life with regard to income. What we want, however, is not to investigate the extent to which illness causes low income or low income causes illness but to clarify the extent and the manner in which the two misfortunes exist together. Regardless of the direction of the causal relation, such information provides a factual basis for considering what steps, if any, can be taken to alleviate the misery implied by the figures.

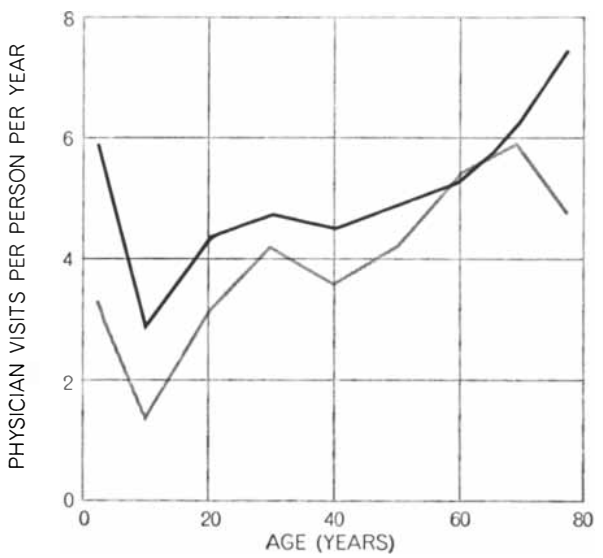
Without undertaking to untangle the cause-and-effect mixture of poor health, low income and old age, the National Health Survey reveals that lower-income people—in spite of their increased level of illness and greater need for health care—receive fewer health services than people with higher incomes. On the basis of information gathered between mid-1963 and mid-1964, 59 percent of the people with family incomes of less than $2,000 had consulted a physician at least once during the preceding year. The proportion of the population with one visit or more to physicians rose steadily with income. It was 66 percent for people in families with $4,000 tc $7,000 a year, 73 percent in families with $10,000 or more.

The services provided by medical specialists show an even sharper gradient with income. The percentage of people availing themselves of these services increases consistently from 13 percent for those with family incomes of less than $2,000 to 28 percent for those with incomes of $7,000 or more.

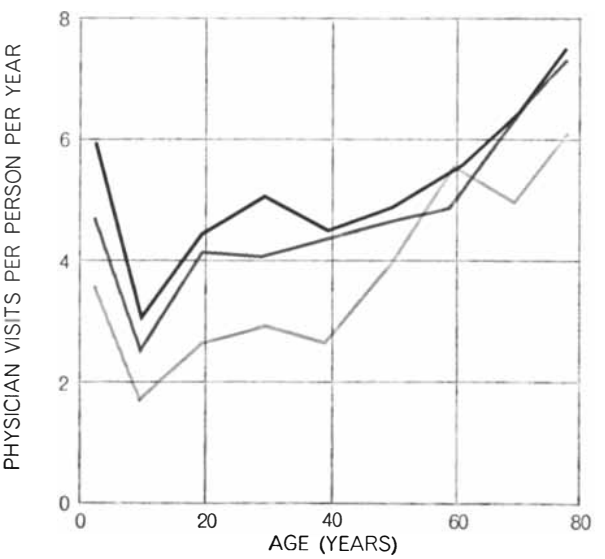
The rate of visits to the doctor is not the only statistic that illustrates the inverse relation of income to health services and protection. The number of dental appointments per capita (perhaps one of the best indexes of elective health care) is more than three times as high for upper-income groups as for the lowest-income group. Poorer people lag, as might be expected, in their per capita expenditures for health services. They also get relatively less care as inpatients in general hospitals. This may be in part because they have significantly less insurance coverage. Only 34 percent of the people with family incomes of less than $2,000 are covered, compared with 88 percent of those with incomes in excess of $7,000.

What will be the effects on health of the increasing concentration of the population in cities and large urban aggregations? Urban conditions of living now obtain not only within the legally defined limits of large cities but also in suburban areas. In its earlier reports the National Health Survey classified its data into "urban," "rural nonfarm" and "rural farm" categories. Now, recognizing the significance of "urban sprawl," we follow the definitions of the Bureau of the Census, classifying residences as being either within one of the 212 Standard Metropolitan Statistical Areas (SMSA's), outside the SMSA's and not on farms, or outside the SMSA's on farms. (An SMSA includes a central city, the county in which it is situated and contiguous counties oriented economically and socially toward the central county. Of the 186 million people in the U.S. in 1961, 119 million lived in metropolitan areas.)

In spite of such known urban pressures on health as air and water pollution, water shortage, overcrowding, poor housing, the stresses of city transportation and the generally accelerated pace of city life, there is no substantial evidence from the National Health Survey that the overall health of the urban resident is worse than that of the rural resident. Indeed, the weight of the evidence indicates that the rural resident is at some disadvantage in terms



VISITS TO PHYSICIANS serve as one measure of the amount of medical care. Statistics from interviews show that nonwhites (*gray line*) see physicians less frequently than do whites (*black line*).



PHYSICIANS' SERVICES are apparently less available to people who live on farms (*light gray*) and to rural-nonfarm residents (*dark gray*) than they are to people in metropolitan areas (*black*).

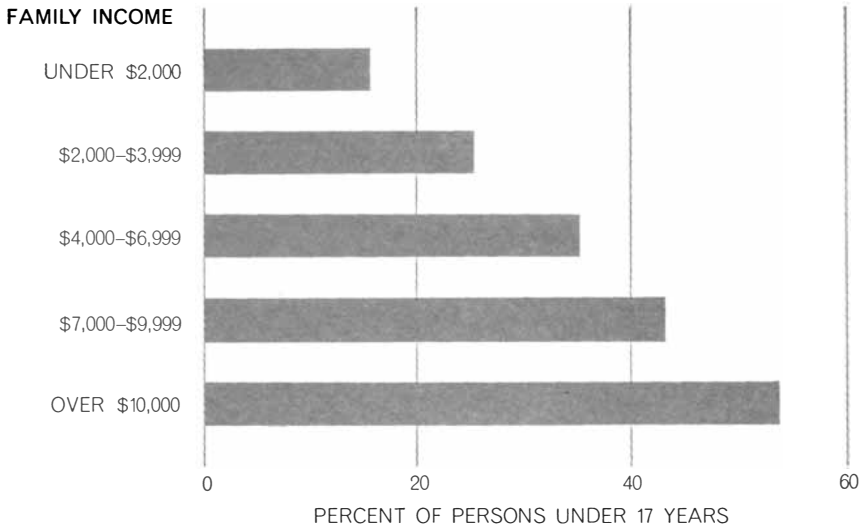
of both general health and health facilities and services.

For example, in 1964 there were 15.6 days of restricted activity per person per year for residents of metropolitan areas, whereas the per capita figure was more than 17 for people outside such areas. SMSA residents reported 5.2 days lost from work per year; people outside SMSA's and not on farms, 5.9 days, and those living on farms, 7.2 days. In 1961 urban residents reported 27.2 accidental injuries per 100 persons per year, rural-nonfarm residents 29.2 injuries and rural-farm residents 27.6.

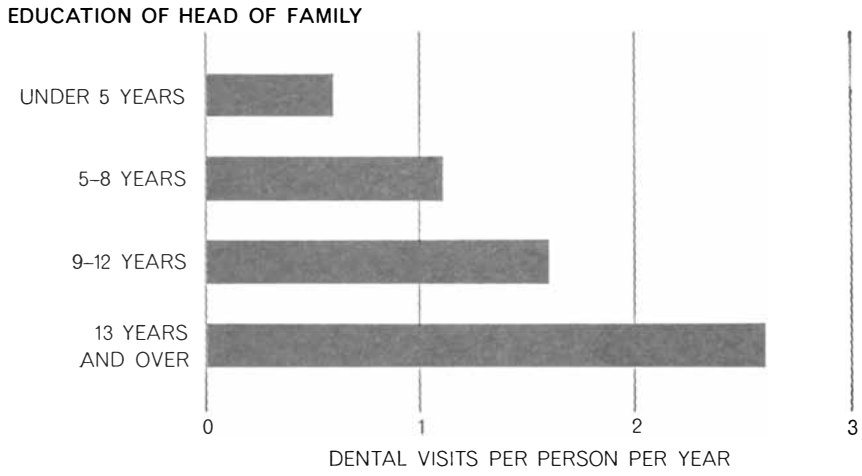
Although these overall figures seem to show a slight advantage for the urban members of the population, there is evidence that urban children and young adults have a higher rate of illness, presumably because they are more exposed to transmissible diseases. Urban children and young adults have more days of restricted activity and of bed disability, days lost from school and from work. Presumably for the same reason, the total number of acute conditions per person is higher in the more urban areas than in the rural-nonfarm and rural-farm areas. Among older people, in whom immunity to common infectious diseases is better established, urban residents have a better record on all these indexes.

One thing that is quite clear is that urban residents have greater access to health services and take advantage of that access. At every age the metropolitan population gets more medical and dental services, and a higher percentage of urban children receive routine physical examinations. Increased protection is also indicated by health-insurance coverage: in 1963 approximately 50 percent of the rural-farm population had hospital insurance; 64 percent of the rural-nonfarm population were covered and 75 percent of the urban population.

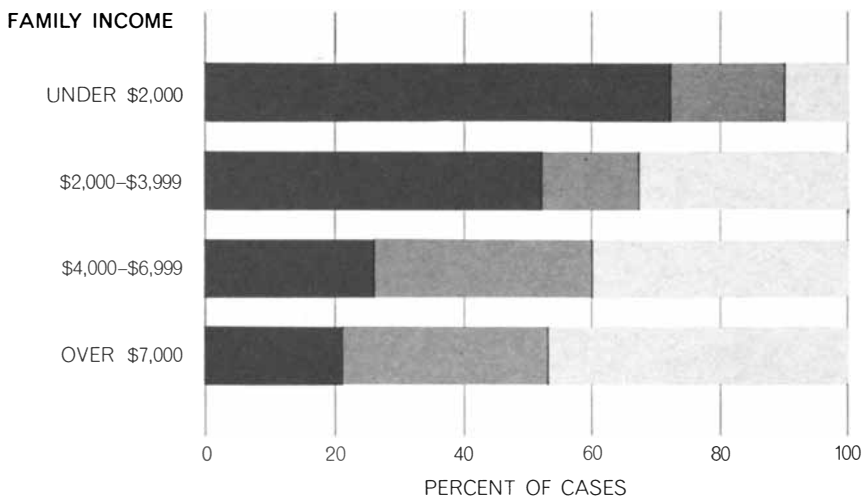
These indications of the relation of health to income and of differences in the health status of urban and rural residents merely illustrate the relevance of the health survey's findings to urgent national problems. Much remains to be learned; new pressures for more information arise continually from the quickened tempo of medical investigation and the enlarged Federal interest in health. Only on the basis of precise data with increasing scope and detail can advances in medical science and enlightened public policy be translated into decent health care for the entire population.



OPTIONAL SERVICES show a sharp gradient with income. The chart indicates the percentage of children under 17 who had a routine physical in the year preceding the interview.



DENTAL CARE, to a large extent elective, also varies with social and economic factors. The chart relates number of dental visits to the education of the head of the family.



INSURANCE COVERAGE varies in extent and adequacy. Bars show distribution by income class of cases in which no part (*dark gray segment*), less than three-quarters (*lighter*) or more than three-quarters (*lightest*) of the surgical or delivery fee was paid by insurance.

Locating Radio Sources with the Moon

By timing when a celestial radio source goes behind the moon and reappears, its position can be accurately fixed. This simple method led to the discovery of the first quasi-stellar radio source

by R. W. Clarke

For the past 20 years astronomers have been asking the question, "What are celestial radio sources and why do they emit radio waves?" Although the sun was the first radio source to be recognized, the study of these sources really began with the recognition in 1946 of the source named Cygnus A, after the constellation in which it is located. Many thousands of radio sources have now been discovered, and presumably thousands more remain to be found as radio astronomers build more sensitive telescopes.

One of the most striking things about radio sources is that the large majority of them are not associated with bright visible objects. The exceptions to this general rule either are clouds of gas within our own galaxy or are bright nearby galaxies. Two such galaxies were identified with the radio sources Virgo A and Centaurus A by the Australian workers J. G. Bolton, G. J. Stanley and O. B. Slee in 1949. Thereafter little progress could be made in selecting the faint visible objects with which the majority of sources are identified until the techniques for measuring the position of radio sources had been improved.

In 1951 F. Graham Smith at the University of Cambridge was able to make a precise determination of the position of Cygnus A. With this information Walter Baade, using the 200-inch telescope on Palomar Mountain, found that the position of the radio source coincided with that of a faint object of the 18th magnitude [*see illustration on opposite page*]. It was originally thought that this unusual object represented the collision of two galaxies and that the strong radio emission came from the energy released in the cataclysm. For various reasons astronomers no longer accept the colliding-galaxy hypothesis. There does seem to be something unusual about the galaxies associated with Cygnus A and with many other strong radio sources, but the origin of their radio energy remains a mystery.

By 1961 fewer than a tenth of the stronger radio sources had been identified with visible objects. It was clear that if most of the sources were similar to those already identified, the rate of identification would not improve until much better radio-position measurements were available. It had been found, however, that at least three radio sources appeared to coincide in position with rather faint stars in our own galaxy. This was a somewhat embarrassing discovery because the great weight of other evidence had suggested that radio sources (with the above-mentioned exceptions) were extragalactic objects.

Then in 1962 there occurred a fortunate accident of nature. A series of occultations, or eclipses, of one of the strongest radio sources by the moon could be observed from Parkes in Australia, the site of a large radio telescope that had just been built by the Commonwealth Scientific and Industrial Research Organization (CSIRO). Radio astronomers had long known that the occultation of radio sources should provide highly accurate measurements of position for those sources that lie in the small region of the sky traversed by the moon.

The very precise position secured from these occultations showed that the source 3*C* 273 (No. 273 in the third Cambridge catalogue of radio sources) was also associated with what appeared to be a star in our galaxy. Now, however, careful measurements by Palomar astronomers showed that the object was not a star but a compact galaxy of a type previously unknown. Many more of these objects—the quasi-stellar radio sources, or quasars—have since been found. They are believed to represent at least 30 percent of all radio sources. The discovery of quasars has been one of the most important and stimulating scientific events of the past few years [see "Quasi-stellar Radio Sources," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, December, 1963].

The study of a radio source does not end when it has been identified with a visible object. Many sources have been found to consist of more than one radiating region, and these components are often separated by distances that are much greater than the diameter of the visible object. This is the case, for example, with Cygnus A, and it provides an important argument against the colliding-galaxy hypothesis. If astrophysicists are to understand the mechanism that generates the energy of radio sources, structural information of this kind is required for many more sources [*see illustration on page 32*].

One of the restrictions in such investigations is the fact that it would be impracticable to build a radio telescope that would provide as detailed a picture as the one that can be obtained with an optical telescope. To secure a radio map with a resolution of one second of arc at a wavelength of 21 centimeters would require the equivalent of a paraboloidal telescope some 30 miles in diameter. The radio astronomer is therefore obliged to use other observing techniques to obtain the details of his picture.

The early methods of measuring the positions of radio sources involved two small aerials placed a few hundred feet apart and connected to the same re-

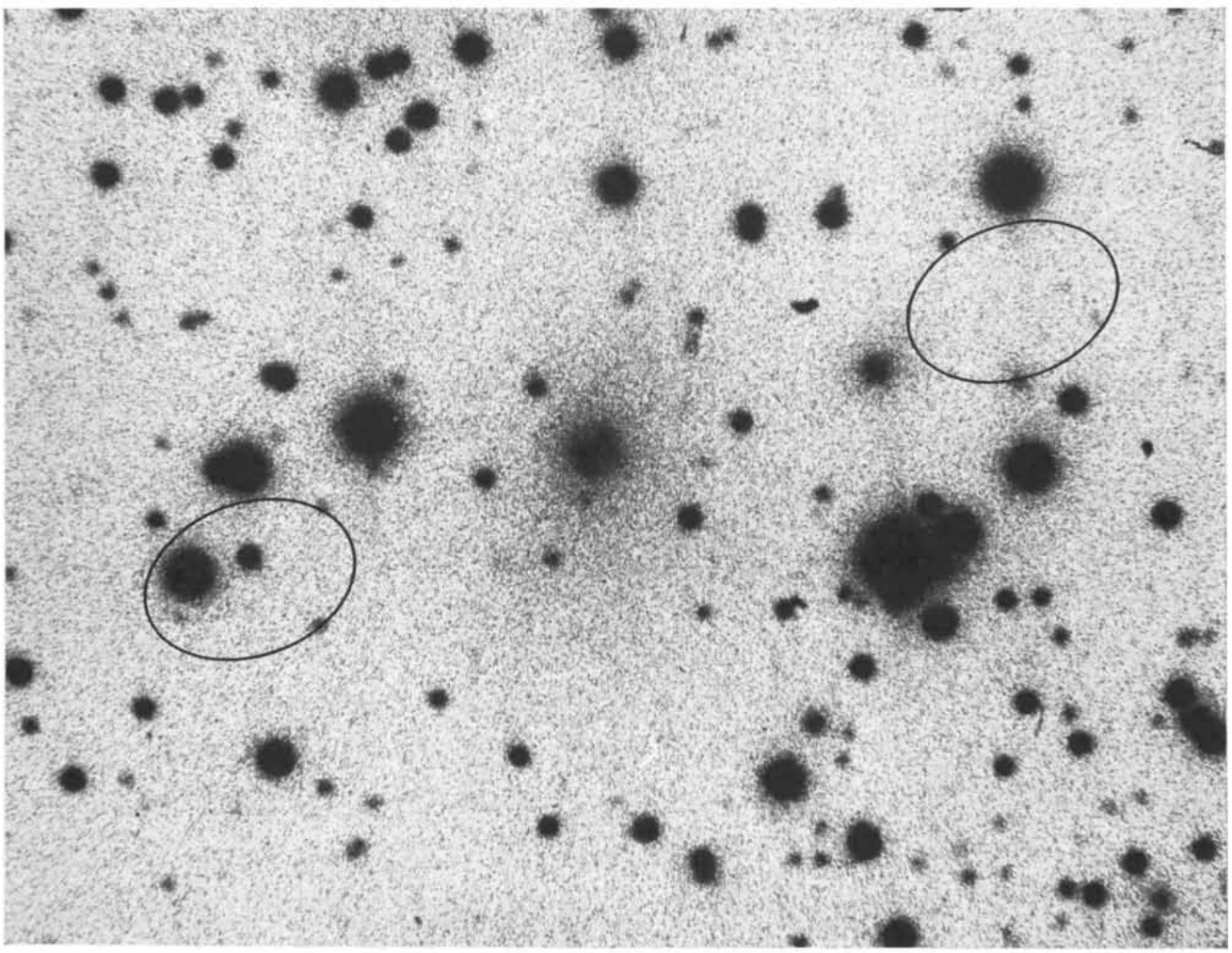
ceiver. Radio waves from a given source reach the two aerials at slightly different times and produce interference patterns. Using the principles of interferometry, one can determine the position of a strong radio source with the same accuracy that one could obtain with a single aerial as large as the distance between the two small aerials. This technique has been used extensively by radio astronomers at the University of Cambridge and at the California Institute of Technology. It was also applied in a different manner in the "Mills cross" telescope built at Sydney in Australia. More recently observers at Parkes and at the National Radio Observatory in Green Bank, W.Va., have employed a large single aerial to pinpoint radio sources.

By these various methods positions have been measured with an accuracy of between five and 10 seconds of arc. New interferometric telescopes at Cambridge, Green Bank and at the Royal Radar Establishment in England should be capable of measuring positions with an accuracy of one or two seconds of arc. For purposes of comparison the angular diameter of the moon as it is seen from the earth is 30 minutes (1,800 seconds) of arc.

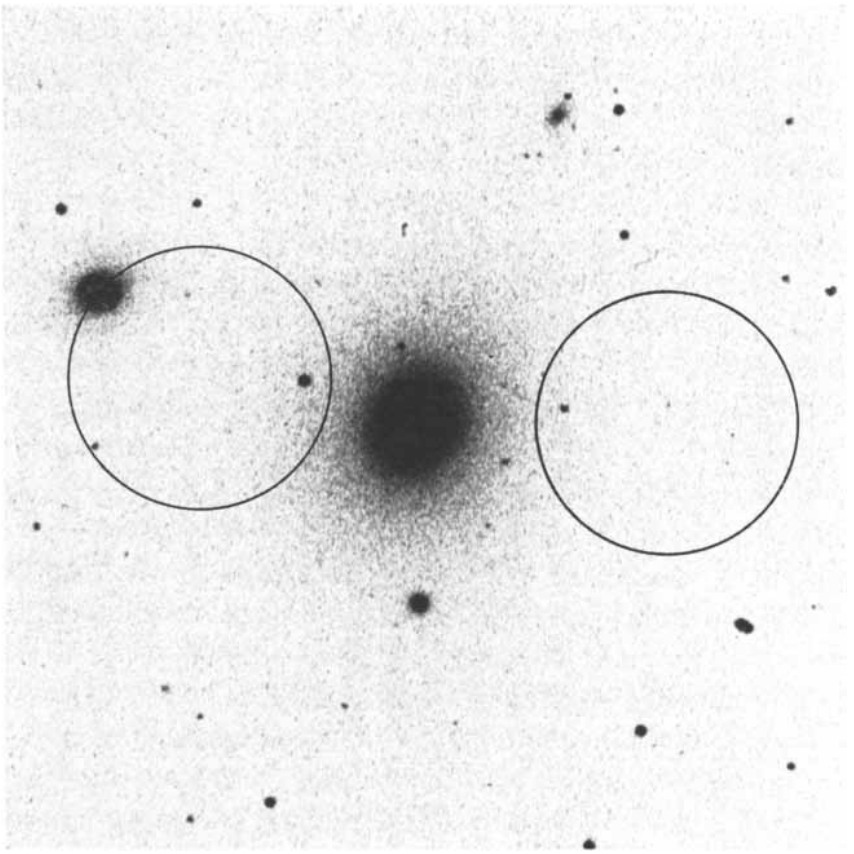
It is a limitation of these observing techniques that if the source has more than one component, the position found is the mean position. There is often no indication that the source is complex. In a few cases, as when there is interference between the radio signals from different parts of the source, interferometer measurements may even have large errors.

One way to obtain additional information on the structure of radio sources is to use an interferometer with a very long base line between aerials and to vary the length of the base line. Astronomers at the Jodrell Bank radio observatory in England have made measurements over a range of distances between aerials to derive the overall size and the size of individual components for many radio sources. Their most recent observations, made in conjunction with astronomers at the Royal Radar Establishment over a base line of 79 miles, have shown that some sources have an angular diameter of less than .1 second of arc. Because of experimental difficulties such measurements cannot be used to find the absolute position of a source; they are employed in conjunction with a mean position already secured by other methods.

If observations of the same source are made with an interferometer that has many base lines oriented at various angles, one can process the measurements by computer to obtain a radio



RADIO SOURCE CYGNUS A, the brightest radio source in the sky, is the hazy object in the center of this photograph, reproduced as a negative. Walter Baade, who made the photograph with the 200-inch telescope on Palomar Mountain, identified the 18th-magnitude galactic object as Cygnus A after F. Graham Smith at the University of Cambridge had made a careful determination of its radio position in 1951. Subsequent studies showed that the radio emission actually comes from two elliptical regions on each side.



RADIO SOURCE 3*C* 33 provides another example of how radio emissions tend to originate from regions centered on a radio galaxy. The radio distribution was determined by Per Maltby, Thomas A. Matthews and Allen T. Moffet of the California Institute of Technology. The photograph was made with the 48-inch Schmidt telescope on Palomar Mountain.

picture of the sky that is the same as one obtainable with a paraboloidal aerial equal in diameter to the longest base line. In a recent series of observations utilizing this technique Cambridge astronomers have simulated a paraboloid a mile in diameter. This method is undoubtedly an excellent one for observing faint sources, which require long integration, or recording, times; it is a rather laborious means of making observations of strong radio sources, for which these long integration times are not necessary.

There is one way, however, in which almost any steerable radio telescope can be used to secure, in only a few minutes of observing time, the position and structural details of a radio source with an accuracy of one or two seconds of arc. This is the method used to identify the source 3*C* 273: observing the occultation of the source by the moon. The main disadvantage of the technique is that only about a tenth of all radio sources are ever occulted; moreover, if an observation goes awry, it may be several years before it can be repeated. The advantages are that the observations are simple and rapid. Most important of all, no elaborate equipment is required beyond a steerable radio telescope and a table of the positions of the moon.

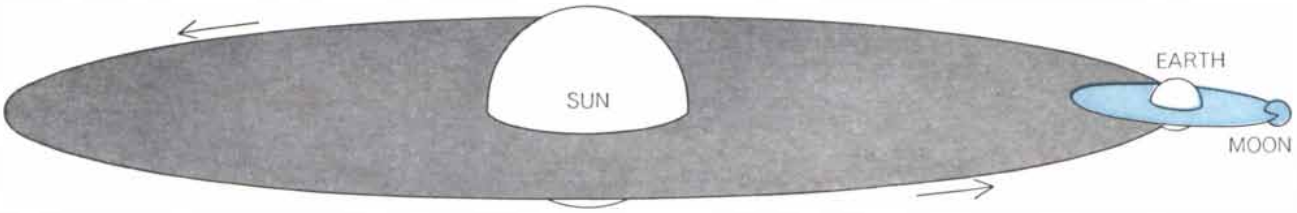
Anyone who has looked at the sky on successive nights knows that the moon changes its apparent position with respect to the stars by several degrees during a period of 24 hours. If we neglect variations of a few percent, the moon travels across the sky about 13 degrees per day; it moves a distance equal to its own diameter (half a degree) every hour. Because of this motion, stars, radio sources and other astronomical objects are steadily being eclipsed and then returned to view. The moon takes 27.3 days to complete one revolution around the earth and return to almost the same apparent position among the stars; the mean time between new moons (29.5 days) is longer because the earth is also moving around the sun. During one lunar month all the objects within a strip covering 180 square degrees—a trifle less than half of 1 percent of the total sky—will have been eclipsed.

If this were the limit of the coverage, the occultation method would be useful but soon exhausted. Fortunately the moon does not repeat its path exactly from one month to the next. To get a better idea of the total area of sky covered by the moon over a period of several years it is necessary to consider briefly the relative positions and motions of the sun, the earth and the moon. Each of the three bodies is rotating on its own axis; the earth is revolving around the sun and the moon around the earth [*see top illustration on opposite page*]. Because the axis of rotation of the earth is inclined at 23.5 degrees to the axis of the earth's orbit around the sun, the apparent path of the sun in the sky, known as the ecliptic, follows a track that goes 23.5 degrees to the north and south of the celestial equator. The axis of the moon's orbit around the earth is inclined by about five degrees to the axis of the ecliptic; this means that the apparent path of the moon in the sky is a circle inclined at five degrees to the path of the sun.

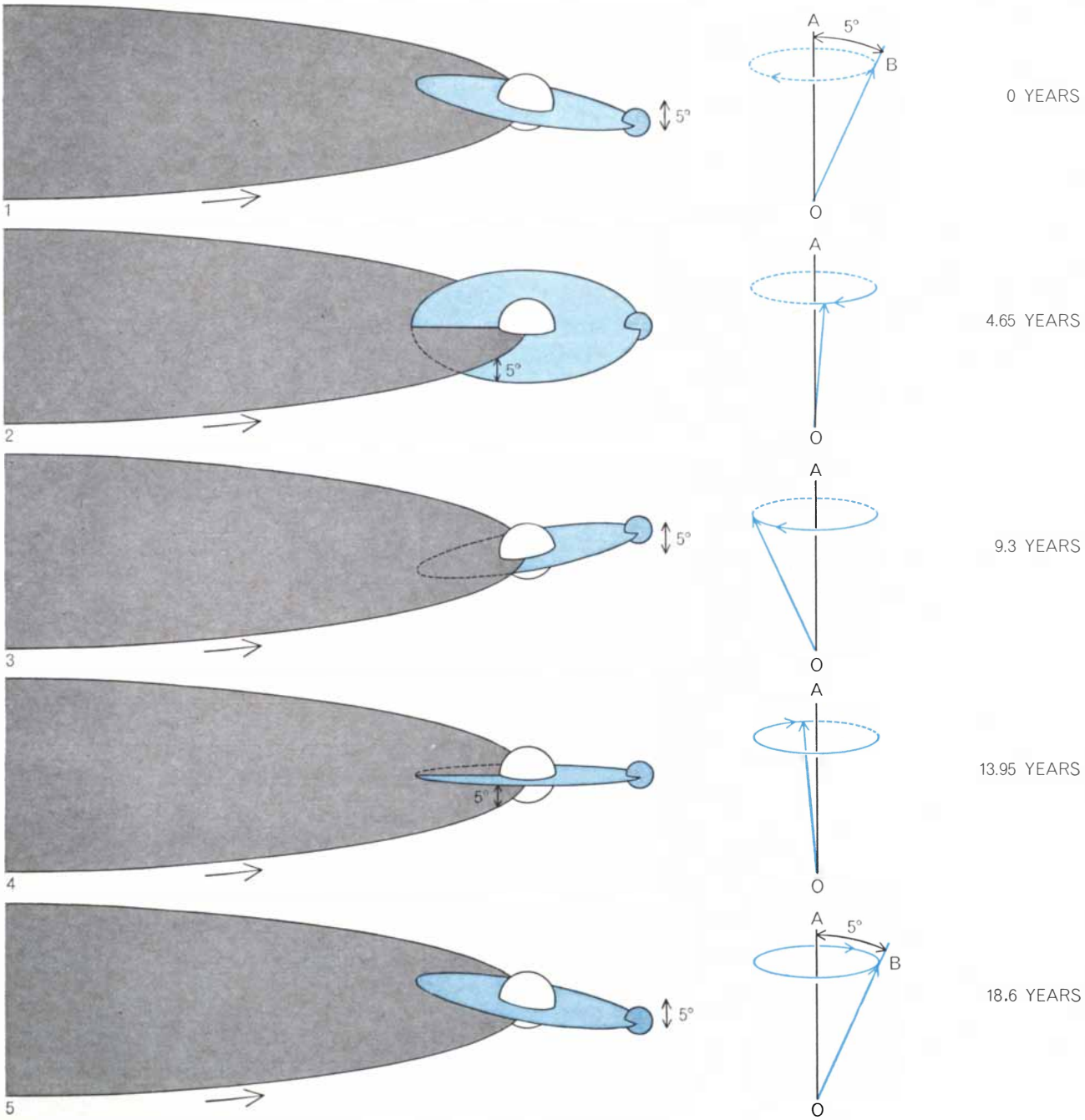
Because of the inclination of the moon's orbit around the earth, the moon spends most of the time out of the plane of the ecliptic. The forces of attraction exerted by the sun and the earth on the moon are always pulling the moon back into this plane; a continuous force acts to twist the moon's orbit into the plane of the ecliptic. The interaction of this twist and the movement of the moon along its orbit around the earth causes the axis of the moon's orbit around the earth to rotate around the axis of the earth's orbit around the sun [*see bottom illustration on opposite page*].

This effect, known as precession, is commonly seen when a child's spinning top slows down and the axis of rotation is no longer vertical. The force of gravity then tries to twist the top around a horizontal axis and the main axis of rotation starts to move around the vertical direction. In the same way the axis of the moon's orbit around the earth precesses around the axis of the earth's orbit around the sun once every 18.6 years. During this time the moon's path will cross all the sky within five degrees of the sun's path. Thus the moon can eclipse all the objects lying within a belt 10 degrees wide around the sky, which represents about 9 percent of the total area of the sky, or 20 times the area of sky covered in one lunar revolution [*see top illustration on page 34*].

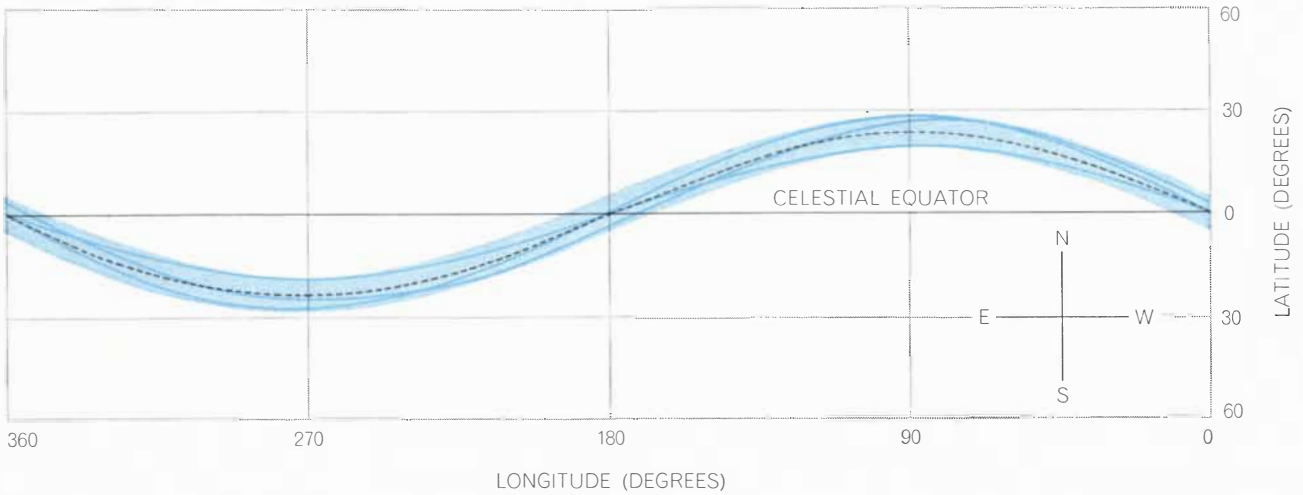
The position and the apparent diam-



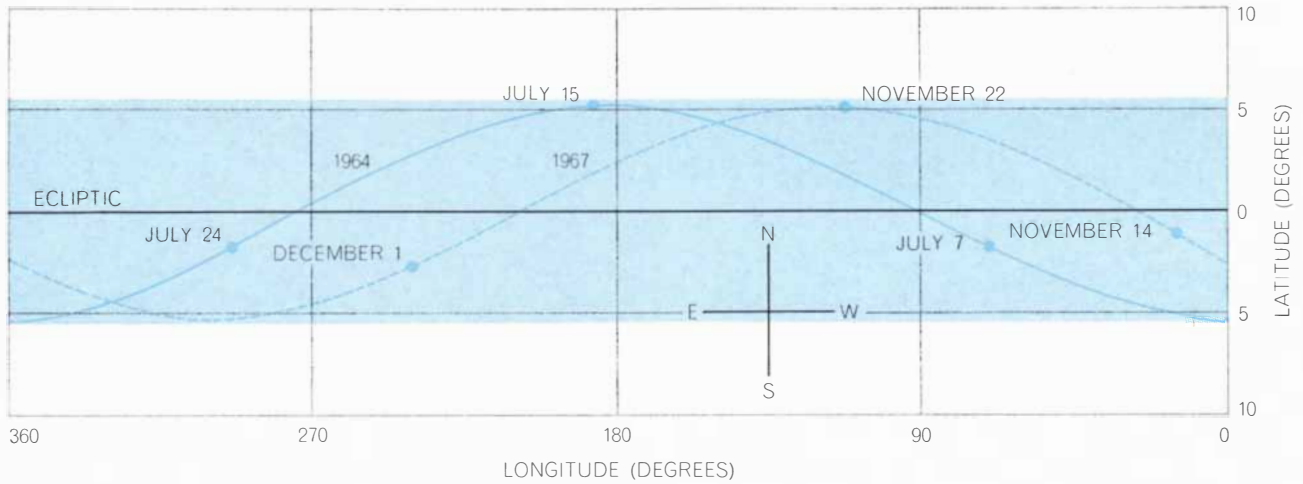
ORBITAL PLANES of the earth and the moon intersect at an angle of five degrees, with the result that the plane of the moon's orbit around the earth precesses, or wobbles, on an 18.6-year cycle, as shown below. The intersecting angle is exaggerated for clarity.



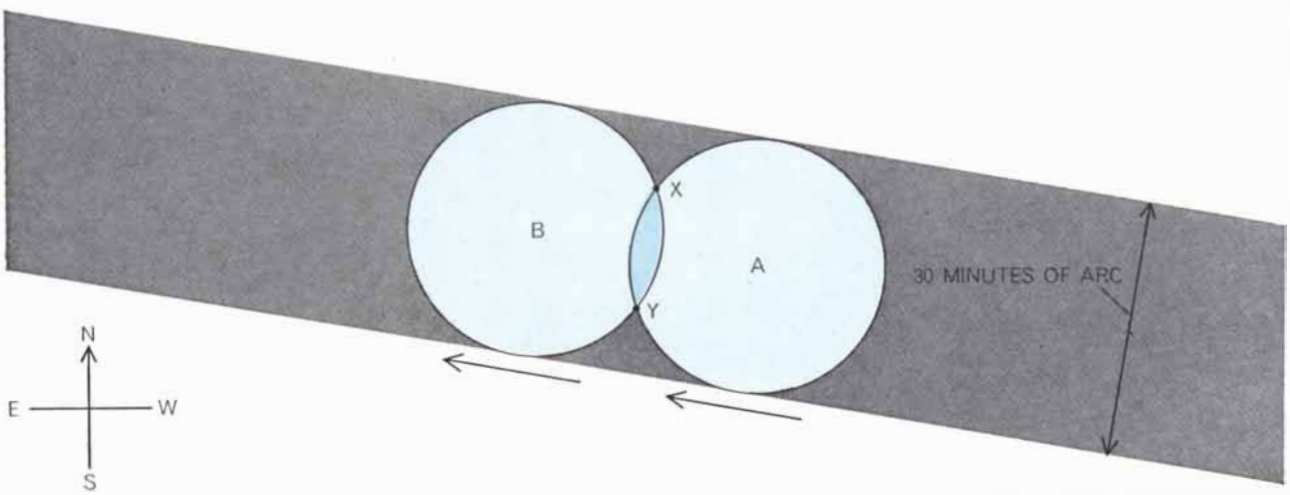
PRECESSION OF MOON'S ORBITAL PLANE corresponds to a clockwise rotation of the axis of the moon's orbit around the earth (*OB*) in relation to the axis of the earth's orbit around the sun (*OA*). For the astronomer the precession has the desirable effect of making the moon occult, or eclipse, many more celestial objects than it otherwise would. It also means, however, that some objects are occulted only once in 18.6 years, which puts a premium on having one's equipment working when the opportunity presents itself.



MOON'S PATH ACROSS SKY extends 23.5 degrees north and south of the celestial equator. The wobble in the plane of the moon's orbit carries the moon another five degrees north and south of the ecliptic (*broken line*), the apparent path of the sun, so that in 18.6 years the moon covers the entire band shown in color. Individual passages of the moon are shown in solid colored lines.

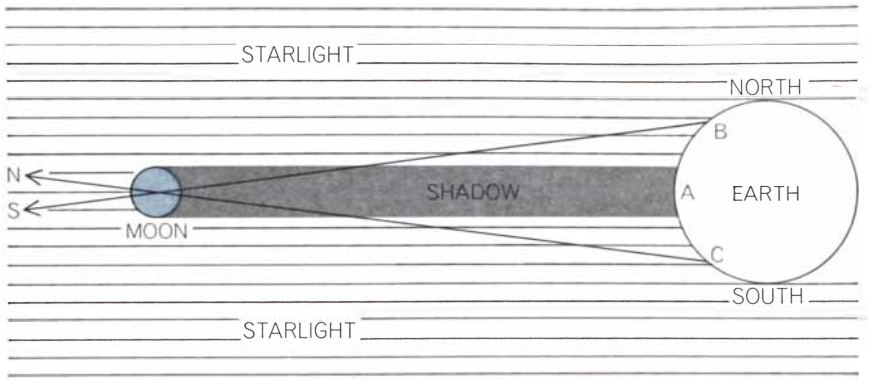


TYPICAL LUNAR ORBITS are shown with the ecliptic represented as a horizontal line. Because of the effects of precession the points at which the moon's orbit crosses the ecliptic move westward across the sky at the rate of about 1.5 degrees every lunar month.



POSITION OF RADIO SOURCE is found by determining the position of the moon at the moment when the source disappears (*circle A*) and its position when the source reappears (*circle B*). The position of the radio source could be at either *X* or *Y*, the two points where the two circles intersect. Position measurements made by other techniques, or a second occultation measurement performed when the moon is in a different location, will usually rule out one of the two points and indicate the true location of the radio source.

eter of the moon at any time are known precisely from optical astronomy. It is a fairly simple matter to calculate from tables the time at which an object will first be eclipsed and then uncovered as the moon passes in front of it. For a number of years the Nautical Almanac Office in England has been computing details of these expected occultations for a large number of the stronger radio sources and sending the information to radio observatories throughout the world. Because the positions of most of the radio sources are not known precisely these predictions are necessarily approximate, but they are sufficiently accurate to allow the occultations to be observed.



EFFECT OF PARALLAX limits the region of the earth where the occultation of a particular celestial object by the moon can be observed. Thus a star or radio source that will be occulted for an observer located at *A* will not be occulted for an observer at *B*, who sees the moon in the direction *S*, nor for an observer at *C*, who sees the moon in the direction *N*.

Reduced to its simplest terms the measurement of a radio-source position by an occultation consists of pointing a radio telescope at the source and noting the time at which the radiation is cut off as the source disappears behind the moon and also noting the time at which the radio signal reappears. By reference to tables one can determine the apparent diameter and position in the sky of the moon at the times of disappearance and reappearance. If one then draws two circles to represent the limb, or edge, of the moon at these times, the circles will intersect at two points; one of these will be the position of the radio source [*see bottom illustration on opposite page*]. Earlier radio measurements usually make it obvious which position is the correct one.

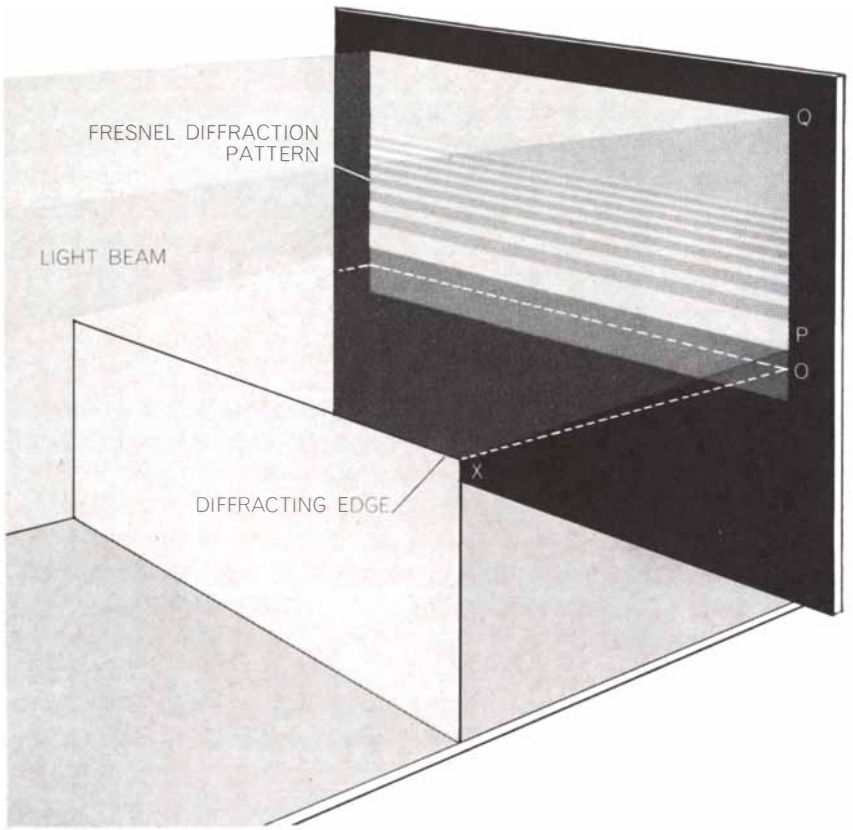
If the two times are measured with a maximum error of one second, which should be easy for the stronger radio sources, the two positions of the moon will be established to within .5 second of arc. This should yield the position of the source to within one second of arc, provided that the two circles in the diagram do not intersect at a very acute angle. It is interesting to note that the measurements of the position of the moon that are used to compile the tables also involve occultations, but in that case the occultations are those of bright stars and it is the positions of the stars that are known and the position of the moon that is being determined.

The radio astronomer who wishes to use the occultation method to determine the position of radio sources must be aware of certain problems. Because the moon is a close object its apparent position among the stars depends to a critical degree on the observer's position on the surface of the earth [*see illustration on this page*]. An error of one mile in the adopted values of the observer's coordinates with respect to the center of the earth (the observing point for which lunar tables are compiled) can produce an error of up to one second of arc in the coordinates computed for the position of the moon.

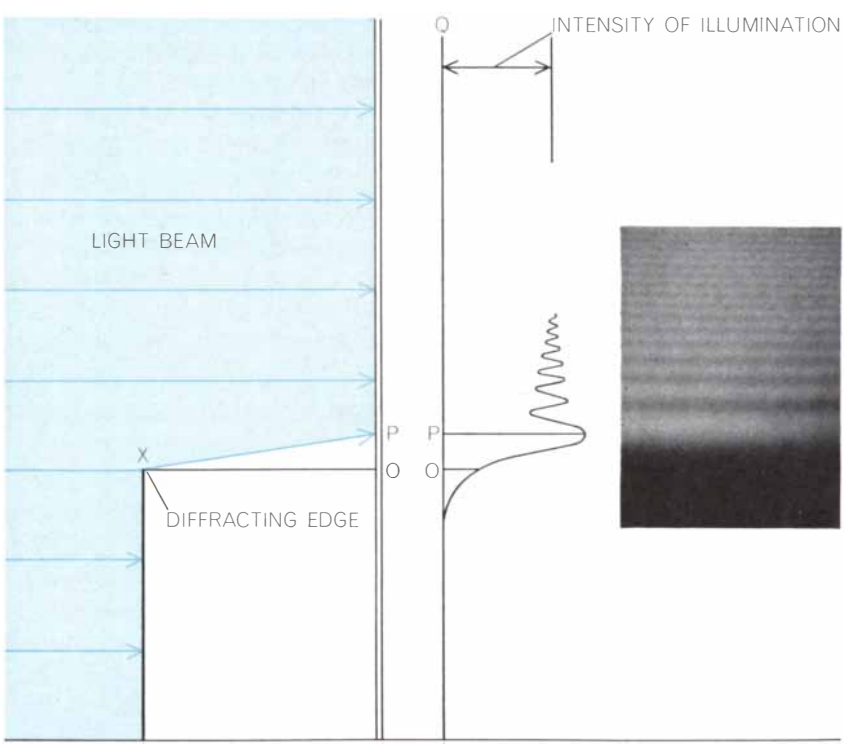
The measurement of astronomical time also presents a problem: it can be measured in two different ways and the two will not quite agree. The more familiar method measures the time required for the earth to rotate around its axis. This is expressed as Universal Time, or Greenwich Mean Time; it is the basis for the standard civil time used throughout the world. The other method, which yields Ephemeris Time, is derived from the time required for the moon and the planets to move around their orbits. At present Ephemeris Time is gaining on Universal Time by about a third of a second per year. The positions of the moon and the planets made available by the Nautical Almanac Office give the coordinates as a function of Ephemeris Time, not Universal Time. Astronomical observations, however, are made in Universal Time. If the difference between the two time scales were constant or uniformly varying, this would be no more than a nuisance. Unfortunately there appear to be short-term random variations of a few tenths of a second superposed on a uniform change. These random and largely indeterminate errors can be as important as the timing errors in the observations. The measurement of the difference between Ephemeris Time and Universal Time depends largely on measurements of the occultation of stars; because of the time needed to reduce the data and to sort out trends the mean differences are not known precisely until at least a year later.

Corrections also have to be applied for the effect of lunar mountains, which rise as much as 17,000 feet above the surface of the moon. A 17,000-foot mountain is seen from the earth as a projection of three seconds of arc from the mean limb of the moon. If no correction is applied, such a mountain could introduce an error of six seconds in the time of an occultation. To enable astronomers to make the necessary corrections extensive tables have now been prepared at the U.S. Naval Observatory showing the outline of the limb of the moon for each of the aspects in which it can be seen from the earth.

We are now ready to examine more closely what the radio astronomer observes when the moon eclipses a radio source. Except for its slight curvature and the irregularities due to its surface features, the moon can be regarded as a straightedge that comes between the observer and the source of radiation. The 17th-century Italian painter Francesco Grimaldi was the first to notice that a straightedge illuminated by a beam of light does not cast a perfectly sharp shadow. Close examination showed that there was some illumination inside the region that ought to be totally dark and that there was a series of small fluctuations in the intensity on the bright side of the shadow. This phenomenon, known as diffraction, was not very striking. Isaac Newton, who favored the theory that light consisted of particles rather than waves, believed it was caused by slight repulsions that perturbed the stream of particles as they passed the straightedge. In 1815, however, the French physicist Augustin Fresnel was able to demonstrate that the wave theory could account for both the fact that light is propagated in straight lines and the fact that it is dif-



DIFFRACTION PATTERN is produced when a parallel beam of light grazes a sharp edge and falls on a screen. *O* shows where the edge should appear on the screen if there were no diffraction. *P* is the center of the nearest and brightest diffraction fringe. If the distance *XO* is one meter, the distance *OP* is about .6 millimeter. The level of illumination at *P* is 37 percent higher than the level of illumination in the unaffected part of the beam (*Q*).



PHOTOGRAPH OF DIFFRACTION PATTERN (*right*) shows how the intensity of fringes grows weaker with the distance from *O*. The intensity at *O* is about 18 percent of that at *P*.

fracted by a straightedge. Since then this type of diffraction has been known as Fresnel diffraction.

Only a few characteristics of a diffraction pattern need concern us here. The top illustration at the left shows a beam of light falling on a screen after passing a straightedge. At *O*, the edge of the shadow if diffraction did not occur, the illumination is 25 percent of the value at *Q*, a point well away from the disturbances associated with the shadow region. The intensity of illumination in the fringes, or fluctuations, can be greater than the intensity would be if the diffraction edge did not exist. The maximum illumination, reached at *P*, is 37 percent greater than the level of illumination at *Q*.

The scale of the pattern depends on the wavelength of the radiation and on the distance from the diffracting edge to the observing screen. If the radiation is near the middle of the visible spectrum, and if the distance from the straightedge to the screen is one meter, the distance from the expected position of the straightedge on the screen (point *O*) to the center of the first fringe (*P*) is about .6 millimeter.

The distance *OP* increases as the square root of the product of the wavelength of the radiation and the distance between the straightedge and the screen. If we move the straightedge to the distance of the moon and observe the optical diffraction pattern of a star, the distance *OP* is now about 12 meters. If we replace the star with a radio source whose radiation has a wavelength of 75 centimeters, the distance *OP* is increased to 14 kilometers.

If we now replace the straightedge by the moon, a radio source being eclipsed will still cast the same diffraction pattern on the ground. But because the moon is moving steadily the diffraction pattern cast by the source will move across the ground and past a stationary observer. If the observer keeps his radio telescope pointed at the source as it is eclipsed, he can expect to measure the varying peaks and valleys in the diffraction pattern as it sweeps past him. Similarly, when the source returns to view he will observe the pattern in the reverse direction.

The time required for 14 kilometers of the radio diffraction pattern (distance *OP*) to move past the observer is about 16 seconds. There should therefore be little difficulty in observing the pattern from strong radio sources with large radio telescopes and in obtaining a record with a good signal-to-noise ratio. For purposes of comparison the equiva-

lent time interval for the occultation of a visible star would be about a hundredth of a second.

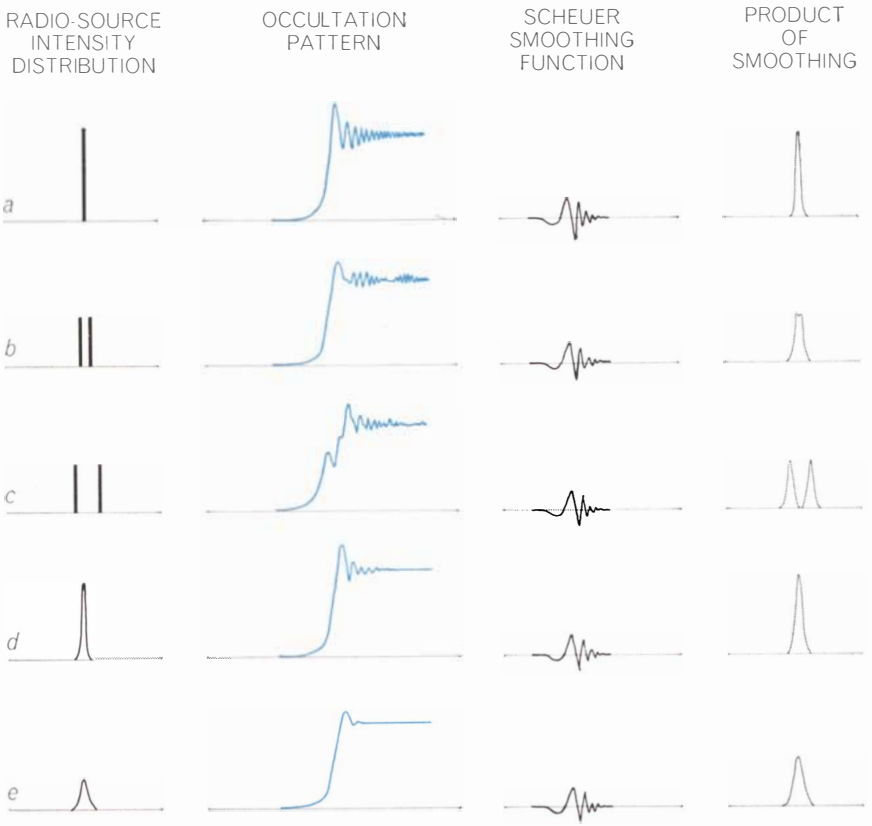
If the radio source is made up of two components, each of small diameter, each will cast its own diffraction pattern and the observed pattern will be the sum of the two individual patterns [*see top illustration at right*]. The fringes of the diffraction pattern from different parts of an extended radio source will be added to each other; if the width of the source is comparable to the width of the first fringe, the diffraction pattern will be smoothed out and the fluctuations will largely disappear.

How are the occultation records interpreted to secure the distribution of intensity across a radio source? The trace that is obtained from the occultation of a point source of radio waves can be interpreted by comparing it with a theoretical curve. The method can be extended to include the interpretation of double sources by the fitting of "model" curves appropriate to such sources, but the process is very tedious. If the distribution of intensity is more complex, the fitting of model curves is almost impossible.

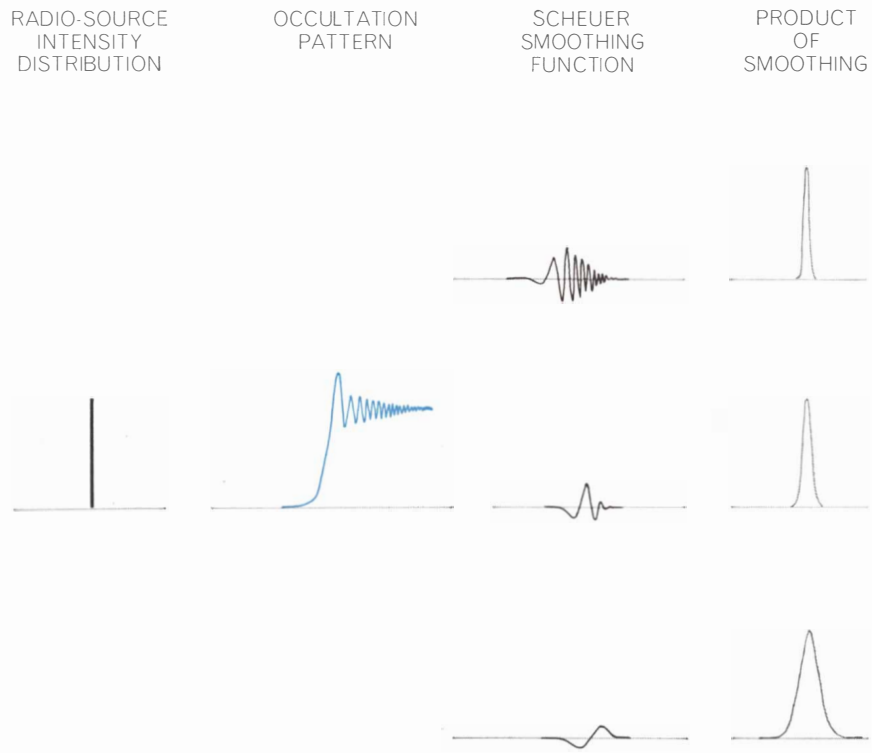
Peter A. G. Scheuer, who was formerly at the Radiophysics Laboratory of the CSIRO and is now at the University of Cambridge, has considered in some detail the problem of obtaining the distribution of intensity in a radio source from occultation curves. He has shown that it is possible to calculate mathematical functions that can be used to convolve, or smooth, the recorded trace and reconstruct the distribution of intensity across the source. Technically it is impossible to discover the original distribution because the theoretical smoothing function is infinitely long, but one can use a shorter smoothing function to reconstruct a version of the original distribution from which only the finest detail has been lost by smoothing [*see bottom illustration at right*].

Even though it is theoretically possible to bring out finer and finer detail in the original intensity distribution by smoothing with longer and longer functions, the procedure is usually limited by various instrumental effects that are present in any actual occultation measurement. Two effects are the most important, and one or the other usually sets the limit.

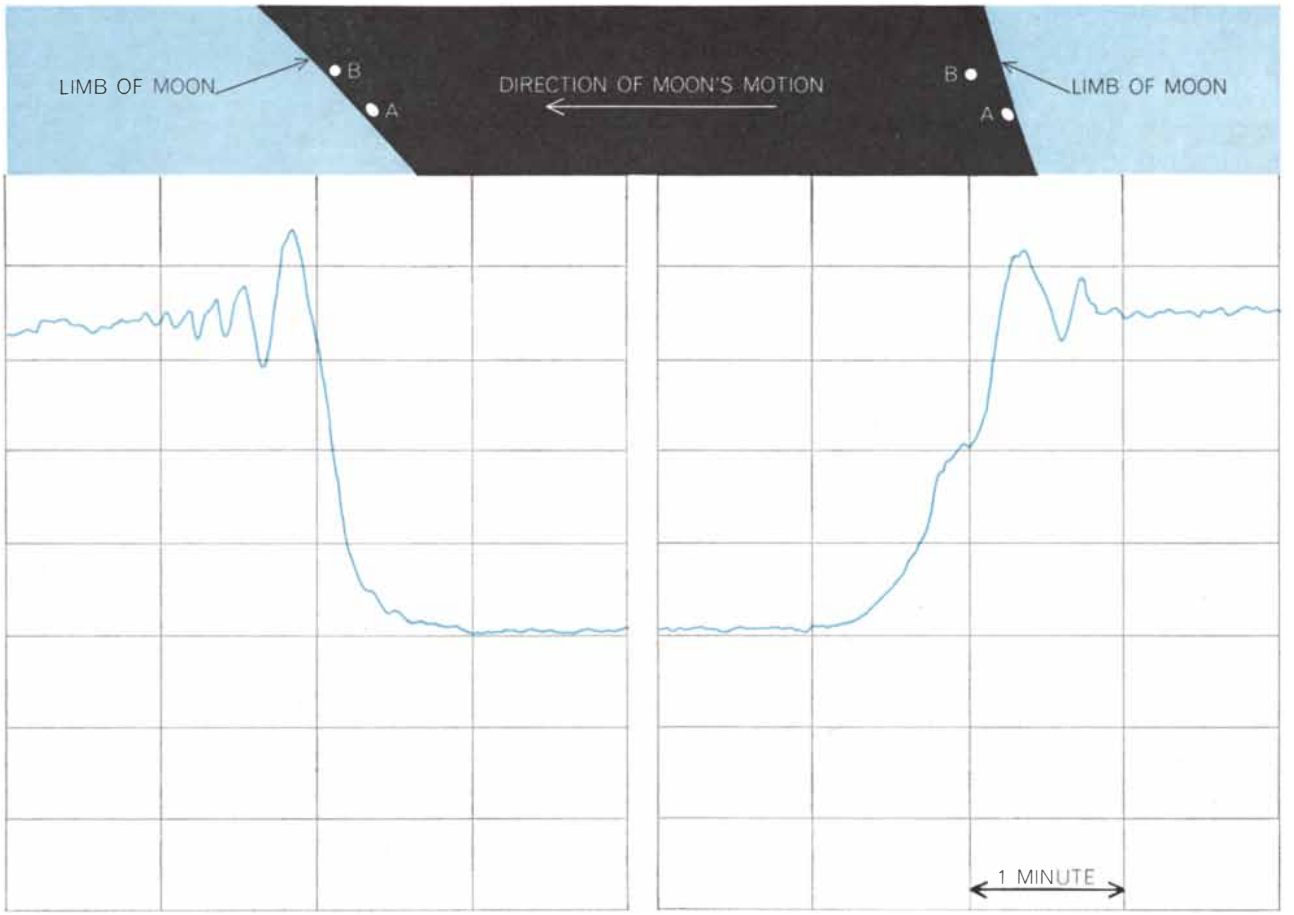
The first limit is introduced by the fact that radio receivers cannot be tuned to a single wavelength but must accept a finite band of wavelengths. As we have seen, the distance between fringes



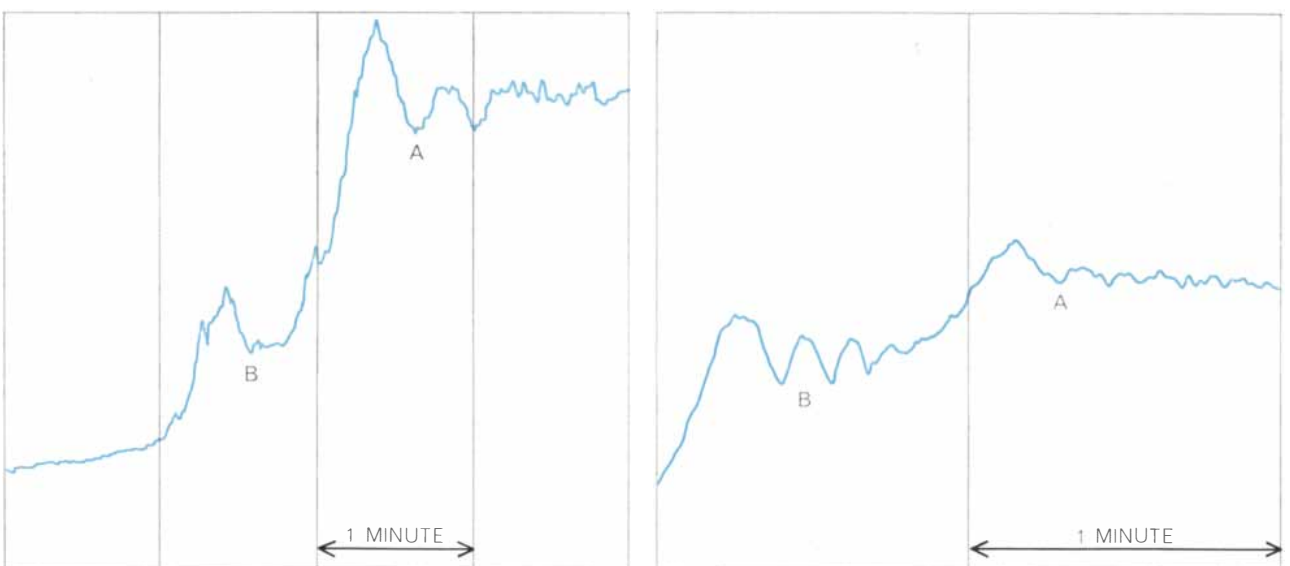
OCCULTATION PATTERNS OF RADIO SOURCES vary according to the intensity distribution of the source. The theoretical patterns shown here are for a single point source (*a*), two point sources with different separations (*b*, *c*), extended sources of two different widths (*d*, *e*). A Scheuer "smoothing function" produces the intensity distributions at the right.



DIFFERENT SCHEUER FUNCTIONS yield varying amounts of detail from the same occultation pattern. The diffraction pattern in each case is that produced by a point radio source. Although it is impossible to turn the diffraction pattern back into the original point distribution, it can be approximated by extending the length of the smoothing function.



OCCULTATION OF RADIO SOURCE 3*C* 273 produced these patterns, recorded by the 210-foot radio telescope at Parkes in Australia. The pattern at right was obtained as the source disappeared behind the moon on August 5, 1962. The pattern at left shows its reappearance an hour later. Both records were made at a frequency of 410 megacycles. The difference between the two records suggested that the source had two components that disappeared at slightly different times but then reappeared almost simultaneously.

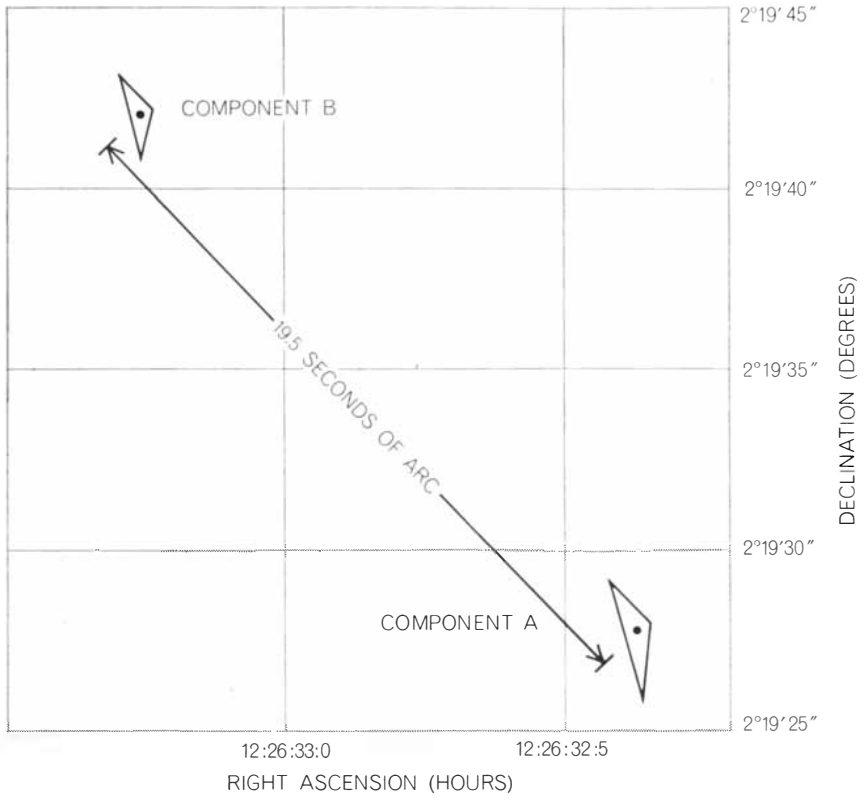


ADDITIONAL PATTERNS OF 3*C* 273 were obtained simultaneously at two different frequencies as the radio source disappeared behind the moon on October 26, 1962. It could not be observed on reappearance because the moon was too low in the sky. The pattern at right was made at 1,410 megacycles; the one at the left, at 410 megacycles. These observations clearly revealed two components (*A and B*). The diffraction pattern produced by a point source is confined to a narrower angle and takes less time to pass at 1,410 megacycles than at 410 megacycles. Thus the separation of 3*C* 273 into two components is clearer at 1,410 megacycles.

in a diffraction pattern is related to the wavelength of the diffracted radiation; thus for each wavelength accepted by the receiver there is a slightly different pattern. Even when the object being occulted is a point source, the different patterns interfere with one another and the rapidly varying components of the resulting pattern are lost in much the same way that they are lost in the occultation of an extended source. The effect of the receiver's bandwidth, therefore, is to give the source a pseudo-diameter. It is impossible to obtain detail finer than this diameter.

The other limit is set by the signal-to-noise ratio of the original observation. Each attempt to reconstruct finer detail from the occultation record yields a poorer signal-to-noise ratio in the reconstruction. A point is eventually reached beyond which there is nothing to be gained by continuing the process. This second limit is the dominant one in most occultation measurements.

A minor limitation of the occultation method is that if different parts of a complex source are eclipsed at the same instant, no amount of reconstruction of the record will allow these parts to be distinguished. Fortunately, however, the direction in which the limb of the moon crosses the source when the source reappears, or when the source is occulted on another occasion, is unlikely to be the same. It will then be possible to separate the principal features of the source. A very complex source will still require a large number of occultation measurements for the interpretation of its intensity distribution.



COMPONENTS OF RADIO SOURCE 3*C* 273 are deduced to have this position and configuration on the basis of the moon occultations of August and October, 1962, observed by Cyril Hazard, M. B. Mackey and A. J. Shimmins with the 210-foot radio telescope at Parkes. The sides of the triangles represent the positions of the limb of the moon at the time of the occultations. The occultation measurements led to the identification of 3*C* 273 as the first of a new class of extremely compact galaxies of great brilliance, the quasi-stellar radio sources.

The first successful attempts to observe the occultation of a radio source seem to have been made in 1954 and 1955. During that period a series of occultations occurred of sources associated with two supernova remnants: the Crab Nebula and IC 443 (object No. 443 in the Index Catalogue of nebulae). The Crab Nebula, the remnant of the supernova seen on the earth in A.D. 1054, has a diameter of five minutes of arc. Because of its breadth it produces no diffraction fringes, and a fair picture of the brightness distribution across the source can be obtained by a simple analysis of the occultation curve. The interpretation of the occultation curve of IC 443, the remnant of an earlier supernova, is much more difficult because the source has an angular diameter of 50 minutes of arc, nearly twice the diameter of the moon.

In 1960 Cyril Hazard, now at Cornell University, used the 250-foot steerable radio telescope at Jodrell Bank to study occultations of the radio source 3*C* 212. He was able to measure the position of the source to within three seconds of arc and also to estimate its angular extent.

In 1962 Hazard, then at the University of Sydney, and M. B. Mackey and A. J. Shimmins of the CSIRO Radiophysics Laboratory, observed the occultations of the radio source 3*C* 273 that led to its identification with a visible object. They were able to observe both the disappearance and the reappearance on August 5 but only the disappearance on October 26 [*see illustrations on opposite page*]. At the time of reappearance on the latter date the moon was at a point too low in the sky to be reached by the telescope. It was clear from these observations, particularly those of October 26, that the source had two components. Further study revealed that the components, designated *A* and *B*, were separated by 19.5 seconds of arc [*see illustration above*]. This interpretation was supported by records obtained at three different frequencies: 1,410, 410 and 136 megacycles. These frequencies correspond respectively to wavelengths of 21, 73 and 220 centimeters.

Diffraction fringes were prominent in the occultation of component *B* at 1,410 megacycles but not in the occultation of component *A*, whereas fringes could be observed for both components at 410 megacycles. *B*, therefore, must be narrower than two seconds of arc, the scale of diffraction fringes at 1,410 megacycles. *A* is probably more extended than this but narrower than six seconds of arc, the scale of the pattern at 410 megacycles. Further comparison of the observations at the two frequencies showed that at 1,410 megacycles *B* is the stronger component, whereas at 410 megacycles *A* is the stronger. The ratio of intensities (B/A) decreases from 1.4 at 1,410 megacycles to .45 at 410 megacycles; it is therefore clear that the two components have very different spectra of radio frequencies. This is confirmed by the observations at 136 megacycles, where the B/A ratio falls to about .1.

Scheuer has reconstructed the distribution of intensity from some of these

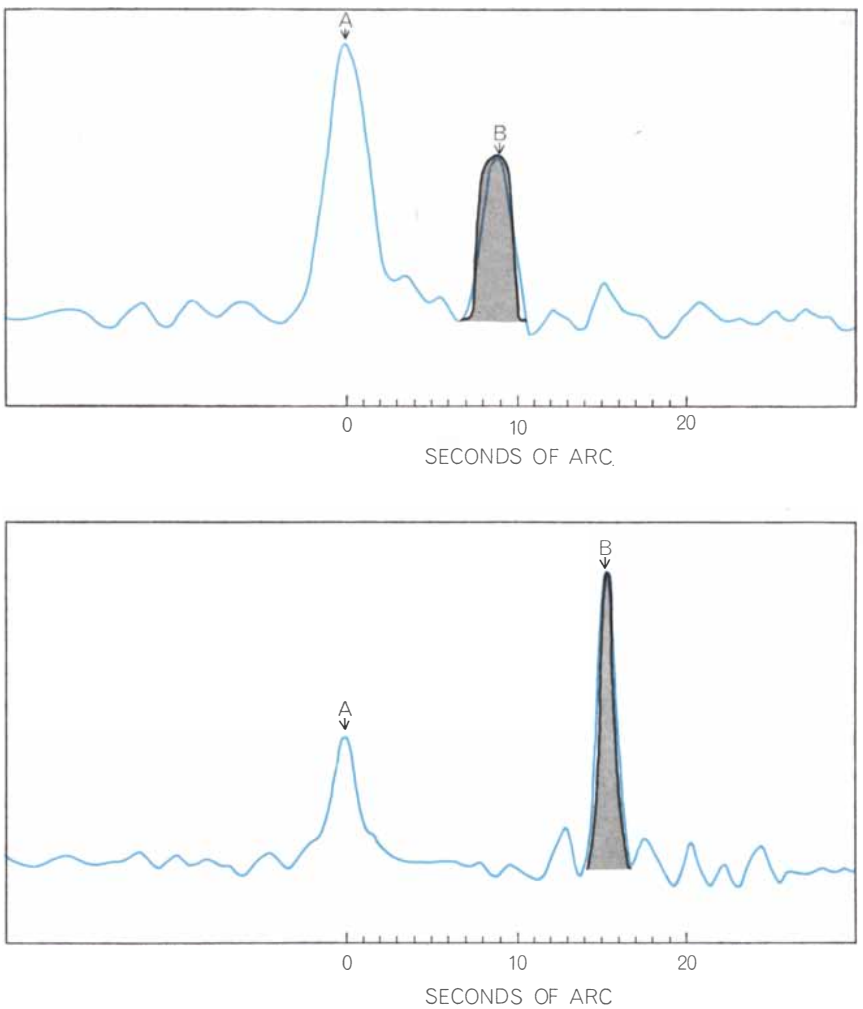
records with the method described earlier. He finds that when the outline produced by the smoothing function is approximately one second of arc wide, *B* is unresolved but the trace from *A* is broader than the theoretical outline [*see illustration below*]. The estimated true width of component *A* is 1.5 seconds of arc. If the smoothing function is modified to provide a narrower outline at 1,410 megacycles, it can be shown that the width of component *B* is about .5 second of arc.

As soon as the position of the source 3*C* 273 was available, it was sent to the astronomers at Palomar Mountain, who then undertook to use the 200-inch telescope to try to identify the source with a visible object. They found that component *B* appeared to coincide with a 13th-magnitude star and component *A* with the end of a jet that seems to issue from the star [*see illustration on opposite page*]. Measurements of the optical spectrum of the source by Maarten Schmidt showed that its emission lines are sharply shifted to the red end of the spectrum, indicating that 3*C* 273 is moving away at a velocity of 41,000 kilometers per second, or 14 percent of the speed of light. Because this speed is far greater than the velocities associated with stars moving within our galaxy, it seemed necessary to conclude that 3*C* 273 is outside the galaxy and taking part in the general expansion of the universe. If this were true, the object would be at a distance of 1.2 billion light-years and would be optically 100 times brighter than the large galaxies usually associated with radio sources. Thus 3*C* 273 was recognized as the first quasi-stellar radio source. Shortly thereafter another "star," 3*C* 48, was also identified as a quasar. Since then many more of these objects have been found; it is now believed they represent about 30 percent of all the extragalactic radio sources.

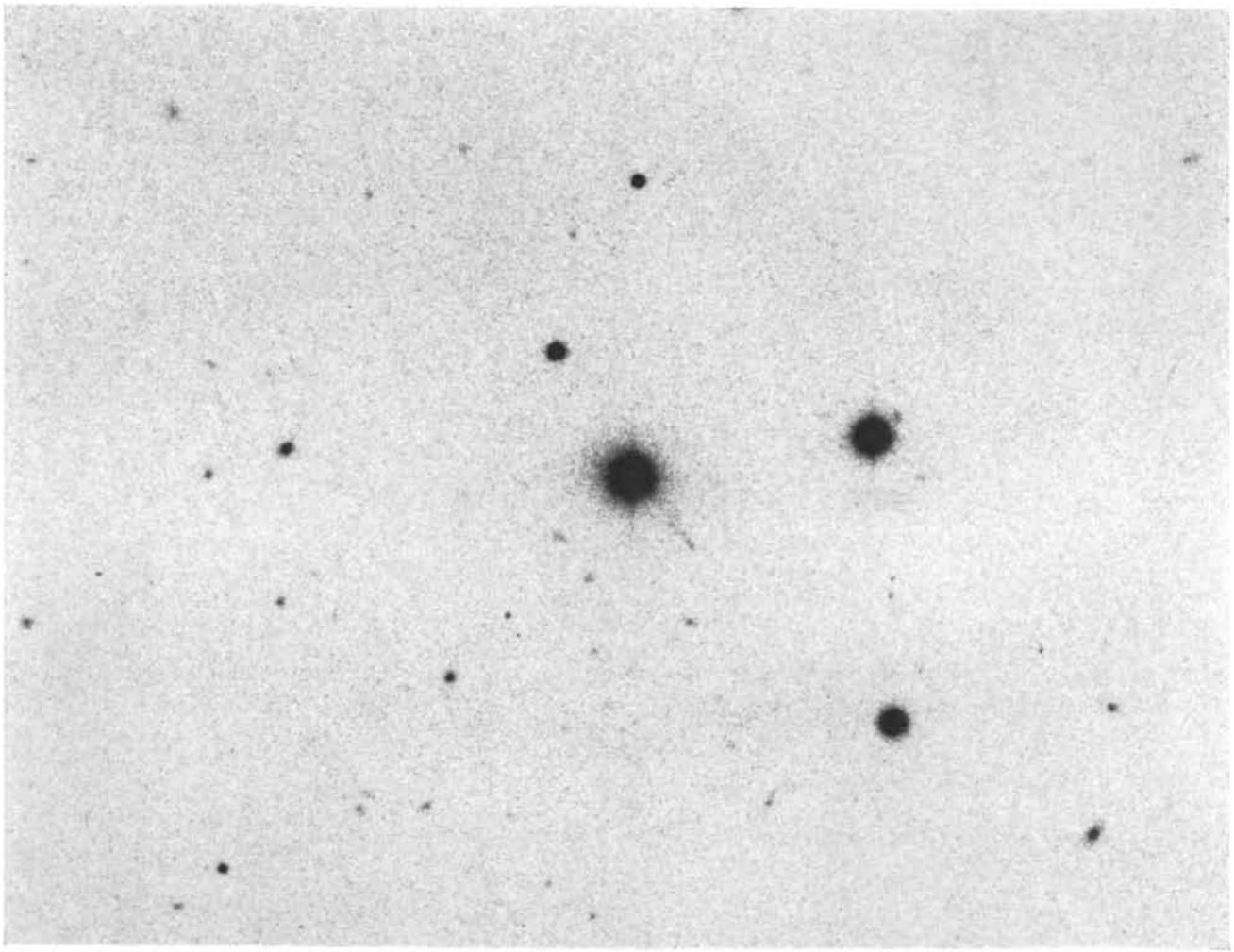
Quasars have been the subject of intensive study since 3*C* 273 was first identified. Because they are optically so bright quasi-stellar sources can be recognized at much greater distances than ordinary galaxies; they represent the most distant objects yet discovered. The farthest-known has a speed of recession of 82 percent of the speed of light, corresponding to a distance of about 10 billion light-years. Such distant objects are seen as they were billions of years ago, long before the solar system was formed. The study of them should tell much about the history of the universe and help to solve many outstanding problems in cosmology.

Occultation observations are now being made on a routine basis by a number of observatories. They should provide much useful data on the position and structure of radio sources, although it would be unreasonable to expect another discovery as significant as that of the quasi-stellar sources. The measurements should particularly provide important information on the relative positions of the components of a radio source and their associated visible features. Without occultation measurements it would have been difficult to determine that 3*C* 273 is a double source and to discover that one component is centered on the starlike object and the other on the jet.

Most of the occultations studied so far have been occultations of objects outside our galaxy, but there is increasing interest in occultations of radio sources within the galaxy. During the next few years the moon will pass close to the direction of the center of the galaxy; observers in the Northern Hemisphere can expect to see occultations of the center itself. The region around the galactic center has been closely studied by means of both the broad-band radio emission that extends over a wide range of frequencies and the discrete 21-centimeter wavelength line radiation emitted by hydrogen atoms. The recent discovery of 18-centimeter radiation from hydroxyl radicals (OH) in space has given further impetus to these studies [see "Hydroxyl Radicals in Space," by Brian



SMOOTHED OCCULTATION RECORDS OF 3*C* 273 were obtained with Scheuer smoothing functions. The intensity distribution at top was obtained by smoothing the disappearance of August 5, 1962, recorded at 410 megacycles. The bottom curve was derived from the disappearance of October 26, 1962, recorded at 1,410 megacycles. The profile that would be expected from a radio source of very small angular extent is shown in gray behind the peaks for 3*C* 273's *B* component. In both curves the *B* component fits within the theoretical profile of a very narrow source, whereas *A* is slightly wider. Further analysis showed that at 1,410 megacycles the angular size of *A* is .9 second of arc and of *B* .5 second of arc.



QUASI-STELLAR OBJECT 3*C* 273 appears in the center of this photograph made by Allan R. Sandage with the 200-inch Palomar telescope. Component *B* of the radio source coincides with the position of the quasi-stellar object itself. A faint elongated feature that looks like a narrow jet projects from the lower-right quadrant of the object. The *A* component of 3*C* 273 lies at the end of the jet.

J. Robinson; SCIENTIFIC AMERICAN, July, 1965]. The hydrogen and hydroxyl pictures of the galactic center differ in many respects, and one hopes that occultations will provide the increased positional accuracy that is necessary to resolve some of the problems. It is recognized, however, that because the sources may be of large angular extent, interpretation of the observations could be difficult.

The technique of observing occultations is not restricted to ground-based radio and optical astronomy. In July, 1964, occultation data were recorded from a rocket fired at White Sands in New Mexico. Earlier rocket flights had disclosed that there are several discrete sources of X rays in the sky and that the direction of one of them coincides with the direction of the Crab Nebula [see "X-ray Astronomy," by Herbert Friedman; SCIENTIFIC AMERICAN, June, 1964]. The rocket instruments were unable to show whether the X rays come from the entire nebula or from a point source located within it. An occultation of the Crab Nebula by the moon presented an opportunity to resolve the question. A rocket carrying X-ray detectors was fired to a height of 60 miles during the period in which the eclipse would occur.

The moon spends 12 minutes in occulting the entire Crab Nebula, but because rocket observations can be made only as the rocket soars above the atmosphere the observing period was limited to five minutes. The time of the observation was chosen to coincide with the period during which the center of the nebula would be occulted; this seemed to be the most likely location for a source of small diameter. It was found that the X rays were eclipsed in a period of two minutes. This was too long a time for the occultation of a point source but of course not as long a time as would be needed for the occultation of the entire nebula. It therefore seems that the source of X rays in the Crab Nebula is probably a gas cloud about one minute of arc in diameter, about a fifth of the total diameter of the nebula.

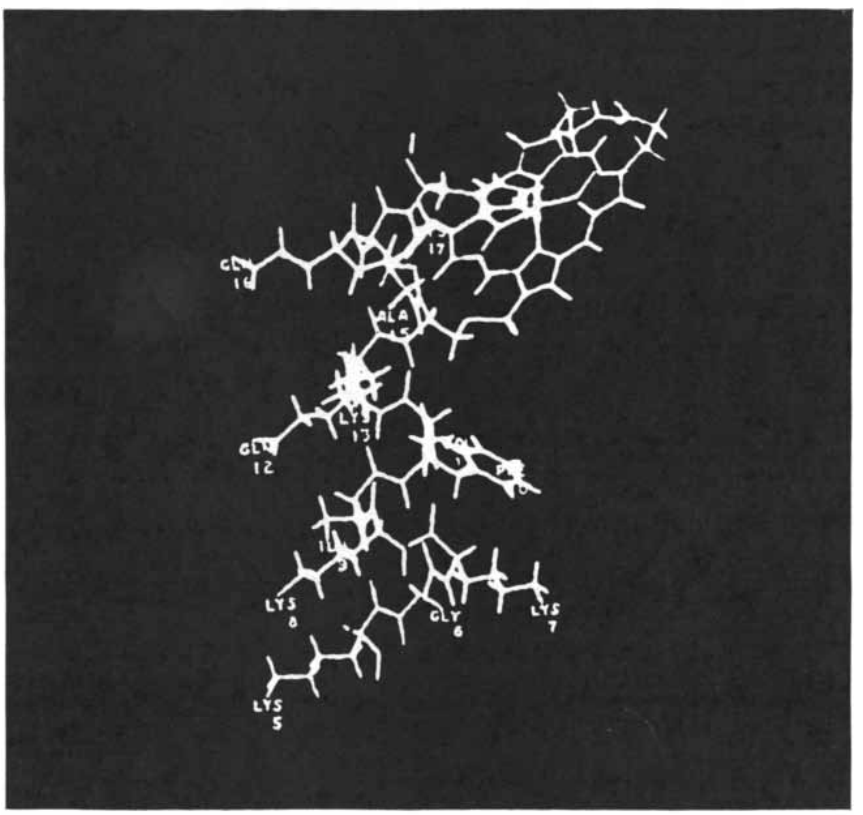
With the further development of large instrumented space vehicles the moon can be used to occult a radio source or any other celestial object no matter where the object may be located in the sky. Before such techniques can be fully exploited, however, one will need more precise information about the exact apparent shape of the moon when it is viewed from directions quite different from those to which we are accustomed on the earth. One can even imagine trajectories selected so that the space vehicle can spend many minutes or even hours cruising through the diffraction pattern, collecting the energy emitted by faint sources.

Molecular Model-building by Computer

In which biochemists observe models of giant molecules as they are displayed on a screen by a computer and try to fold them into the shapes that they assume in nature

by Cyrus Levinthal

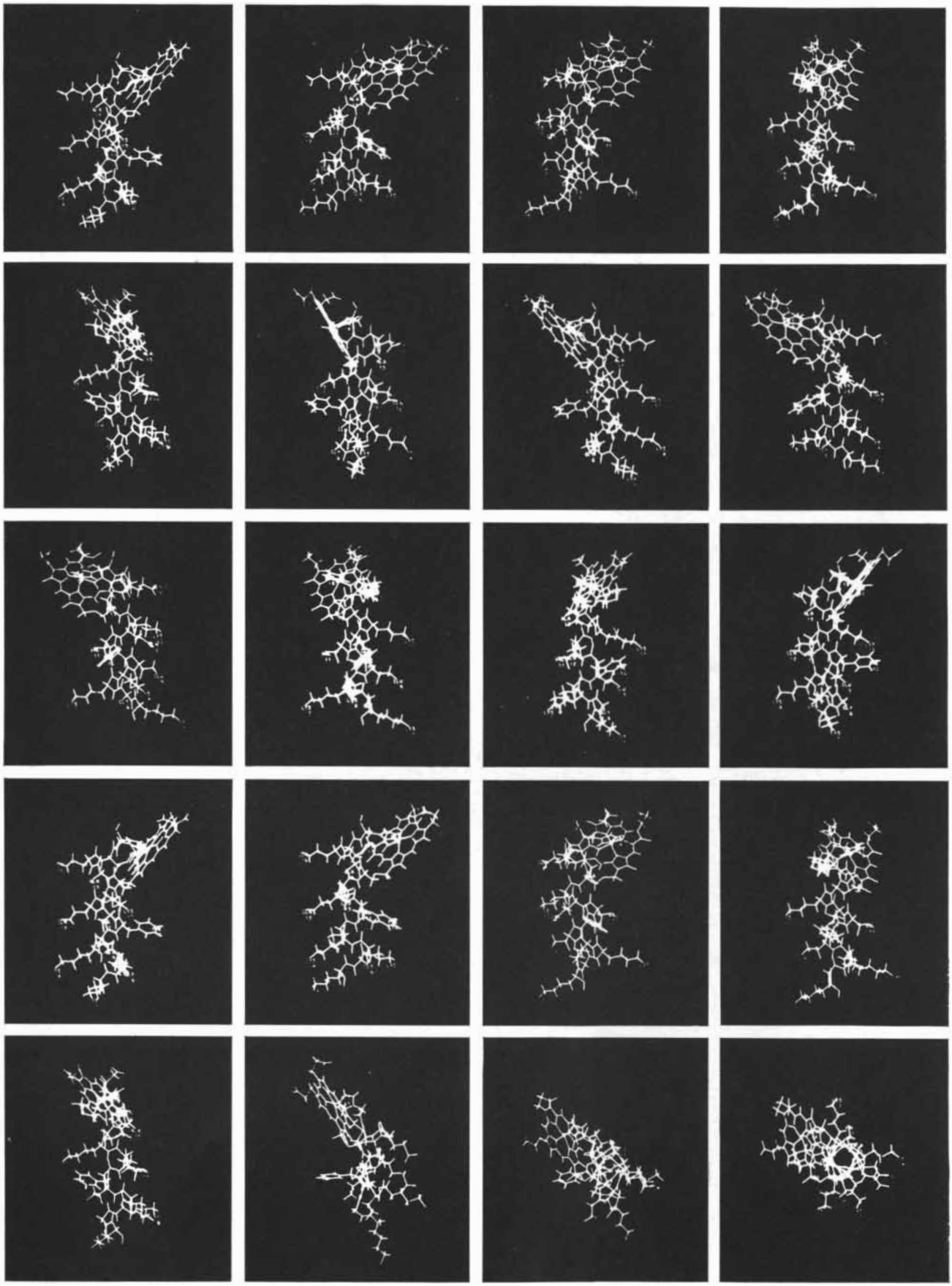
Many problems of modern biology are concerned with the detailed relation between biological function and molecular structure. Some of the questions currently being asked will be completely answered only when one has an understanding of the structure of all the molecular components of a biological system and a knowledge of how they interact. There are, of course, a large number of problems in biology into which biologists have some insight but concerning which they cannot yet ask suitable questions in terms of molecular structure. As they see such problems more clearly, however, they invariably find an increasing need for structural information. In our laboratory at the Massachusetts Institute of Technology we have recently started using a computer to help gain such information about the structure of large biological molecules.



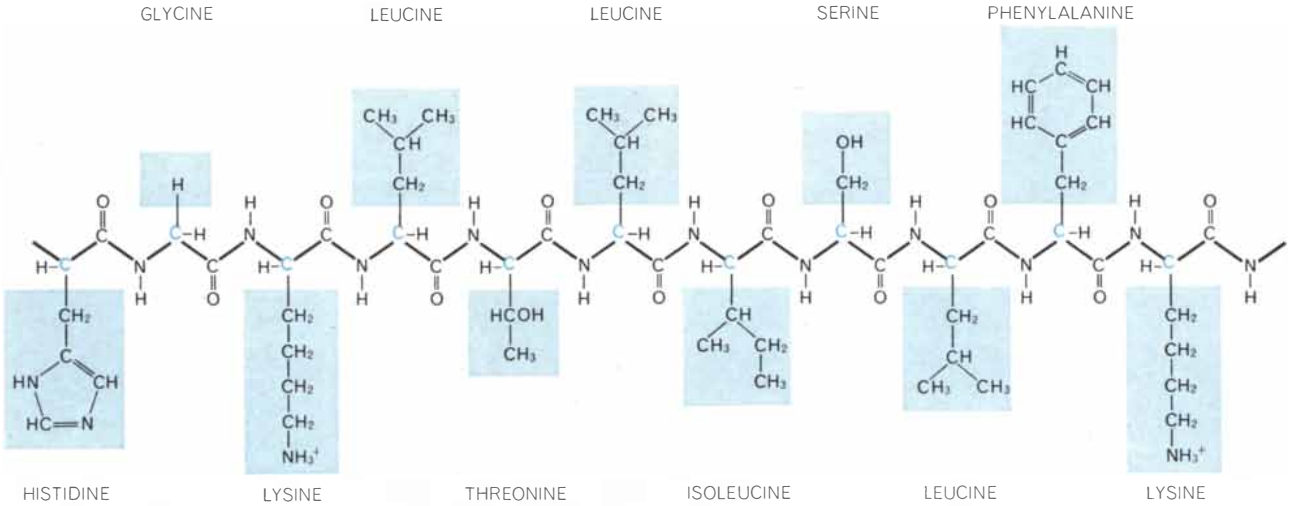
MOLECULAR MODEL of a segment of cytochrome *c*, a protein that plays an important role in cell respiration, is shown as it is displayed on an oscilloscope screen. The protein has 104 amino acid subunits; this segment consists of units 5 through 18 (designated here by their abbreviated names). The heme group, which acts as a carrier of electrons, is known to be attached to amino acids 14 and 17. In the hypothetical structure shown here this stretch of the molecule is assumed to be in the characteristic "alpha helix" configuration.

For the first half of this century the metabolic and structural relations among the small molecules of the living cell were the principal concern of biochemists. The chemical reactions these molecules undergo have been studied intensively. Such reactions are specifically catalyzed by the large protein molecules called enzymes, many of which have now been purified and also studied. It is only within the past few years, however, that X-ray-diffraction techniques have made it possible to determine the molecular structure of such protein molecules. These giant molecules, which contain from a thousand to tens of thousands of atoms, constitute more than half of the dry weight of cells. Protein molecules not only act as enzymes but also provide many of the cell's structural components. Another class of giant molecules, the nucleic acids, determine what kind of protein the cell can produce, but most of the physiological behavior of a cell is determined by the properties of its proteins.

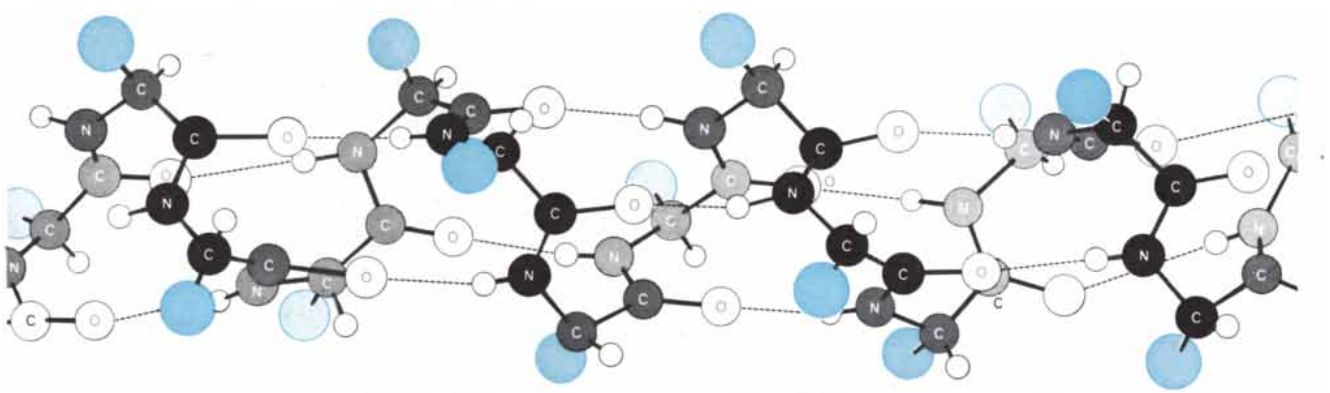
The X-ray-diffraction methods for investigating the three-dimensional structure of protein molecules are difficult and time-consuming. So far the structures of only three proteins have been worked out: myoglobin, hemoglobin and lysozyme [see "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew, SCIENTIFIC AMERICAN, December, 1961, and "The Hemoglobin Molecule," by M. F. Perutz, November, 1964]. In their studies of the hemoglobin molecule M. F. Perutz and his associates at the Laboratory of Molecular Biology in Cambridge, England, have observed that the structure of the molecule changes slightly when



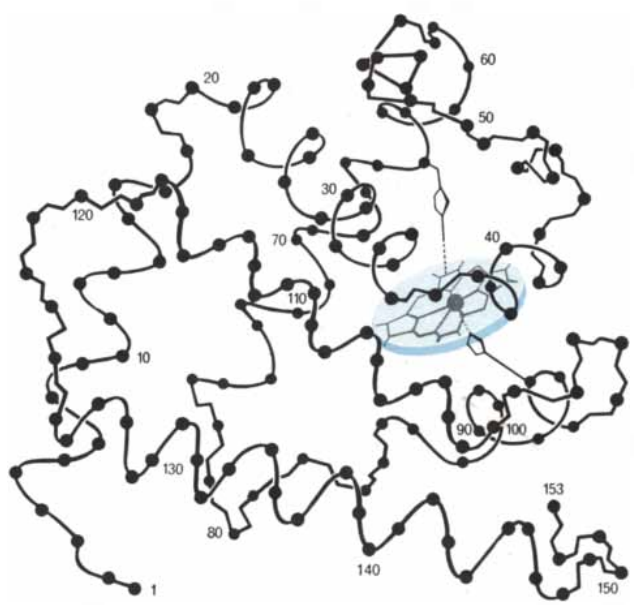
CYTOCHROME HELIX is rotated on the screen (*left to right, top to bottom*), a procedure that makes it possible for the investigator to perceive the three-dimensional arrangement of the atoms. A set of three-dimensional vectors connecting the atoms of the molecule is stored in the computer's high-speed memory. The computer calculates the projection of those vectors on a plane and draws the projected vectors on the screen. The operator controls the rotation of the plane, thus apparently turning the model.



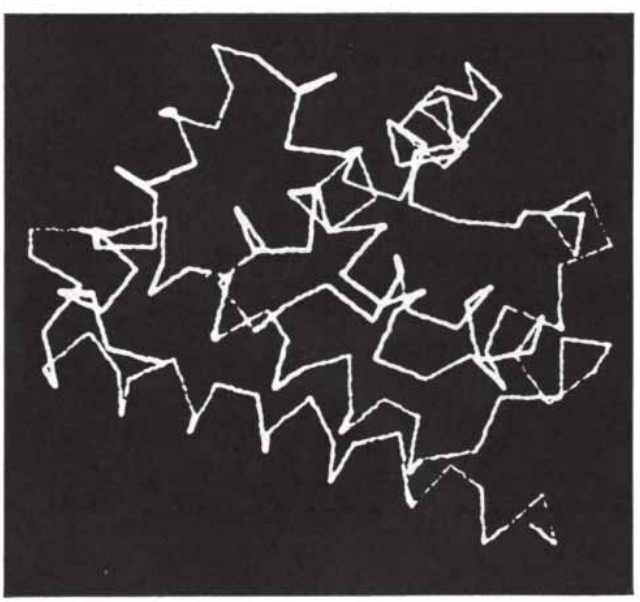
PROTEIN BACKBONE is a chain of peptide groups (six atoms: carbon, carbon, oxygen, nitrogen, hydrogen, carbon). Each amino acid in a chain contributes a group to the backbone and also has a distinguishing side group (*color tint*). The amino acid sequence of a number of proteins is known. What is shown here is a short segment of the protein myoglobin, which stores oxygen in muscle.



ALPHA HELIX results from the arrangement of planar peptide groups (CCONHC) pivoted about the carbons to which side groups (*color*) are attached. Shade of atoms indicates nearness to viewer. The entire helix is held rigid by hydrogen bonds (*broken lines*).



MYOGLOBIN MOLECULE is a folded, partly helical chain, as shown in drawing (*left*) of its form as determined through X-ray analysis by John C. Kendrew of the Laboratory of Molecular Biology in Cambridge, England. The chain enfolds an oxygen-carrying heme group (*colored disk*). Every 10th amino acid is numbered. The computer model of myoglobin is shown at right.

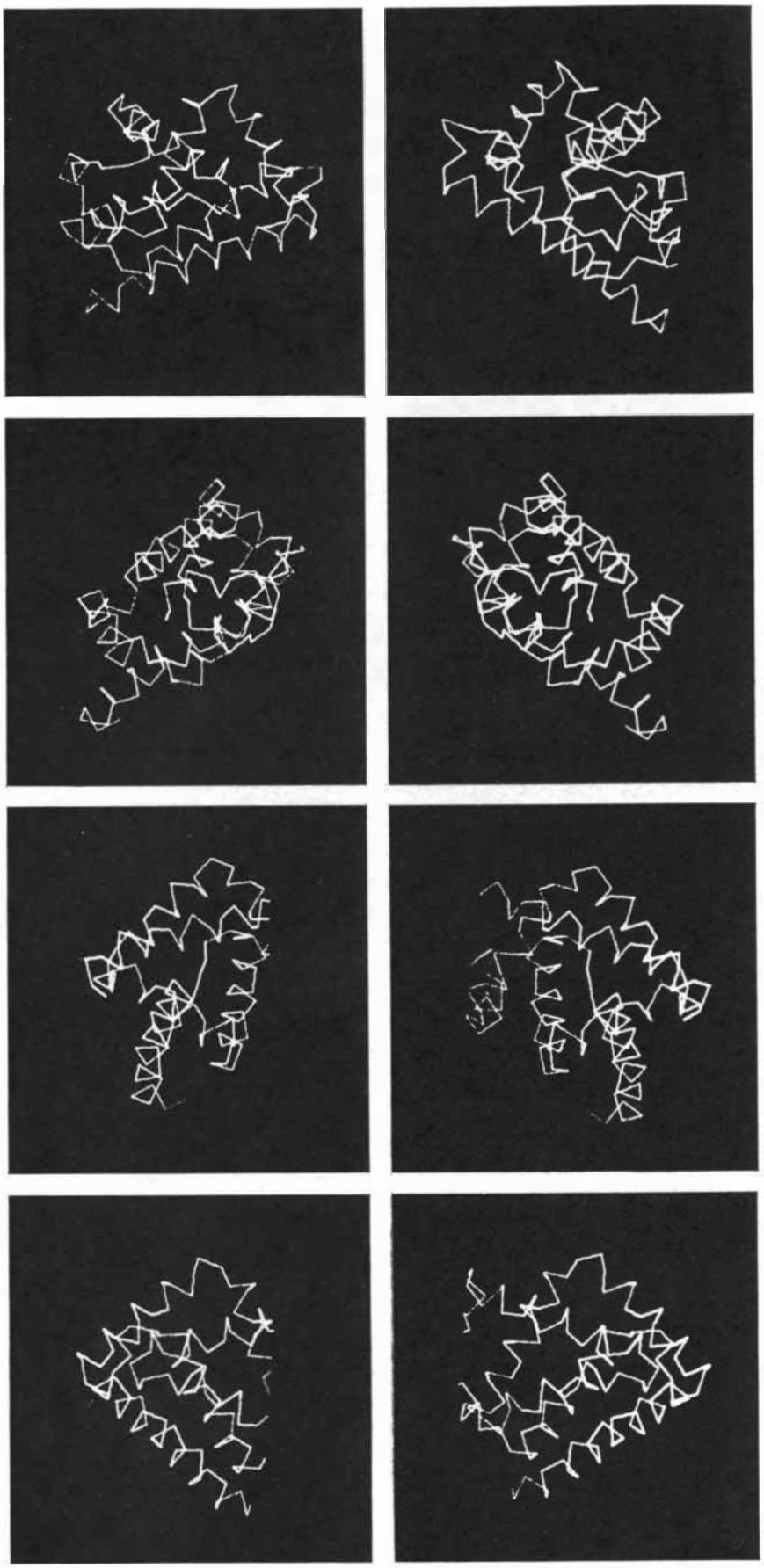


oxygen is attached to it or removed from it. The hemoglobin molecule is the only one for which this kind of study has as yet been carried out. It is known, however, that many proteins change their shape as they perform their functions and that their shape is further modified by the action of the small molecules that activate or inhibit them. The large number of enzyme systems involved in regulating the complex metabolic pathways of the living cell have been studied so far only at the level of the overall shape of the enzyme molecule; practically nothing is known of the specific structural changes that may be important for enzyme function and control.

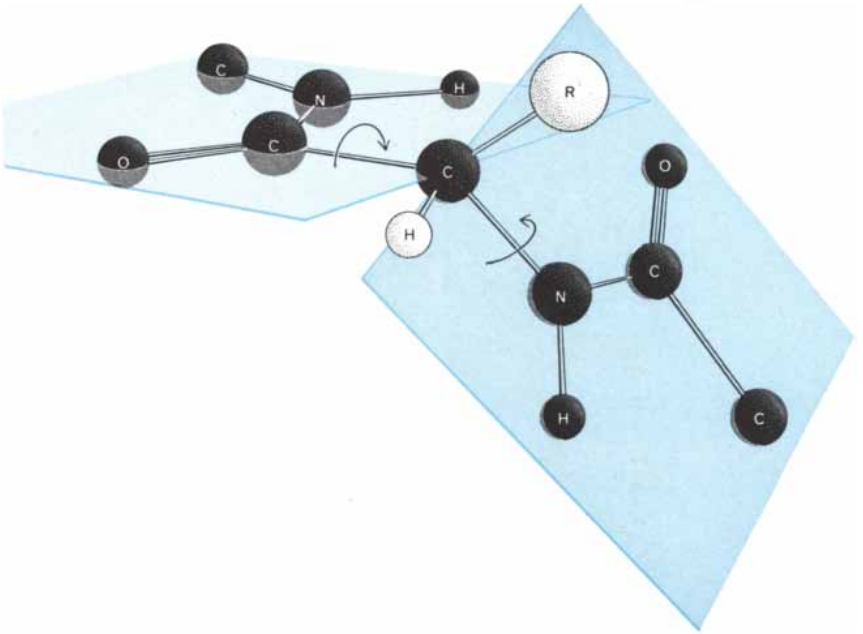
Another problem currently being investigated by many workers concerns the way in which proteins achieve their final three-dimensional configuration when they are synthesized. During the past few years many of the processes involved in protein synthesis have become rather well understood. As a result one knows, at least in general terms, how the cell determines the sequence of amino acids from which protein molecules are assembled and how this sequence establishes the way in which the atoms of a protein are connected [*see top illustration on opposite page*]. It is not, however, the chemical sequence, or connectedness, that establishes the functional properties of a protein. These properties are a consequence of the exact three-dimensional arrangement of the molecule's atoms in space.

As a result of work in the past 15 years, there is now a considerable body of evidence showing that the three-dimensional configuration of a protein molecule is determined uniquely by its amino acid sequence. The number of possible sequences is immense because the cell has at its disposal 20 kinds of amino acid building block. The configuration assumed by any particular sequence reflects the fact that the molecule arranges itself so as to minimize its total free energy. In other words, each protein has the shape it has because outside energy would be needed to give it any other shape. The experimental evidence for this conclusion comes from results obtained with many different proteins.

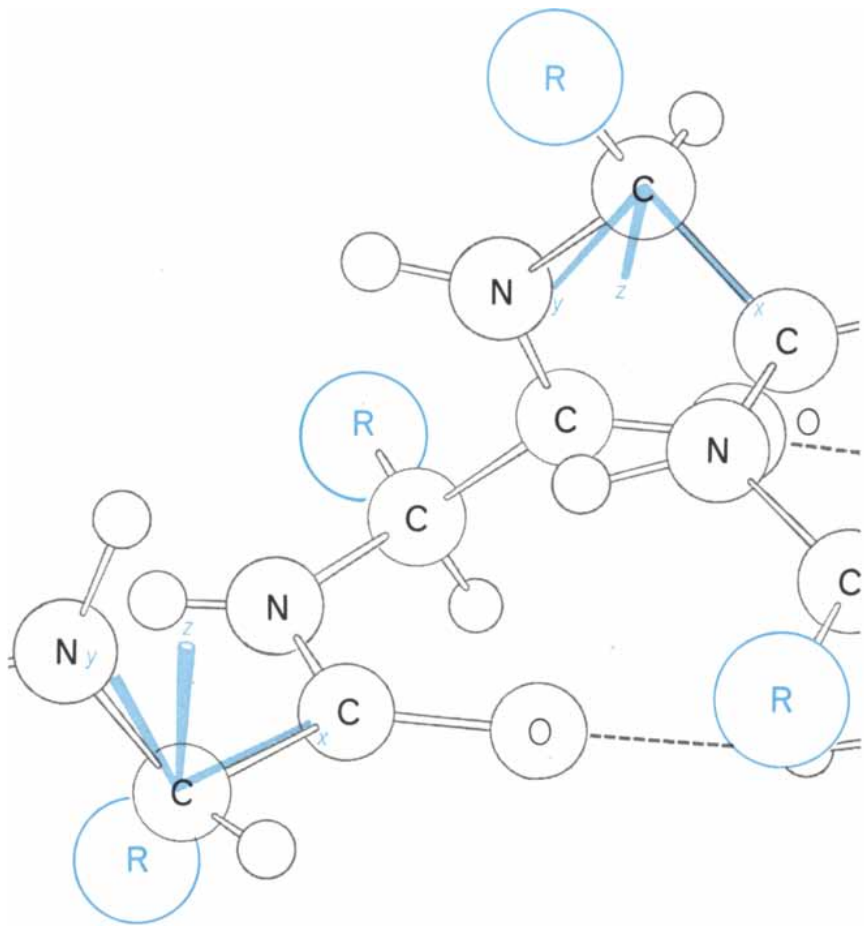
The first really critical experiments in this regard were carried out by Christian B. Anfinsen and his collaborators at the National Institutes of Health with the enzyme ribonuclease, a protein consisting of 153 amino acids



COMPUTER MODEL of myoglobin, which was based on coordinates supplied by Kendrew, is rotated on the screen in this sequence (*top to bottom, left to right*). This display omits the heme group. The pictures are selected frames from a 16-millimeter motion-picture film.



ROTATION ANGLES determine the relation of two successive peptide groups in a chain. Two such groups are shown here. The six atoms (CCONHC) of each group lie in a plane. Two adjacent planes have one atom—the carbon to which a hydrogen and a side group (*R*) are bonded—in common. Two rotation angles (*arrows*) give the relation of the two planes.



RECTANGULAR COORDINATE SYSTEMS establish the location of atoms in the model. One (*left*), at the amino end of the peptide chain, is the frame of reference for the entire chain. Others (*right*) are local systems defining positions of atoms in side groups. The computer calculates the transformation that refers local systems back to the original system.

in a single chain. In our laboratory we have studied the enzyme alkaline phosphatase, which consists of about 800 amino acids arranged in two chains. Both proteins can be treated so that they lose their well-defined three-dimensional configuration without breaking any of the chemical bonds that establish the connectedness of the molecule. In this "denatured" state the proteins are no longer enzymatically active. But if the denaturing agent is removed and the proteins are put in a solution containing certain salts and the correct acidity, the activity can be reestablished.

The alkaline phosphatase molecule has two identical subunits that are inactive by themselves. They can be separated from each other by increasing the acidity of the solution, and they reassemble to form the active "doublet" when the solution is made neutral once again. In addition the subunits themselves can be denatured, with the result that they become random, or structureless, coils. Under the proper conditions it takes only a few minutes to reestablish the enzymatic activity from this disrupted state, along with what appears to be the original three-dimensional configuration of the doublet molecule. An enzymatically active hybrid molecule can even be formed out of subunits from two different organisms. The individual subunits from the two organisms have different amino acid sequences, but they fold into a shape such that the subunits are still able to recognize each other and form an active molecule. These renaturation processes can take place in a solution containing no protein other than the denatured one, and without the intervention of other cellular components.

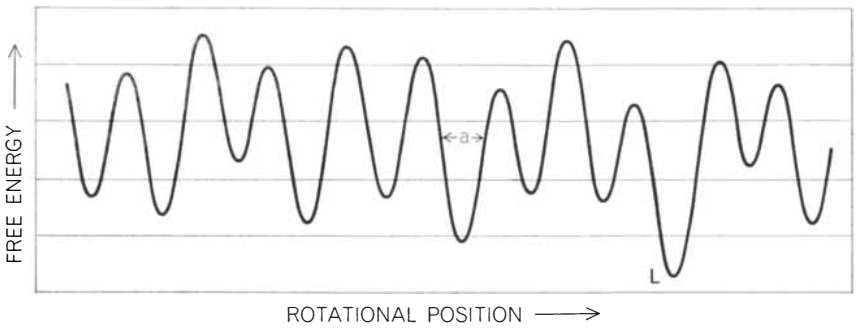
Apart from the renaturation experiments, the mechanism of synthesis has suggested an additional factor that may be relevant in establishing the correct three-dimensional form of the protein. It is known that the synthetic process always begins at a particular end of the protein molecule—the end carrying an amino group (NH_2)—and proceeds to the end carrying a carboxyl group (COOH). It is plausible to imagine that proteins fold as they are formed in such a way that the configuration of the amino end is sufficiently stable to prevent its alteration while the rest of the molecule is being synthesized. Although this hypothetical mechanism seems to be contradicted by the renaturation experiments just described, it may represent the way some proteins are folded. Because the mechanism would place certain constraints on the folding of a

protein molecule, it implies that the active protein is not in a state in which free energy is at a minimum but rather is in a metastable, or temporarily stable, state of somewhat higher energy.

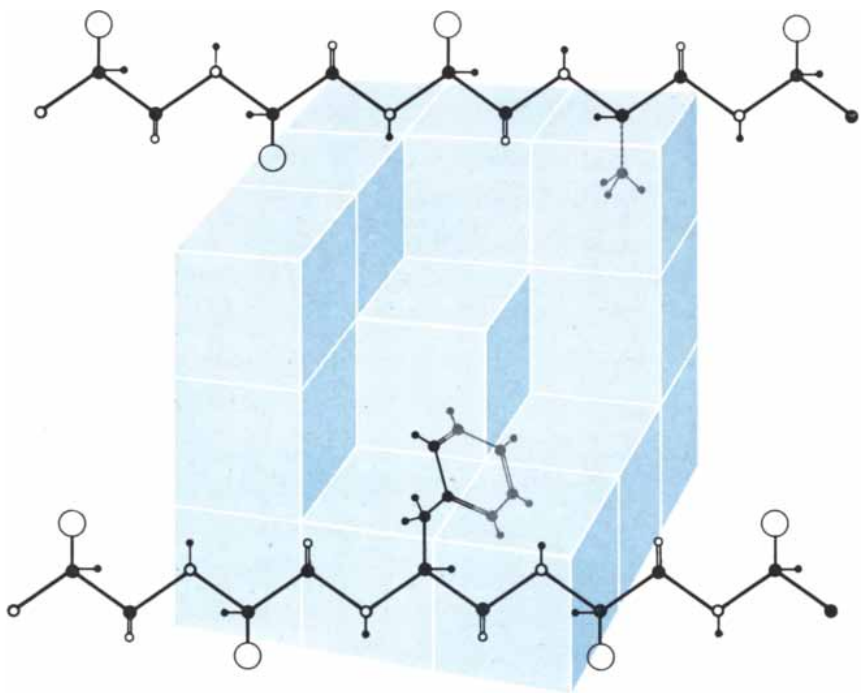
A molecular biologist's understanding of a molecular structure is usually reflected in his ability to construct a three-dimensional model of it. If the molecule is large, however, model-building can be frustrating for purely mechanical reasons; for example, the model collapses. In any event, the building of models is too time-consuming if one wishes to examine many different configurations, which is the case when one is attempting to predict an unknown structure. When one is dealing with the largest molecules, even a model is not much help in the task of enumerating and evaluating all the small interactions that contribute to the molecule's stability. For this task the help of a computer is indispensable.

Any molecular model is based on the nature of the bonds that hold particular kinds of atoms together. From the viewpoint of the model-builder the important fact is that these bonds are the same no matter where in a large molecule the atom is found. For instance, if a carbon atom has four other atoms bonded to it, they will be arranged as if they were located at the corners of a tetrahedron, so that any two bonds form an angle of approximately 109.5 degrees. The lengths of bonds are even more constant than their angles; bonds that are only one to two angstrom units long are frequently known to be constant in length with an accuracy of a few percent. In general the details of atomic spacing are known from the X-ray analysis of small molecules; this knowledge simplifies the task of building models of large molecules.

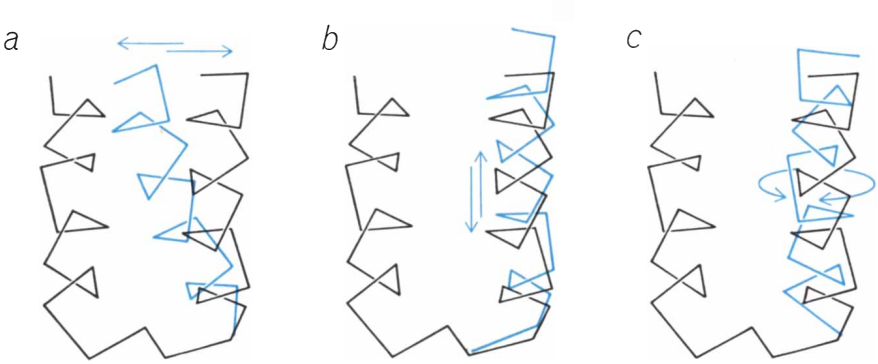
An example of the value of such knowledge was the discovery by Linus Pauling and Robert B. Corey at the California Institute of Technology that the fundamental repeating bond in protein structures—the peptide bond that joins the CO of one amino acid to the NH of the next—forms an arrangement of six atoms that lie in a plane. This knowledge enabled them to predict that the amino acid units in a protein chain would tend to become arranged in a particular helical form: the alpha helix. It was subsequently found that such helixes provide a significant portion of the structure of many protein molecules. Thus in advance of any crystallographic information about the structure of a particular protein molecule, one knows



TOTAL ENERGY of a configuration varies with distance between atoms, which depends on all the rotation angles. It is easy to distinguish lowest-energy point *L* from local valleys, or metastable states, by visual inspection, but a computer must calculate each point in the curve, repeating the operation often enough not to miss a valley. It must calculate the energy at angles separated by no more than a small fraction of the interval indicated as *a*.



CUBING PROCEDURE eliminates unnecessary computation by identifying atoms that are sufficiently near each other to affect the molecule's energy. The computer searches the area around an atom residing in the center cube and reports if there are any atoms in the 26 adjacent cubes. This also helps to reveal a molecule's edges and holes inside it.



MANIPULATION of the computer-built model is accomplished by three different routines. The routine called "close" in effect puts a spring between any pair of points indicated by the investigator (*a*). The routine "glide" causes a single helical region to be pulled along its own axis (*b*). "Revolve" imposes a torque that rotates a region about its axis (*c*).

the spatial arrangement of atoms within the peptide bonds, as well as the detailed geometry of its alpha-helical regions.

The planar configuration of the peptide bond allows an enormous reduction in the number of variables necessary for a complete description of a protein molecule. Instead of three-dimensional coordinates for each atom, all one needs in order to establish the path of the central chain of the molecule are the two rotation angles where two peptide bonds come together [*see top illustration on page 46*]. The complete description requires, in addition to this information, the specification of the rotation angles of the side chains in those amino acids whose side chains are not completely fixed.

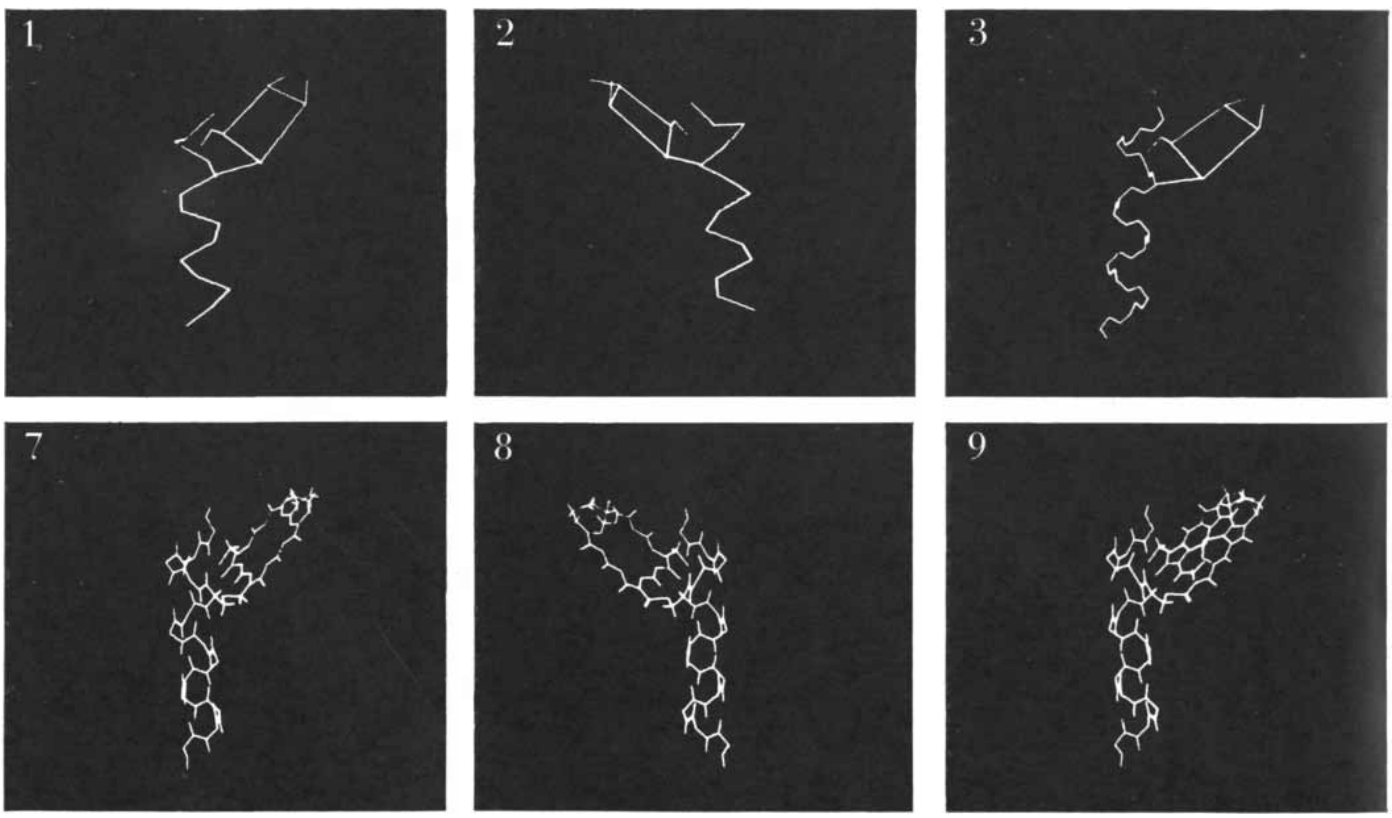
A further reduction in the number of variables would be possible if one could predict from the amino acid sequence which parts of the molecule are in the form of alpha helixes. The few proteins whose structures have been completely determined provide some indication of which amino acids are likely to be found in helical regions, but not enough is yet known to make such predictions with any assurance.

Because protein chains are formed by linking molecules that belong to a single class (the amino acids), the linkage process can be expressed mathematically in a form that is particularly suited for a high-speed digital computer. We have written computer programs that calculate the coordinates of each atom of the protein, using as input variables only those angles in which rotational changes can occur; all other angles and bond lengths are entered as rigid constraints in the program. The method of calculation involves the use of a local coordinate system for the atoms in each amino acid unit and a fixed overall coordinate system into which all local coordinates are transformed.

The transformation that relates the local coordinate systems to the fixed coordinate system is recalculated by the computer program each time a new atom is added to the linear peptide backbone. Each chemical bond is treated as a translation and a rotation of this transformation. The process requires a substantial amount of calculation, but each time the backbone reaches the central atom of a new amino acid the relative positions of the side-group atoms can be taken from the computer memory where this information is stored for each of the 20 varieties of amino acid. It is then a simple matter to translate and rotate the side-group atoms from their local coordinate system into the fixed-coordinate system of the entire molecule.

The new value of the transformation at each step along the backbone is determined by the fixed rotation angles and translation distances that are built into the computer program and by the variable angles that must somehow be determined during the running of the program. The principal problem, therefore, is precisely how to provide correct values for the variable angles. A number of investigators are working on this problem in different ways. Before discussing any of these approaches I should emphasize the magnitude of the problem that remains even after one has gone as far as possible in using chemical constraints to reduce the number of variables from several thousand to a few hundred. Because each bond angle must be specified with an accuracy of a few degrees, the number of possible configurations that can result when each angle is varied by a small amount becomes astronomical even for a small protein. Moreover, these small rotations can produce a large effect on the total energy of the structure [*see top illustration on preceding page*].

One way to understand the difficulty



CYTOCHROME *C* segment seen in the two opening illustrations is shown on this page and the opposite page in the various degrees of detail of which the system is capable. At first only the carbon atoms to which the side groups are attached are displayed, along with the

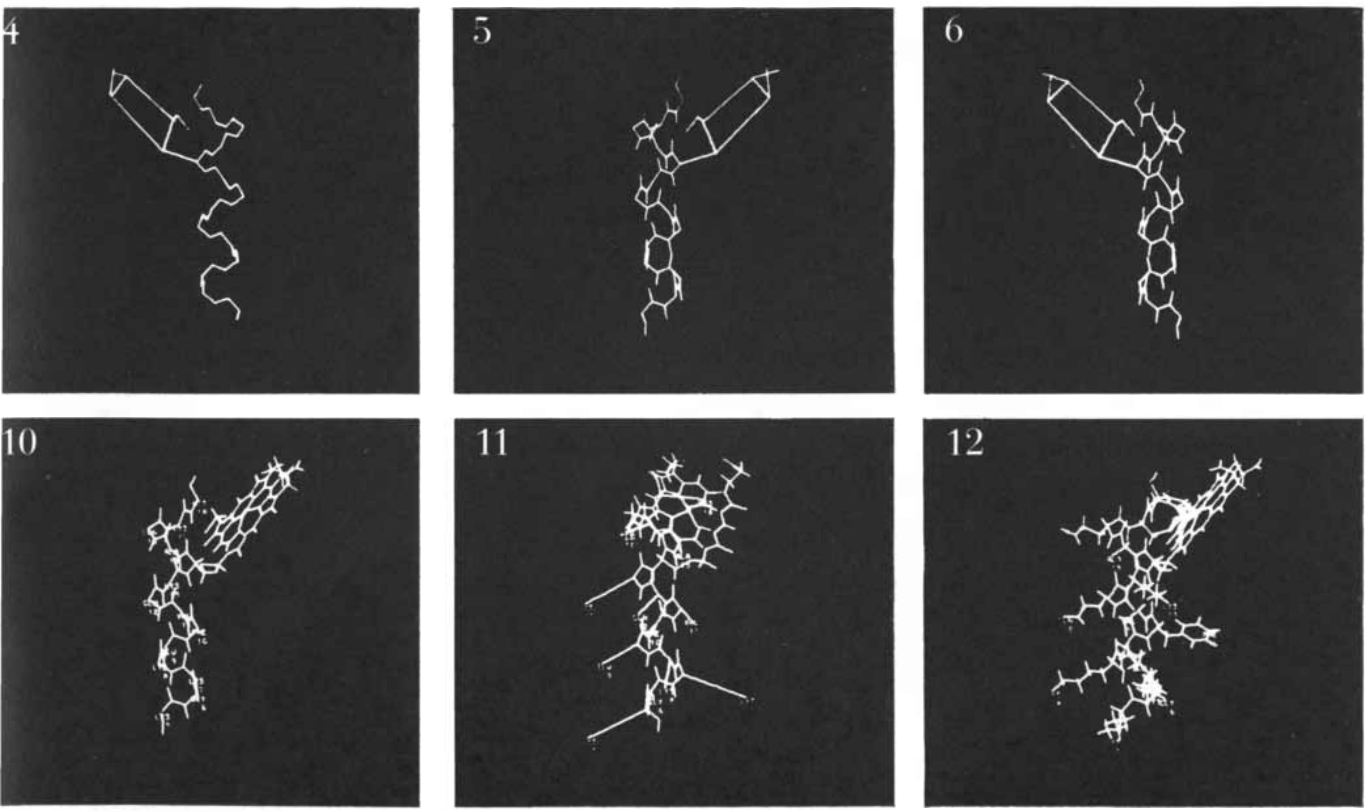
of finding a configuration of minimum energy is to imagine the problem facing a man lost in a mountainous wilderness in a dense fog. He may know that within a few miles there is an inhabited river valley leading into a calm lake. He may also know that the lake is at the lowest point in the area, but let us assume that he can only determine his own elevation and the slope of the ground in his immediate vicinity. He can walk down whatever hill he is standing on, but this would probably trap him at the bottom of a small valley far from the lake he seeks. In finding a configuration of minimum energy the comparable situation would be getting trapped in a metastable state far from a real energy minimum. Our lost man has only two dimensions to worry about, north-south and east-west; the corresponding problem in a molecule involves several hundred dimensions.

Our approach to this problem has assumed that even sophisticated techniques for energy minimization will not, at least at present, be sufficient to determine the structure of a protein from its amino acid sequence in a fully automatic fashion. We therefore decided to develop programs that would make use of a man-computer combination to do a kind of model-building that neither a man nor a computer could accomplish alone. This approach implies that one must be able to obtain information from the computer and introduce changes in the way the program is running in a span of time that is appropriate to human operation. This in turn suggests that the output of the computer must be presented not in numbers but in visual form.

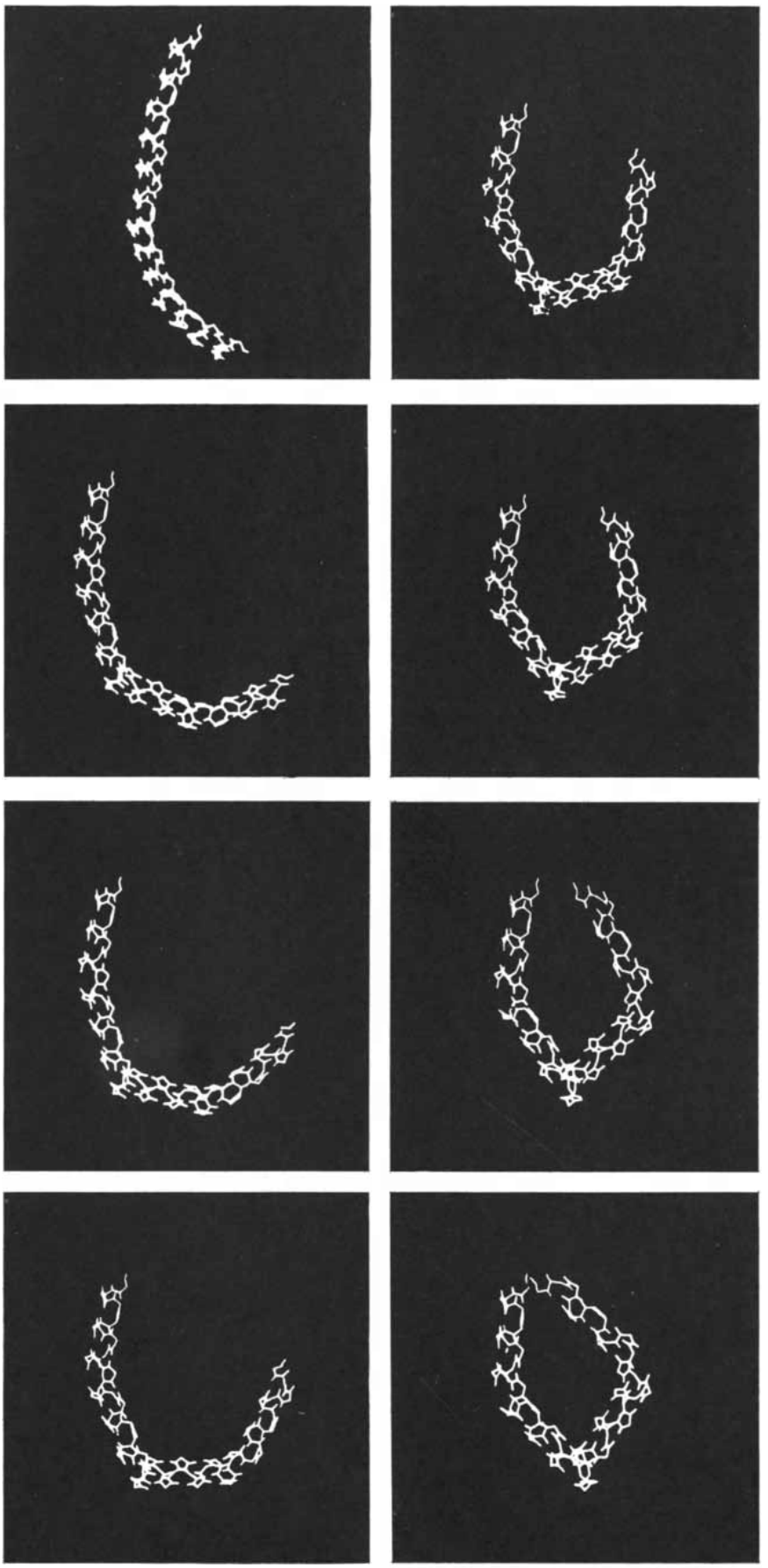
I first became aware of the possibilities of using visual output from a computer in a conversation with Robert M. Fano, the director of Project MAC at the Massachusetts Institute of Technology. (MAC stands for multiple-access computer.) It soon became clear that the new types of visual display that had been developed would permit direct interaction of the investigator and a molecular model that was being constructed by the computer. All our subsequent work on this problem has made use of the large computer of Project MAC, which operates on the basis of "time-sharing," or access by many users. The system, developed by Fernando J. Corbatō, allows as many as 30 people to have programs running on the computer at the same time. For all practical purposes it seems to each of them that he is alone on the system. A user can have any of his data in the high-speed memory printed out on his own typewriter, and he can make whatever changes he wants in this stored data. What is more important from our point of view is the ability to make changes in the commands that control the sequential flow of the program itself.

It is true, of course, that one of 30 users has access to a computer that, when it is fully occupied, has only a thirtieth of the speed of the normal machine, but for many problems this is enough to keep the man side of the man-machine combination quite well occupied. The program that acts to supervise the time-sharing system is organized in such a way that no user can interfere with the system or with any other user, and the computer is not allowed to stand idle if the man takes time out to think.

In working with molecular models we are interested in being able to obtain data quickly in order to evaluate the effect of changing the input variables of the program. For any particular molecular configuration the computer can readily supply the positions (in the three-dimensional coordinates x, y and z) of all the atoms. The important question is: What can be done with 5,000 to 10,000 numbers corresponding to the



square outline of the heme group connected to this segment (*1, 2*). The other atoms of the backbone are added (*3, 4*), then the oxygen and hydrogen atoms (*5, 6*). The heme group is shown in more detail (*7–9*), and side groups are named (*10*) and displayed (*11, 12*).



"CLOSING" ROUTINE is applied to a hypothetical peptide chain assumed to consist of several helical sections. The individual sections do not bend, but the rotation angles between sections are changed (*top to bottom, left to right*) to close the chain into a circle.

position of every atom in even a small protein? Obviously if we could formulate specific questions concerning energy, bond angles and lengths, overall shape, density and so on, the computer could calculate the answer and there would be no need for a man ever to look at the numerical values of the coordinates. We realized that our best hope of gaining insight into unexpected structural relations—relations that had not been anticipated—lay in getting the computer to present a three-dimensional picture of the molecule.

Although computer-controlled oscilloscopes have been available for about 10 years, they have been used mainly to display numbers and letters. It is only recently that they have been used to produce the output of computer programs in graphical form. The oscilloscope tube can of course present only a two-dimensional image. It is no great trick, however, to have the computer rotate the coordinates of the molecule before plotting their projection. If this is done, the brain of the human viewer readily constructs a three-dimensional image from the sequential display of two-dimensional images. Such sequential projections seem to be just as useful to the brain as simultaneous stereoscopic projections viewed by two eyes. The effect of rotation obtained from the continuously changing projection nonetheless has an inherent ambiguity. An observer cannot determine the direction of rotation from observation of the changing picture alone. In the Project MAC display system, designed by John Ward and Robert Stotz, the rate of rotation of the picture is controlled by the position of a globe on which the observer rests his hand; with a little practice the coupling between hand and brain becomes so familiar that any ambiguity in the picture can easily be resolved.

In evaluating the energy of a particular configuration of a protein molecule one must add up all the small interactions of atomic groups that contribute to this energy. These must include interactions not only between the different parts of the protein molecule but also between the parts of the protein molecule and the surrounding water molecules. If we are interested in altering the configuration in the direction of lower energy, we must be able to calculate the derivative of each of the energy terms—that is, the direction in which the energy curves slope—as changes are made in each of the rotation angles. Accordingly we must calcu-

late a very large number of interatomic distances and the derivative of these distances with respect to the allowed rotation angle.

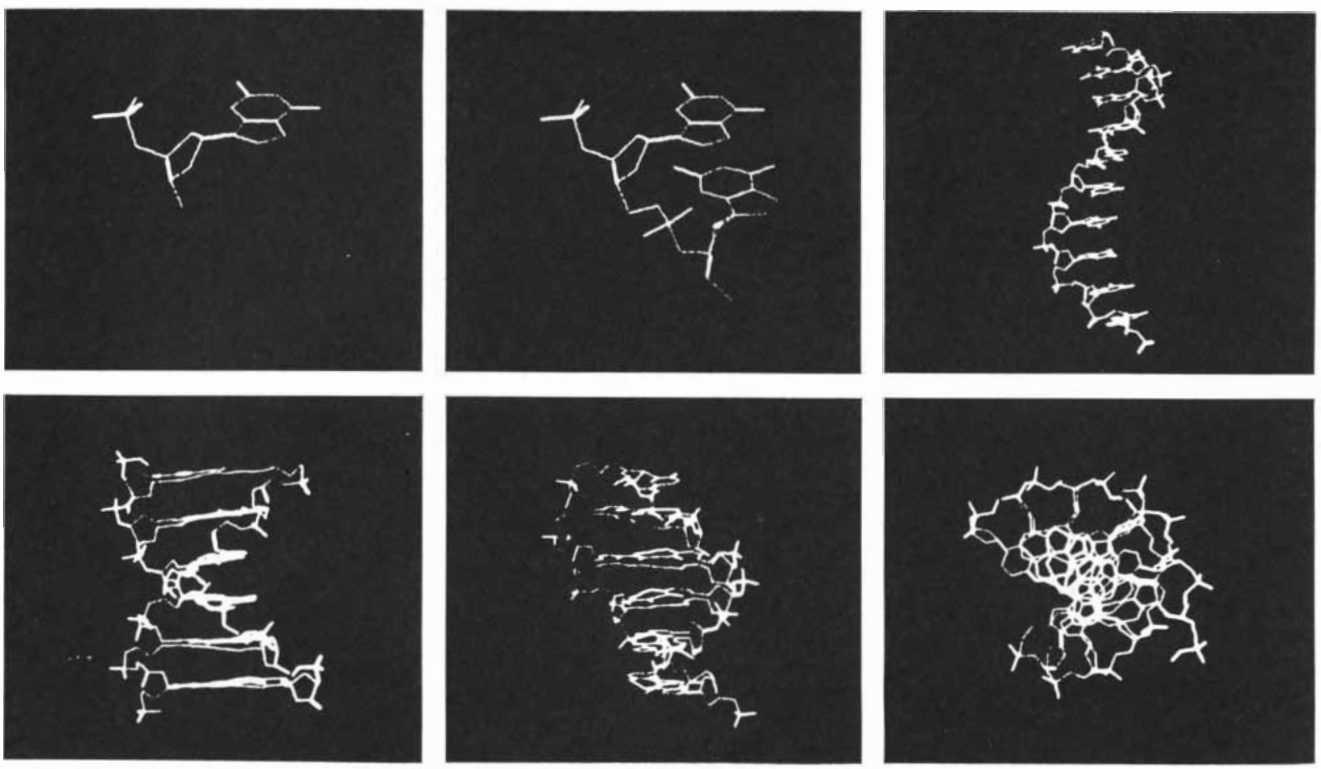
The derivatives can be calculated, however, without going through the extended transformation calculations needed to generate the coordinates themselves. The rotation around any chemical bond will cause one part of the molecule to revolve with respect to another. If both members of a pair of atoms are on the same side of the bond being altered, the rotation will not give rise to a change in their distance. If the two atoms are on opposite sides of the rotating bond, one of the atoms will move in a circle around the axis of rotation while the other remains stationary. By analyzing the geometry of this motion we can simplify the derivative calculations to the point where they require very little computation.

Even though each of these derivative calculations can be done in a few hundred microseconds of computer time, there would still be an excessive amount of calculation if it were done for all possible pairs of atoms within the molecule. Fortunately the interactions with which we are concerned are short-range ones, and most of the pairs of atoms are too far apart to contribute appreciably to the overall energy. In order to select out all pairs of atoms that are close to each other, we have developed a procedure called cube-testing. All the space in the region of the molecule is divided into cubes of some predetermined size, let us say five angstroms on an edge (two or three times the typical bond length) and each atom is assigned to a cube. To consider the interactions involving any given atom one need only determine the distance between this atom and all others in the same cube and in the 26 surrounding ones [*see middle illustration on page 47*]. Although the procedure is still time-consuming, it is much faster than having to do calculations for all possible pairs of atoms in the molecule.

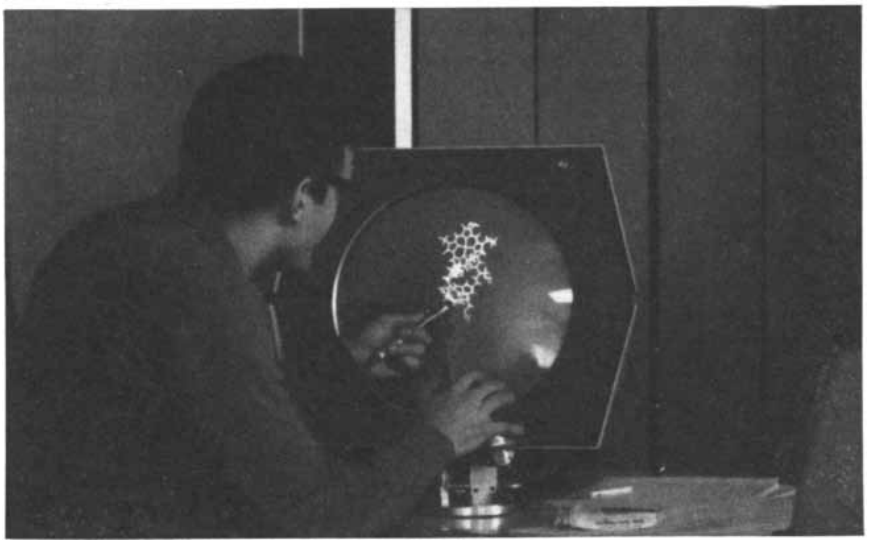
In addition to enabling us to screen the data for close pairs, the cubing procedure provides information about which groups in the protein molecule can interact with the surrounding water molecules. In order to enumerate such interactions, we first define the "insideness" and "outsideness" of the molecule, outsideness meaning that a particular atom or group of atoms is accessible to the surrounding water and insideness that it is not. If we examine the cubing pattern for a particular molecule, an atom on the outside would be in a cube that is surrounded on one side by filled cubes and on the other by empty ones. In a similar way we can detect holes in the midst of the structure by looking for empty cubes that are surrounded on all sides by filled ones.

By suitable use of derivative calculation and cubing we can alter any configuration of the molecule in the direction of lower energy. This procedure, however, would almost certainly lead to a structure that is trapped in one of the local minima—one of the higher valleys of our wilderness analogy—and may not even be close to the true minimum-energy configuration we are looking for. For a real molecule floating in solution, the local minima would not represent traps because the normal thermal vibration of the molecule and its parts supplies enough energy to move the structure out of any valley that is not a true minimum.

Although there are various ways in which one can use random elements in a computer calculation to simulate thermal vibration, it is our experience that an investigator who is looking at the molecule can frequently understand the reason for the local minimum and by making a small alteration in the structure can return the program to its



DEOXYRIBONUCLEIC ACID (DNA) is modeled by a program devised by Robert Langridge and Andrew A. MacEwan of the Children's Cancer Research Foundation and Harvard Medical School. This DNA sequence (*left to right, top to bottom*) begins with a single nucleotide: a pentagonal sugar plus a phosphate group and a base. A second nucleotide is added, and then more to make a helical chain that joins with a second chain to form the characteristic double helix. Then the helix is rotated in space.



DISPLAY UNIT designed by John Ward and Robert Stotz has access to the large time-shared central computer at the Massachusetts Institute of Technology. The investigator communicates with the computer by typing commands or punching preset buttons on a keyboard or by pointing with the light pen. He regulates the direction and the speed of rotation of the model by moving the gimbaled control on which his right hand rests.

downhill path. Such alterations can be accomplished in the computer by changing the program in such a way as to introduce pseudo-energy terms that have the effect of pulling on parts of the structure. A few simple subprograms that introduce the appropriate pseudo-energies enable us to do the same kind of pulling and pushing in the computer that we can do with our hands while building actual models.

Pulling a structure by means of these pseudo-energy terms is also useful for building a model that observes all the chemical constraints and at the same time has its atoms as close as possible to the positions indicated by X-ray diffraction studies. In this case the pseudo-energies can be regarded as springs pulling designated atoms to their experimentally determined positions. Such calculations have been carried out by Martin Zwick, a graduate student at M.I.T., in order to make a model of myoglobin fit the configuration determined from X-ray data by John C. Kendrew and Herman Watson at the Laboratory of Molecular Biology in Cambridge. For this type of problem a helpful procedure has been developed by William Davidon of Haverford College. In his program one starts by "walking" in the direction of the steepest slope, but with each successive step one builds up information as to how the slope of the hillside changes.

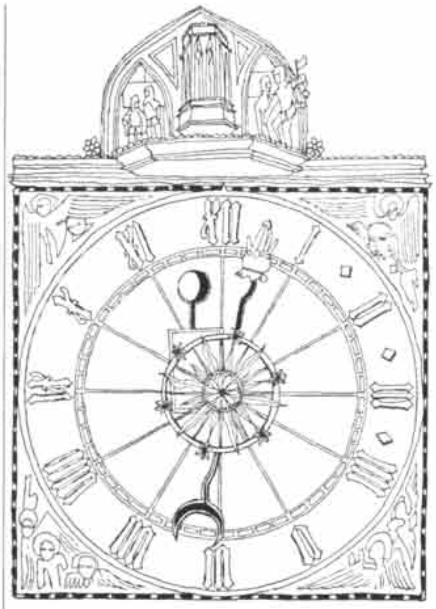
Once we had produced a computer model of myoglobin, we could ask questions concerning the relative importance of short-range forces acting between various parts of the molecule. There are, for example, Van der Waals forces: electrostatic attractions due to the electric dipoles that all atoms induce in one another when they are close together. There are also electrostatic interactions that arise from the permanent electric dipoles associated with the peptide bonds. The permanent dipole attractions turned out to be larger than we had expected. It is thus possible that the electrostatic interaction between different regions of a protein may play a substantial role in stabilizing its structure. This results in part from the fact that the electric dipoles in an alpha helix are added to one another along the direction of the axis. For this reason two helixes that wind in the same direction will repel each other and two that wind in opposite directions will attract each other. In myoglobin the overall effect is a substantial attractive force. This calculation requires some form of model-building, because the electrically charged regions are associated with the C—O and N—H groups along the backbone, and the hydrogen atom is not detected in the X-ray analysis.

Although the electrostatic interaction energy is of the same order of magnitude as that required to denature a protein, it is probably not the dominant energy for the folding of a protein molecule. The primary source of energy for this purpose probably comes from the interaction of the amino acid side chains and the surrounding water; the electrostatic interactions may do no more than modify the basic structure.

We still have much to learn about the magnitude of the various energy terms involved in holding a protein molecule together. Meanwhile we have been trying to develop our computer technique, using the knowledge we have. Is this knowledge enough to enable us to find the lowest energy state of a protein molecule and to predict its structure in advance of its determination by X-ray analysis?

The answer to this question probably depends on how well we understand what really happens when a protein molecule in a cell folds itself up. Our work has been based on the hypothesis that the folding starts independently in several regions of the protein and that the first structural development is the formation of a number of segments of alpha helix. Our assumption is that these segments then interact with one another to form the final molecular structure. In this method of analyzing the problem the units that have to be handled independently are the helical regions rather than the individual amino acids. Thus the number of independent variables is greatly reduced. The success of the procedure depends, however, on the assumption that we can deduce from the amino acid sequence alone which regions are likely to be helical. It is not necessary, however, that we guess the helical regions correctly the first time; we can see what happens when helical regions are placed in many different parts of the molecule. Several other groups working on this problem are following the hypothesis that the folding proceeds only from the amino end of the protein. Until one of these approaches succeeds in predicting the structure of a protein and having the prediction confirmed by X-ray analysis, we can only consider the different hypotheses as more or less plausible working guides in studying the problem.

It is still too early to evaluate the usefulness of the man-computer combination in solving real problems of molecular biology. It does seem likely, however, that only with this combination can the investigator use his "chemical insight" in an effective way. We already know that we can use the computer to build and display models of large molecules and that this procedure can be very useful in helping us to understand how such molecules function. But it may still be a few years before we have learned just how useful it is for the investigator to be able to interact with the computer while the molecular model is being constructed.



SCIENCE AND

The Sexual-Response Study

The first volume of findings from a unique 11-year study of the human sexual response, published in April, contains hitherto unavailable physiological data and reveals a number of gaps between the realities of sexual behavior and widely held beliefs about it. The study, directed by William H. Masters and Virginia E. Johnson of the Reproductive Biology Research Foundation in St. Louis, was begun in 1954 at the Washington University School of Medicine, where Masters works in the department of gynecology and obstetrics. The investigators both observed and recorded with instruments the responses of 694 volunteers (382 female and 312 male) during more than 7,500 female and 2,500 male orgasms, induced by natural and artificial coitus and by automanipulation and mechanical manipulation. The female volunteers ranged in age from 18 to 78; the males from 21 to 89. Many were married couples.

Masters and Mrs. Johnson assert that psychosocial elements are "certainly the primary influence" in sexual response. They confine the present volume to physiological findings that may be useful to physicians counseling patients with sexual problems. They recorded the variations in their subjects' heartbeat, blood pressure and breathing rate from the onset of sexual excitement through orgasm to subsequent relaxation. Among their discoveries are that (1) a distinctive change in the color of the labia minora is a regular prelude to female orgasm; (2) vaginal lubrication, heretofore attributed to substances exuded from the Bartholin glands or the cervix of the uterus, is instead provided by a mucoid "sweat" of the vaginal walls that appears within seconds after the initial sexual stimulus; (3) the comparative duration and intensity of orgasm, both among different subjects and in the same subjects, demonstrates that male and female sexual responses differ in that the female is capable of repeated orgasms without intervals of relaxation, whereas the male is not.

Misconceptions corrected by the study include the belief that there is a correlation between the dimensions of the clitoris or the penis and the individual's sexual capacities. Masters and Mrs. Johnson also discovered, in the course of their studies involving automanipulation, that few females consistently engage in stimulation of the clitoris by direct contact. The male who accepts "marriage manual" advice to use this means of stimulating the female, they conclude, is doing something that most females have found more irritating than stimulating.

Among the misconceptions that apply to males the authors find "probably more firmly entrenched in our culture than any other" the fear that middle age is inevitably accompanied by sexual inadequacy. Among their subjects this was not the case with men who had consistently maintained sexual activity; their 89-year-old subject was sexually competent. They also found no basis for the belief that a high frequency of ejaculation (up to four times a day in the study) can cause mental or physical deterioration.

Masters and Mrs. Johnson plan a second volume on the psychosocial aspects of the sexual response, together with monographs on such topics as the treatment of sexual inadequacy and sexual guidelines for cardiac patients and pregnant women.

Circumlunation

Luna 10, the 540-pound Soviet spacecraft that was placed in orbit around the moon on April 3, has transmitted a number of significant findings. Perhaps the most important is that the moon's surface emits gamma rays similar to those emitted by granites at the

surface of the earth. This implies that the moon was once molten or semi-molten, and that heavy substances could sink as lighter ones rose to the surface. The components of the moon's crust, like those of the earth's crust, would be relatively rich in such radioactive elements as uranium, thorium and potassium, which give rise to gamma rays. If this fractionation had not taken place, the radioactive elements would be distributed more or less uniformly throughout the moon, and the emission of gamma rays at the surface would be much weaker than what was observed.

Other measurements made by *Luna 10* show that it is being bombarded by micrometeorites at a rate 100 times higher than the rate observed in interplanetary space. *Luna 10* also detected energetic electrons at the time of the full moon, when the sun, the earth and the moon were in a line. It seems likely that the electrons originated in the earth's radiation belts and were blown out to the vicinity of the moon by the solar wind. *Luna 10*'s magnetometer has reported the presence of a weak but regular magnetic field. A Soviet investigator said that "it could be the moon's own magnetic field, an interplanetary magnetic field of solar origin or the 'tail' of the earth's magnetic field."

Vaccine for German Measles

Success in preliminary tests of a vaccine made from an attenuated live strain of the rubella virus, the causative agent of what was once deemed a trivial childhood disease, was announced at the April meeting of the American Pediatric Society in Atlantic City by Paul D. Parkman and Harry M. Meyer, Jr., physicians in the U.S. Public Health Service. The virulent effect of rubella, or "German measles," on unborn children was not recognized until 1941, when the Australian ophthalmologist Norman McA. Gregg was able to relate cases of cataract in children to their mothers' history of rubella early in pregnancy. Contraction of the disease in the first three months of pregnancy is now grounds for therapeutic abortion. An epidemic of rubella that swept the U.S. between 1963 and 1965 is conservatively estimated to have caused no fewer than 20,000 fetal deaths and to

have been responsible for defects in the eyes, heart, ears or central nervous system of 30,000 children born during that period.

Earlier live-virus rubella vaccines immunized the recipients by producing a mild case of German measles. Each recipient could infect anyone who was not immune; the risk to expectant mothers was too great to allow general use of such vaccines. The Parkman-Meyer preparation has been used to inoculate 34 children; these children developed immunity while remaining in the company of 30 other children who were susceptible to rubella. In spite of their prolonged contact with the inoculated children, none of the 30 was infected.

Justifiable Pain

A state law prohibiting "unnecessary cruelty" to animals does not bar experiments on living animals in high schools, a New Jersey judge has ruled. In a precedent-setting decision Judge Charles S. Barrett, Jr., held that "if there is a truly useful motive, a real and valid purpose," animals may be treated in ways that are ostensibly cruel or ostensibly cause pain.

The case involved an experiment conducted in 1964 by a 17-year-old East Orange High School biology student who injected four chickens with Rous sarcoma virus. Two of the chickens developed tumors and died. The two survivors were exhibited at a science fair. The New Jersey Society for the Prevention of Cruelty to Animals then filed an action against the East Orange Board of Education under an 1880 statute concerning cruelty to animals. One part of the statute exempts from its provisions "properly conducted scientific experiments" authorized by the State Department of Health, which may authorize such experiments in specified kinds of institutions—not including high schools, argued the S.P.C.A. The law goes on to make it unlawful to "needlessly mutilate or kill" an animal or "inflict unnecessary cruelty." The S.P.C.A. held that live-animal experimentation in itself constitutes unnecessary cruelty and that the state legislature intended to limit all animal experimentation to authorized institutions.

Judge Barrett disagreed. The legislature had not intended to require authorization for all animal experimentation, he wrote; its exempting provision merely designated certain institutions that could remove themselves from any prosecution for cruelty to animals. Other institutions "may conduct living-animal experiments" if they do not specifically violate the provisions on cruelty to animals. "Cruelty," the judge wrote, "to my mind is the unjustifiable infliction of pain with the act having some malevolent or mischievous motive"; educational and scientific achievements could be qualities that would justify the inflicting of pain on animals.

Genetic Code in Three Dimensions

Now that the "dictionary" of the genetic code has essentially been worked out, biochemists have been trying to discover patterns in the relation between particular code groups and the amino acids they specify. British workers have recently found evidence that the various code "words"—each a sequence of three nitrogenous bases in a molecule of nucleic acid—have a three-dimensional structural relation with the amino acids for which they are known to code. Amino acids are of course the building blocks of protein molecules; the particular sequence of amino acids specified by the genetic code gives each kind of protein molecule its distinctive character.

The finding of a lock-and-key relation between code groups and amino acids may help to explain why the genetic code is universal. It would be hard to explain otherwise why mutations had not altered the code in the long evolutionary process that separated man from one-celled organisms. At the same time the finding of a lock-and-key relation comes as something of an embarrassment to existing models of the mechanism of protein synthesis, which make no provision for a structural fit between the three bases of a code group, or codon, and its designated amino acid.

The structural studies of codons and amino acids is reported in a recent issue of *Nature* by S. R. Pelc and M. G. E. Welton of the Medical Research Council Biophysics Research Unit in London. They built models of the various amino acids and codon triplets using "space-filling" plastic atoms, which closely simulate the dimensions of actual atoms. For example, they would examine the fit between a model of the amino acid asparagine and a model of its codon triplet formed by two adenine units and a cytosine unit (the codon designated AAC). They considered the fit satisfactory if they could demonstrate that the amino acid and its triplet would form at least four chemical bonds without undue strain or distortion. They found that 90 percent of the codon–amino acid complexes required by the genetic code would bond in this manner without creating undue strain. They were also able to show in general that structural fitting could not be achieved for complexes of codons and amino acids that violated the genetic code.

These findings suggest that the structural fit between codon and amino acid almost certainly plays an important role in the mechanism of protein synthesis. Exactly what that role is remains obscure.

Retroactive Birth Control

A pill that halts pregnancy after conception has been announced by John McL. Morris and Gertrude van Wagenen of the Yale University School of Medicine. Morris and Miss van Wagenen told a meeting of the American Fertility Society that the pill, if taken by a woman within six days after sexual relations, prevents implantation of the fertilized ovum in the uterus. Implantation normally occurs on the sixth or seventh day after fertilization.

Morris, a professor of gynecology, and Miss van Wagenen, a lecturer in obstetrics and gynecology, began research in postintercourse birth-control drugs several years ago under a grant from the Population Council of New York. Morris said the objective was a drug that was nontoxic and fully effective and did not produce any fetal abnormality if taken in marginal doses or at the wrong time after sexual relations. The first drug to meet those standards as tested in rabbits and monkeys, he said, was ORF-3858, a carboxylic acid derivative developed by the Ortho Research Foundation. Because ORF-3858 does not yet have the approval of the Food and Drug Administration for use in humans, the Yale investigators undertook some limited testing of women with the hormone diethylstilbestrol. This too was effective in arresting pregnancy after conception, Morris said, but it showed some aftereffects that may make it unsuitable for continued use. He added that some drugs other than ORF-3858 and diethylstilbestrol also had been tested successfully. "Which of these different compounds will eventually reach the market I do not know," he said, "but a number of them have a great deal of promise."

Steel from Idle Resources

A technique that may make large quantities of unexploited iron ore usable in steelmaking and also clear some of the accumulations of junked

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SYLVANIA

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automobiles from the countryside is being developed by metallurgists of the U.S. Bureau of Mines. The process is described in a report by M. M. Fine and Charles Prasky of the bureau's Twin Cities Metallurgy Research Center in Minneapolis; the report is entitled "Magnetic Roasting of Iron Ores with Ferrous Scrap." In the process nonmagnetic taconite, an iron ore difficult to use in steelmaking, is roasted with steel scrap in such a way that both materials are changed to the readily usable magnetic ore magnetite. Thus made magnetic, the material is suitable for the magnetic separators used to exclude some of the nonmetallic material from an iron ore before the ore is used in a steelmaking process. Nonmagnetic taconite is abundant as an ore and junked automobiles are abundant as scrap, so that a steelmaking process employing these materials would utilize resources that are now mostly idle.

Two factors motivated the research that led to the new process: first the declining reserves of magnetic ore, and secondly the increase in the number of junked automobiles as improvements in steelmaking have reduced the need for scrap. The key to the taconite-scrap process is in chemical changes that occur during roasting. Nonmagnetic taconite is nonmagnetic because it contains too much oxygen; scrap metal, because of its high iron content, is a good reducing agent. Hence if the nonmagnetic taconite is roasted with ferrous scrap, some of the oxygen is removed from the taconite and it becomes magnetic. Moreover, the scrap itself is converted into magnetite. Fine and Prasky say that "theoretically one pound of iron metal will reduce 11.5 pounds of nonmagnetic iron oxide (Fe_2O_3) and itself be converted to 1.4 pounds of magnetic iron oxide (Fe_3O_4) for a total of almost 13 pounds of magnetite."

Science of Science

In the past few years the concept of a new scientific discipline has been evolving in the hands of a small group composed of scientific investigators, scientific administrators and journalists. The discipline would be "the science of science," or "the examination of the phenomenon of science by the methods of science itself." Its advocates suggest that there are many existing branches of scholarship that can contribute to the analysis of science and that they show signs of cohering in a whole that is greater than the sum of its parts. The new discipline, says one of its proponents, "might be called 'history, philosophy, sociology, psychology, economics, political science and operations research (etc.) of science, technology, medicine (etc.).' " In a recent article in the British journal *The Technologist* J. D. Bernal and A. L. Mackay of the University of London further define the science of science and speculate on what it might accomplish.

Bernal and Mackay write: "Science must examine itself." Why must it do so? Because, they assert, there is a need to learn how science works and make it work better. The proportion of available resources devoted to science has been steadily increasing; such increases cannot continue indefinitely in the developed countries and are impossible in the underdeveloped ones. Accordingly "the strategy of the deployment of limited resources needs practical study." The preconditions for a science of science now exist, Bernal and Mackay suggest, because there is enough science to be studied statistically and enough case histories have accumulated so that their common elements can be recognized and classified. Science operates in enough different cultural and economic environments for its special characteristics in various environments to be identified. Moreover, science itself is providing the tools with which to establish new connections and syntheses that make possible the analysis of complex phenomena.

Typical science-of-science investigations are being conducted by Derek J. de Solla Price and his colleagues at Yale University. In one study they are analyzing the structure of "invisible colleges": informal groups of investigators in a small field of study who collaborate, communicate with and criticize one another. For a second study they have developed a computer method for analyzing a "matrix" of cross citations in technical journals.

The new field of study was institutionalized in 1964 by the formation in London of the Science of Science Foundation, with Bernal and Price among the members of an advisory council, and with Maurice Goldsmith, a British science writer, as director. In addition to promoting investigation in areas ranging from "the analysis of the flow of scientific information" to "the relationship between science and technology," the foundation hopes to encourage studies of national and international scientific policy and the relations of science and government.

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RIVER MEANDERS

The striking geometric regularity of a winding river is no accident. Meanders appear to be the form in which a river does the least work in turning; hence they are the most probable form a river can take

by Luna B. Leopold and W. B. Langbein

Is there such a thing as a straight river? Almost anyone can think of a river that is more or less straight for a certain distance, but it is unlikely that the straight portion is either very straight or very long. In fact, it is almost certain that the distance any river is straight does not exceed 10 times its width at that point.

The sinuosity of river channels is clearly apparent in maps and aerial photographs, where the successive curves of a river often appear to have a certain regularity. In many instances the repeating pattern of curves is so pronounced that it is the most distinctive characteristic of the river. Such curves are called meanders, after a winding stream in Turkey known in ancient Greek times as the Maiandros and today as the Menderes. The nearly geometric regularity of river meanders has attracted the interest of geologists for many years, and at the U.S. Geological Survey we have devoted considerable study to the problem of understanding the general mechanism that underlies the phenomenon. In brief, we have found that meanders are not mere accidents of nature but the form in which a river does the least work in turning, and hence are the most probable form a river can take.

Regular Forms from Random Processes

Nature of course provides many opportunities for a river to change direction. Local irregularities in the bounding medium as well as the chance emplacement of boulders, fallen trees, blocks of sod, plugs of clay and other obstacles can and do divert many rivers from a straight course. Although local irregularities are a sufficient reason for a river's not being straight, however, they are not a necessary reason. For one thing, such irregularities cannot account for the rather consistent geometry of meanders. Moreover, laboratory studies indicate that streams meander even in "ideal," or highly regular, mediums [*see illustration on page 64*].

That the irregularity of the medium has little to do with the formation of meanders is further demonstrated by the fact that meandering streams have been observed in several naturally homogeneous mediums. Two examples are ocean currents (notably the Gulf Stream) and water channels on the surface of a glacier. The meanders in both cases are as regular and irregular as river meanders.

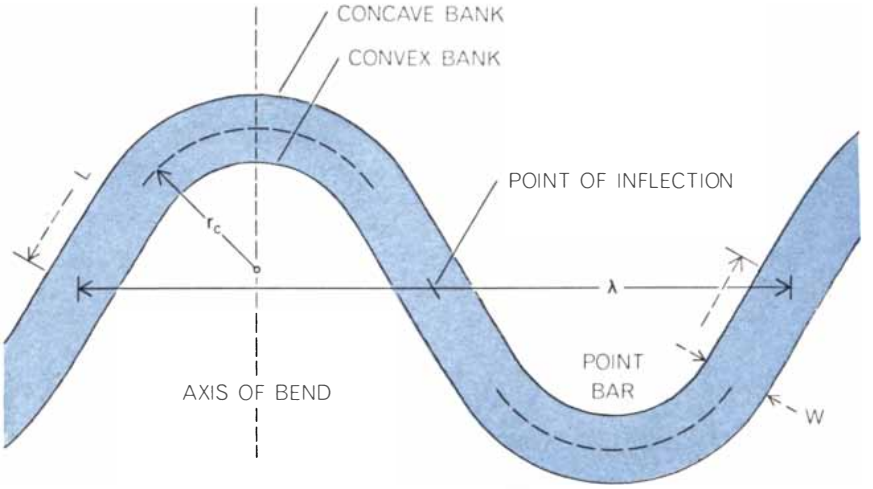
The fact that local irregularities cannot account for the existence of river meanders does not rule out other random processes as a possible explanation. Chance may be involved in subtler and more continuous ways, for example in turbulent flow, in the manner in which the riverbed and banks are formed, or in the interaction of the flow and the bed. As it turns out, chance operating at this level can explain the formation of regular meanders. It is a paradox of nature that such random processes can produce regular forms, and that regular processes often produce random forms.

Meanders commonly form in alluvium (water-deposited material, usually unconsolidated), but even when they occur in other mediums they are invariably formed by a continuous process of erosion, transportation and deposition of the material that composes the medium. In every case material is eroded from the concave portion of a meander, transported downstream and deposited on the convex portion, or bar, of a meander. The material is often deposited on the same side of the stream from which it was eroded. The conditions in which meanders will be formed in rivers can be stated rather simply, albeit only in a general way: Meanders will usually appear wherever the river traverses a gentle slope in a medium consisting of fine-grained material that is easily eroded and transported but has sufficient cohesiveness to provide firm banks.

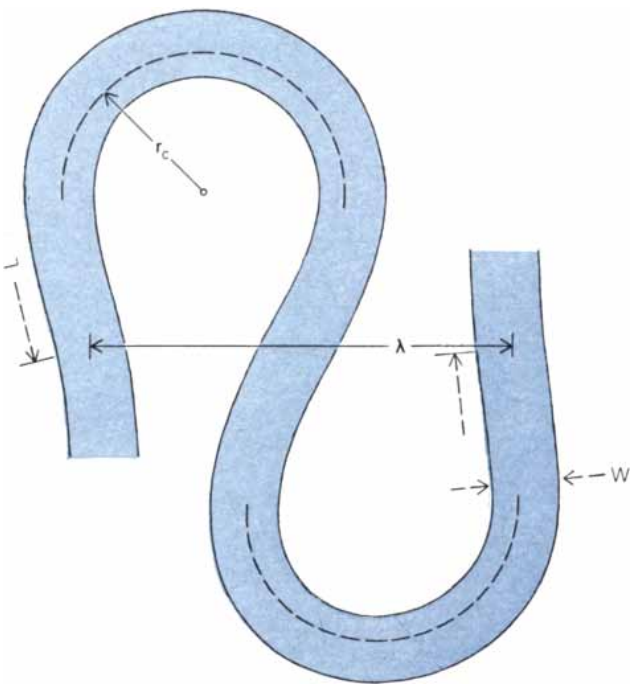
A given series of meanders tends to have a constant ratio between the wavelength of the curve and the radius of curvature. The appearance of regularity depends in part on how constant this ratio is. In the two drawings on page 62 the value of this ratio for the meander that looks rather like a sine wave (*top*) is five for the wavelength to one for the radius; the more tightly looped meander (*bottom*) has a corresponding value of three to one. A sample of 50 typical meanders on many different rivers and streams has yielded an average value for this ratio of about 4.7 to one. Another property that is used to describe meanders is sinuosity, or tightness of bend, which is expressed as the ratio of the length of the channel in a given curve to the wavelength of the curve. For the large majority of meandering rivers the value of this ratio ranges between 1.3 to one and four to one.

Close inspection of the photographs

ENTRENCHED MEANDERS of the Colorado River in southern Utah were photographed from a height of about 3,000 feet. The meanders were probably formed on the surface of a gently sloping floodplain at about the time the entire Colorado Plateau began to rise at least a million years ago. The meanders later became more developed as river cut deep into layers of sediment. Mean downstream direction is toward right.



WIDTH OF CHANNEL (W) = 1
WAVELENGTH (λ) = 11.5
LENGTH OF CHANNEL (L) = 16.5
RADIUS OF CURVATURE (r_c) = 2.3



WIDTH OF CHANNEL (W) = 1
WAVELENGTH (λ) = 6.9
LENGTH OF CHANNEL (L) = 24.8
RADIUS OF CURVATURE (r_c) = 2.3

PROPERTIES used to describe river meanders are indicated for two typical meander curves. A series of meanders has a regular appearance on a map whenever there tends to be a constant ratio between the wavelength (λ) of the curve and its radius of curvature (r_c). The value of this ratio for the meander that looks rather like a sine wave (*top*) is five to one; the more tightly looped meander (*bottom*) has a corresponding value of three to one. An average value for this ratio is about 4.7 to one. Sinuosity, or tightness of bend, is expressed as the ratio of the length of the channel (L) in a given curve to the wavelength of curve. The value of this ratio for the top curve is 1.4 to one and for the bottom curve 3.6 to one. On the average the value of this ratio ranges between 1.3 to one and four to one.

and maps that accompany this article will show that typical river meanders do not exactly follow any of the familiar curves of elementary geometry. The portion of the meander near the axis of bend (the center of the curve) does resemble the arc of a circle, but only approximately. Neither is the curve of a meander quite a sine wave. Generally the circular segment in the bend is too long to be well described by a sine wave. The straight segment at the point of inflection—the point where the curvature of the channel changes direction—prevents a meander from being simply a series of connected semicircles.

Sine-generated Curves

We first recognized the principal characteristics of the actual curve traced out by a typical river meander in the course of a mathematical analysis aimed at generating meander-like curves by means of "random walk" techniques. A random walk is a path described by successive moves on a surface (for example a sheet of graph paper); each move is generally a fixed unit of distance, but the direction of any move is determined by some random process (for example the turn of a card, the throw of a die or the sequence of a table of random numbers). Depending on the purpose of the experiment, there is usually at least one constraint placed on the direction of the move. In our random-walk study one of the constraints we adopted was that the path was to begin at some point A and end at some other point B in a given number of steps. In other words, the end points and the length of the path were fixed but the path itself was "free."

The mathematics involved in finding the average, or most probable, path taken by a random walk of fixed length had been worked out in 1951 by Hermann von Schelling of the General Electric Company. The exact solution is expressed by an elliptic integral, but in our case a sufficiently accurate approximation states that the most probable geometry for a river is one in which the angular direction of the channel at any point with respect to the mean down-valley direction is a sine function of the distance measured along the channel [*see illustration on opposite page*].

The curve that is traced out by this most probable random walk between two points in a river valley we named a "sine-generated" curve. As it happens, this curve closely approximates the

shape of real river meanders [*see illustration on next page*]. At the axis of bend the channel is directed in the mean down-valley direction and the angle of deflection is zero, whereas at the point of inflection the angle of deflection reaches a maximum value.

A sine-generated curve differs from a sine curve, from a series of connected semicircles or from any other familiar geometric curve in that it has the smallest variation of the changes of direction. This means that when the changes in direction are tabulated for a given distance along several hypothetical meanders, the sums of the squares of these changes will be less for a sine-generated curve than for any other regular curve of the same length. This operation was performed for four different curves of the same length, wavelength and sinuosity—a parabolic curve, a sine curve, a circular curve and a sine-generated curve—in the illustration on page 65. When the squares of the changes in direction were measured in degrees over 10 equally spaced intervals for each curve, the resulting values were: parabolic curve, 5,210; sine curve, 5,200; circular curve, 4,840; sine-generated curve, 3,940.

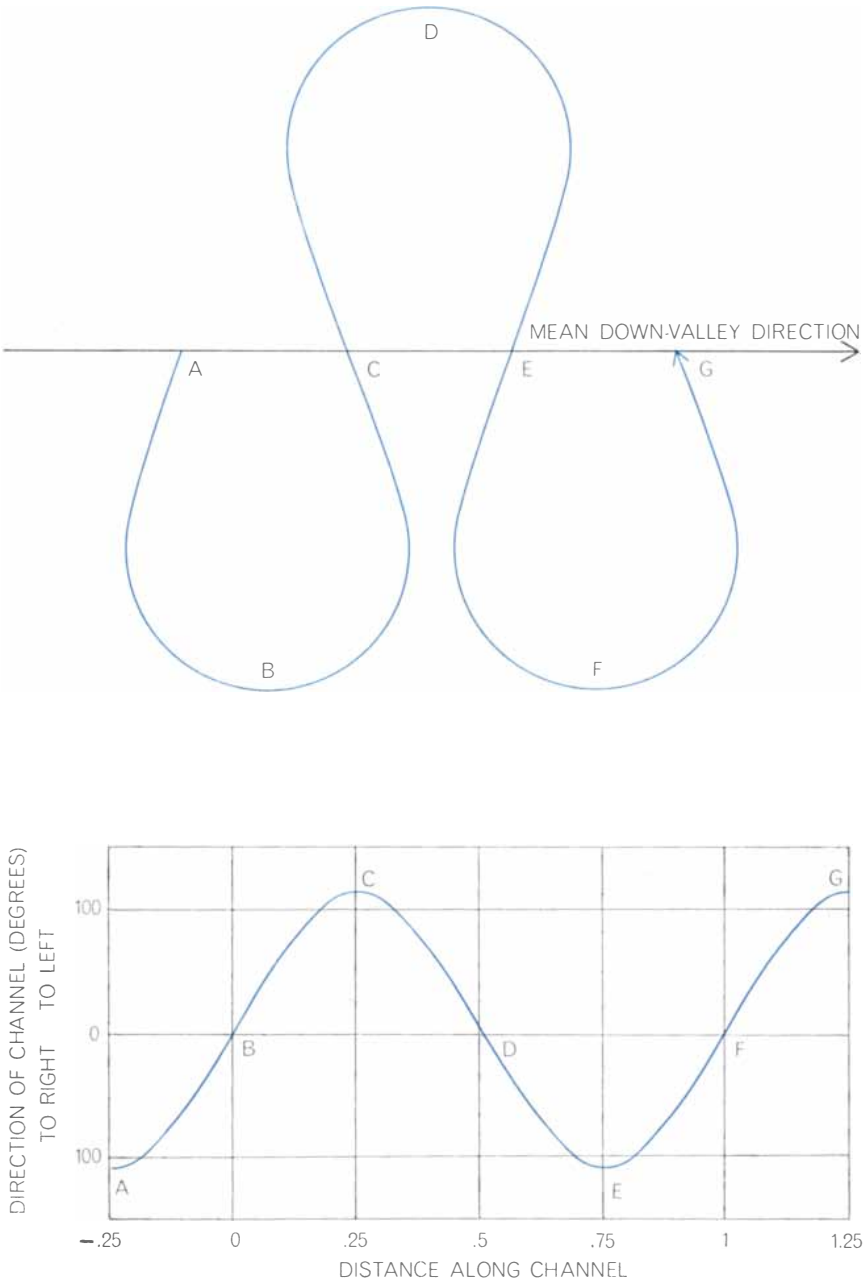
Curve of Minimum Total Work

Another property closely associated with the fact that a sine-generated curve minimizes the sum of the squares of the changes in direction is that it is also the curve of minimum total work in bending. This property can be demonstrated by bending a thin strip of spring steel into various configurations by holding the strip firmly at two points and allowing the length between the fixed points to assume an unconstrained shape [*see top illustration on pages 66 and 67*]. The strip will naturally avoid any concentration of bending and will assume a shape in which the bend is as uniform as possible. In effect the strip will assume a shape that minimizes total work, since the work done in each element of length is proportional to the square of its angular deflection. The shapes assumed by the strip are sine-generated curves and indeed are good models of river meanders.

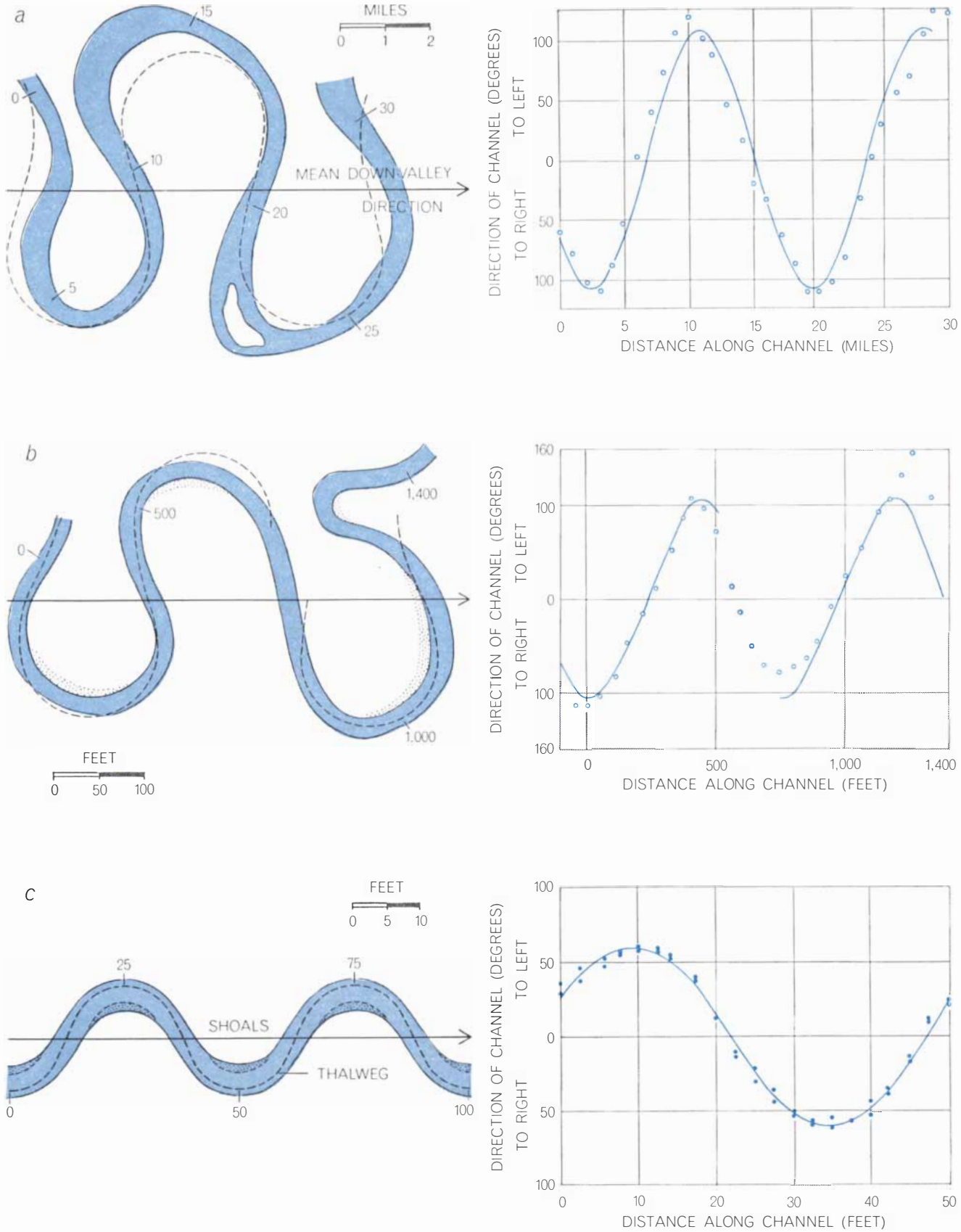
A catastrophic example of a sine-generated curve on a much larger scale was provided by the wreck of a Southern Railway freight train near Greenville, S.C., on May 31, 1965 [*see bottom illustration on page 67*]. Thirty adjacent flatcars carried as their load 700-foot sections of track rail chained in a bundle to the car beds. The train, pulled by five locomotives, collided with a bulldozer and was derailed. The violent compressive strain folded the trainload of rails into a drastically foreshortened snakelike configuration. The elastic properties of the steel rails tended to minimize total bending exactly as in the case of the spring-steel strip, and as a result the wrecked train assumed the shape of a sine-generated curve that distributed the bending as uniformly as possible. This example is particularly appropriate to our discussion of river meanders because, like river meanders, the bent rails deviate in a random way from the perfect symmetry of a sine-generated curve while preserving its essential form.

The Shaping Mechanism

The mechanism for changing the course of a river channel is contained



SINE-GENERATED CURVE (*top*) closely approximates the shape of real river meanders. This means that the angular direction of the channel at any point with respect to the mean down-valley direction (*toward the right*) is a sine function of the distance measured along the channel (*graph at bottom*). At the axis of each bend (*B, D and F*) the channel is directed in the mean down-valley direction and the angle of deflection is zero, whereas at each point of inflection (*A, C, E and G*) the angle of deflection reaches a maximum value.

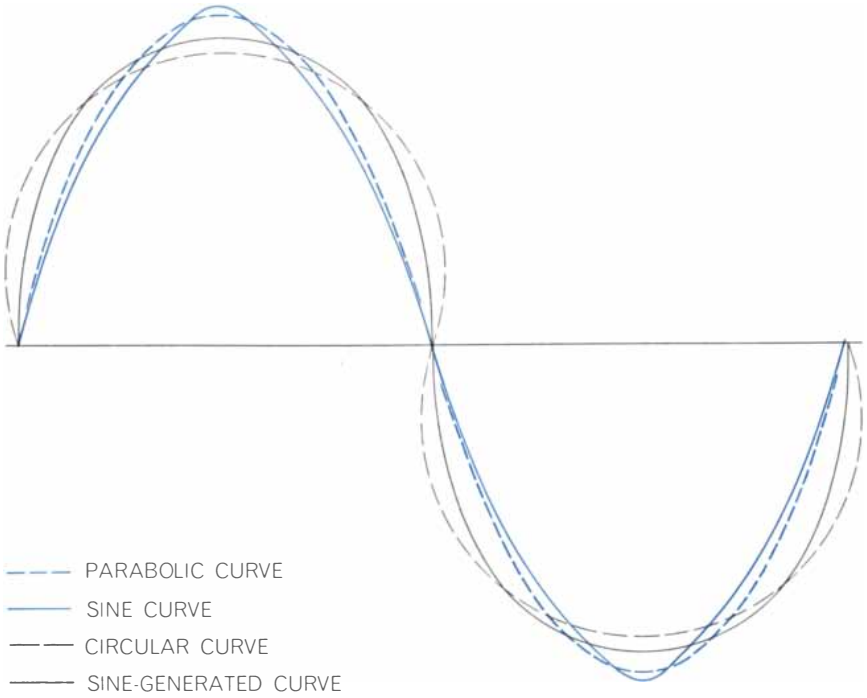


MAPS at left depict segments of two typical meandering streams, the Mississippi River near Greenville, Miss. (*a*), and Blackrock Creek in Wyoming (*b*), as well as a segment of an experimental meander formed in a homogeneous medium in the laboratory (*c*). Measurements of the angular direction of the channels with respect to the mean downstream direction were made at regular intervals along the center lines of the two natural meanders and along the thalweg, or deepest part of the channel, of the experimental meander. When these measurements were plotted against the distance of each channel, the resulting curves closely approximated sine waves (*right*). The corresponding sine-generated curves are superposed on their respective channel maps (*broken black curves*).

in the ability of water to erode, transport and deposit the material of the river's medium. Especially on a curve, the velocity gradient against the channel bank sets up local eddies that concentrate the expenditure of energy and localize erosion. An idealized flow pattern in a typical meander is shown in the top illustration on page 68. The left side of the illustration indicates the velocity vectors at various points for five cross sections along the curve. As the cross sections indicate, the depth of the channel changes systematically along the curve, the shallowest section being at the point of inflection and the deepest section at the axis of bend. At the same time the cross-sectional shape itself changes; it is symmetrical across the channel just downstream from the point of inflection and most asymmetrical at the axis of bend, the deeper section being always nearer the concave bank. The velocity vectors show a normal decrease in velocity with depth except at the axis of bend and near the concave bank, where the highest velocity at any point in the meander occurs somewhat below the surface of the water.

The right side of the same illustration shows the streamlines of flow at the surface of the meander. The maximum-velocity streamline is in the middle of the channel just downstream from the point of inflection; it crosses toward the concave bank at the axis of bend and continues to hug the concave bank past the next point of inflection. Riverboatmen navigating upstream on a large river face the problem that the deepest water, which they usually prefer, tends to coincide with the streamline of highest velocity. Their solution is to follow the thalweg (the deepest part of the river, from the German for "valley way") where it crosses over the center line of the channel as the channel changes its direction of curvature but to cut as close to the convex bank as possible in order to avoid the highest velocity near the concave bank. This practice led to the use of the term "crossover" as a synonym for the point of inflection.

The lack of identity between the maximum-velocity streamline and the center line of the channel arises from the centrifugal force exerted on the water as it flows around the curve. The centrifugal force is larger on the faster-moving water near the surface than on the slower-moving water near the bed. Thus in a meander the surface water is deflected toward the concave bank, requiring the bed water to move toward the convex bank. A circulatory system is set up in the cross-sectional plane, with surface water plunging toward the bed near the concave bank and bed water rising toward the surface near the convex bank. This circulation, together with the general downstream motion, gives each discrete element of water a roughly helical path that reverses its direction of rotation with each successive meander. As a result of this helical motion of water, material eroded from the concave bank tends to be swept toward the convex bank, where it is deposited, forming what is called a point bar.



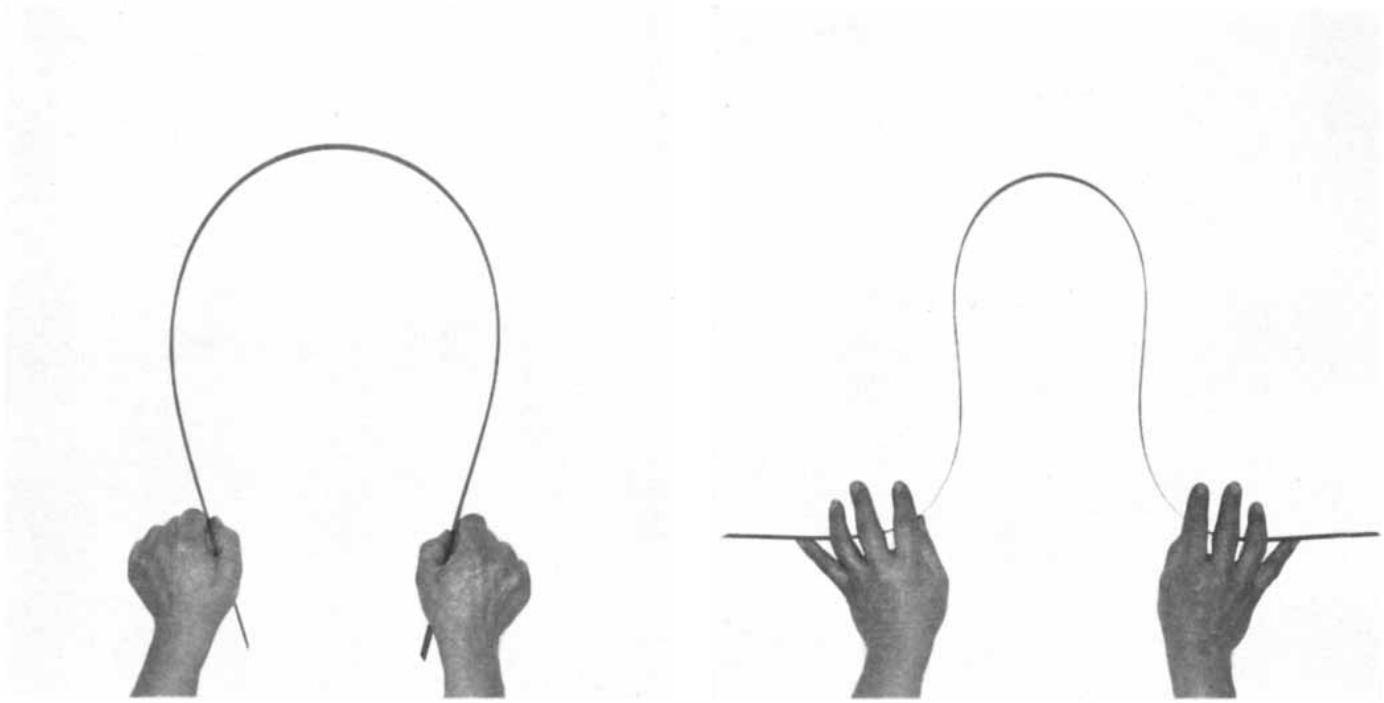
VARIATION IN CURVATURE of a sine-generated curve is less than for any other regular geometric curve. This means that when the changes in direction are tabulated for small distances along several hypothetical meanders, the sums of the squares of the changes in direction will be less for a sine-generated curve than for any other curve. The changes in direction were measured in degrees over 10 equally spaced intervals for each of the four curves depicted here. When the squares of these changes were summed, the following values were obtained: parabolic curve, 5,210; sine curve, 5,200; circular curve, 4,840; sine-generated curve, 3,940. The four curves are equal in length, wavelength and sinuosity.

Erosion of the concave banks and deposition on the convex banks tends to make meander curves move laterally across the river valley. Because of the randomness of the entire process, the channel as a whole does not move steadily in any one direction, but the combined lateral migration of the meanders over a period of many years results in the river channel's occupying every possible position between the valley walls. The deposition on the point bars, combined with the successive occupation by the river of all possible positions, results in the formation of the familiar broad, flat floor of river valleys—the "floodplain" of the river. The construction of a floodplain by the lateral movement of a single meander can be observed even in the course of a few years; this is demonstrated in the bottom illustration on page 68, which is made up of four successive cross sections surveyed between 1953 and 1964 on Watts Branch, a small tributary of the Potomac River near Washington.

The overall geometry of a meandering river is an important factor in determining the rate at which its banks will be eroded. In general the banks are eroded at a rate that is proportional to the degree with which the river channel is bent. Any curve other than a sine-generated curve would tend to concentrate bank erosion locally or, by increasing the total angular bending, would add to the total erosion. Thus the sine-generated curve assumed by most meandering rivers tends to minimize total erosion.

Riffles and Pools

In the light of the preceding discussion it is possible to examine some of the hydraulic properties of meanders in greater detail. If a river channel is re-



STRIP OF SPRING STEEL is used to demonstrate that a sine-generated curve is the curve of minimum total work. The strip is bent into various configurations by holding it firmly at two points and allowing the length between the fixed points to assume an un-

garded as being in a steady state, the form it assumes should be such as to avoid concentrating variations in *any* property at the expense of another property.

For example, variations in depth and velocity are inherent in all river channels, whether they are straight or curved. Even a reach, or length of channel, that is quite straight has a more or less uneven bed that consists of alternating deeps and shallows. Although this is not so obvious in a period of high flow, it becomes quite apparent at low flow, when the shallow sections tend to ripple in the sunlight as water backs up behind each hump in the bed before pouring over its downstream slope. To a trout fisherman this fast reach is known as a riffle. Alternating with the riffles are deeps, which the fisherman would call pools, through which the water flows slower and more smoothly.

The alternation of riffles and pools in a trout stream at low flow is noteworthy for another reason. The humps in the stream bed that give rise to the riffles tend to be located alternately on each side of the stream [*see top illustration on page 69*]. As a consequence the stream at low flow seems to follow a course that wanders successively from one side of the channel to the other, in a manner having an obvious similarity to meandering.

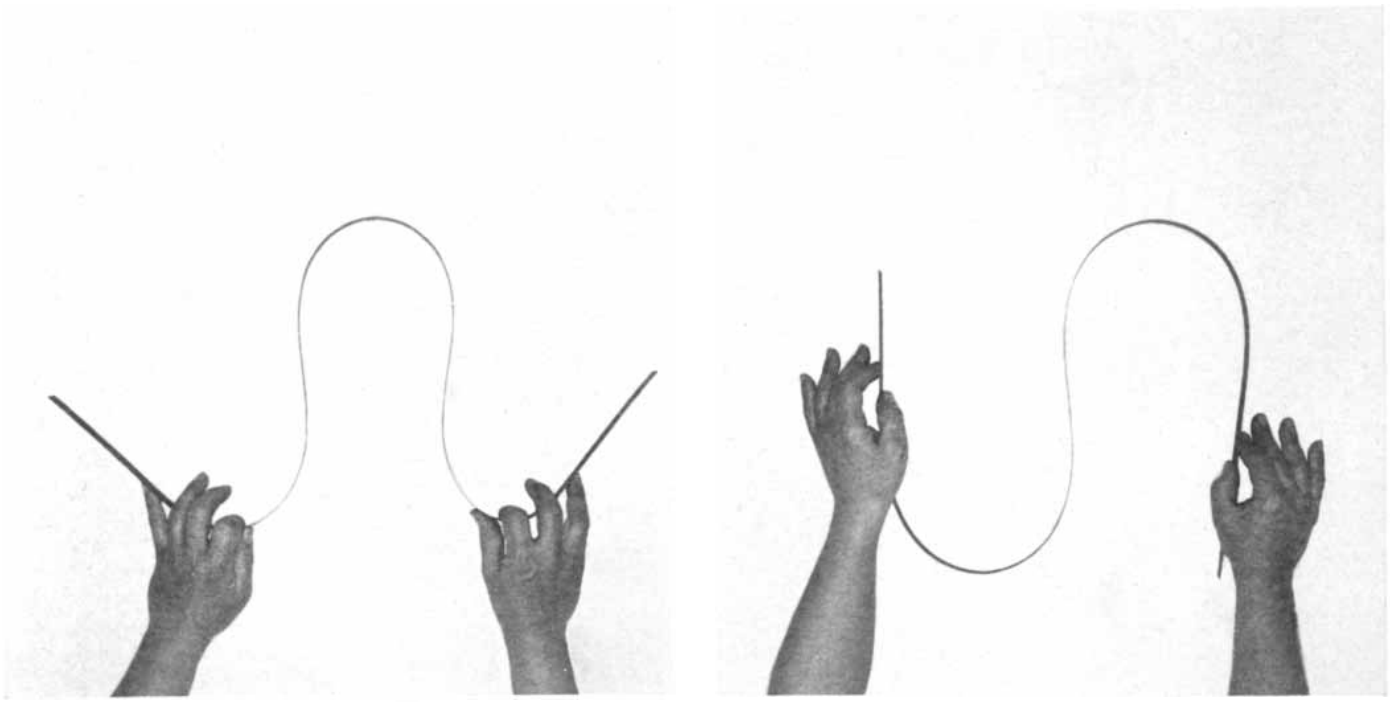
The analogy between this temporary sinuosity and full-scale meandering is strengthened by the fact that the riffles occur at roughly equal intervals along the channel. Moreover, the spacing of the riffles is correlated with the width of the channel. Successive riffles are located at intervals equal to about five to seven times the local channel width, or roughly twice the wavelength of a typical meander. This surprisingly consistent ratio seems even more remarkable when one realizes that each meander contains two riffles, one at each point of inflection. This observation led us to hypothesize that the same mechanism that causes meanders must also be at work in straight channels, and that a detailed study of the form and the hydraulic properties of two segments of channel that differ only in their degree of curvature might shed some light on the formation of meanders.

Obtaining Meander Profiles

In order to test this hypothesis it was necessary to obtain accurate data for all the pertinent hydraulic factors: depth, velocity, water-surface profile and bed profile. For several years we had attempted to measure such factors in small rivers near Washington just after every heavy rainstorm, when there was a rapid increase in streamflow. The water level changed so quickly in such storms, however, that there was never enough time to measure all the hydraulic factors in detail through a succession of two riffles and an intervening pool. Then in 1959 we tried another strategy: we decided to measure a small stream in Wyoming, named Baldwin Creek, in early June, a period of maximum runoff from melting snow. Measurements were made in two places, a meandering reach and a straight reach, that were comparable in all outward aspects except sinuosity. The stream was about 20 feet wide and was nearly overflowing its banks, so that we could just barely walk in it wearing chest-high rubber waders.

Robert M. Myrick, an engineer with the Geological Survey, and one of us (Leopold) began a series of measurements in the midafternoon of June 19, surveying water-surface and bed profiles with a level and a rod, and making velocity and depth measurements with a current meter and a rod. When darkness came, we lighted lanterns and continued our measurements. At about daybreak we slept for a few hours and then resumed the survey, grateful that the melting snow had kept the stream at a steady high flow for such a long time.

Several days later we were able to sit down under a tree and plot the profiles, velocities and depths on graph paper. What emerged was a quite unexpected contrast between meandering reach and straight reach [*see bottom illustration on page 69*]. The slope of the water surface in the meandering reach



constrained shape. The strip will naturally avoid any concentration of bending and will assume a shape in which the bend is as uniform as possible. In each of the four cases shown here this shape is a sine-generated curve and indeed a good model of a river meander.

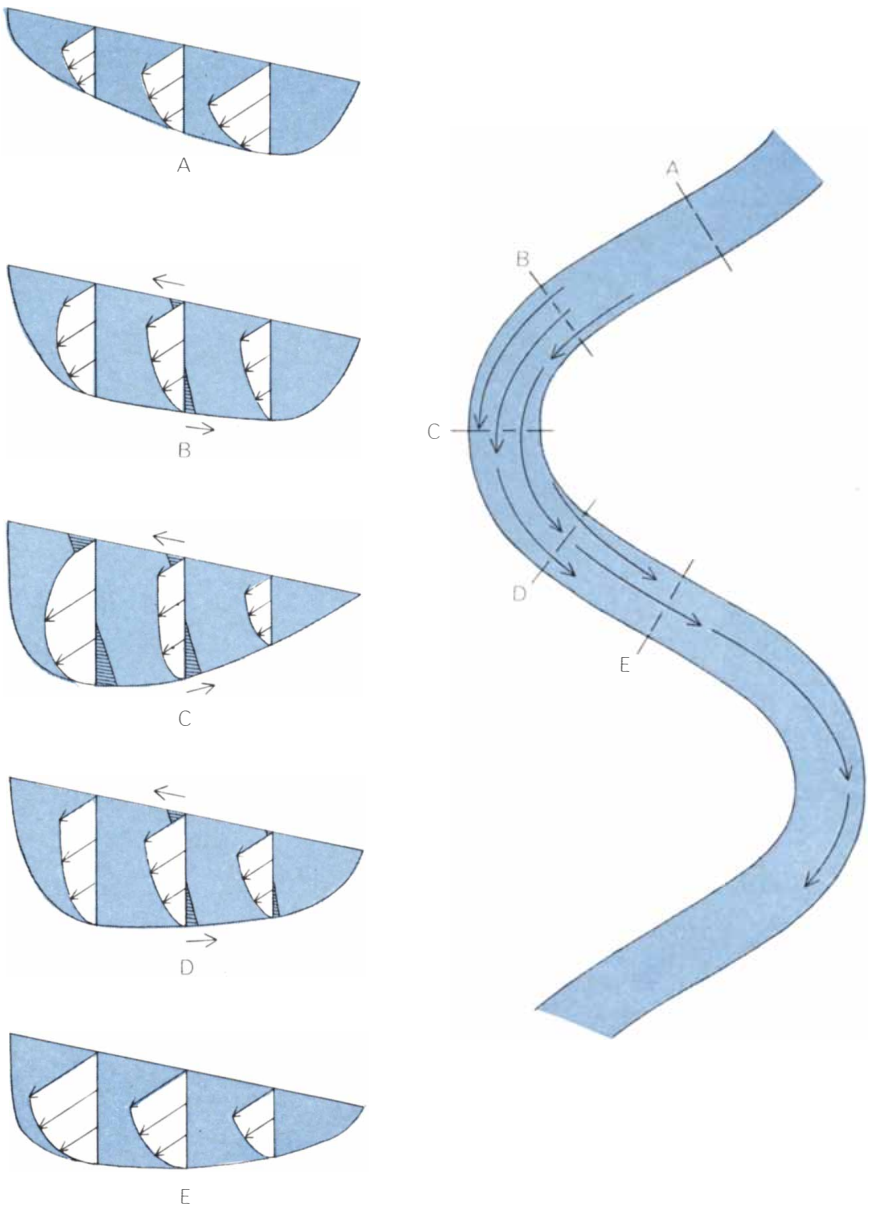
was clearly steeper than that in the straight reach; moreover, the water-surface profile of the meandering reach was nearly a straight sloping line, whereas the straight reach had a stepped profile, steep over the riffle bars and comparatively flat over the intervening pools.

What did this mean? It was as if the river had, to use somewhat anthropomorphic terms, chosen to cut a meander curve in order to achieve a more uniform water-surface profile. This suggested that the river had chosen the curved path in order to achieve the objective of uniform energy loss for each unit of distance along the channel, but had paid a price in terms of the larger total energy loss inherent in a curved path.

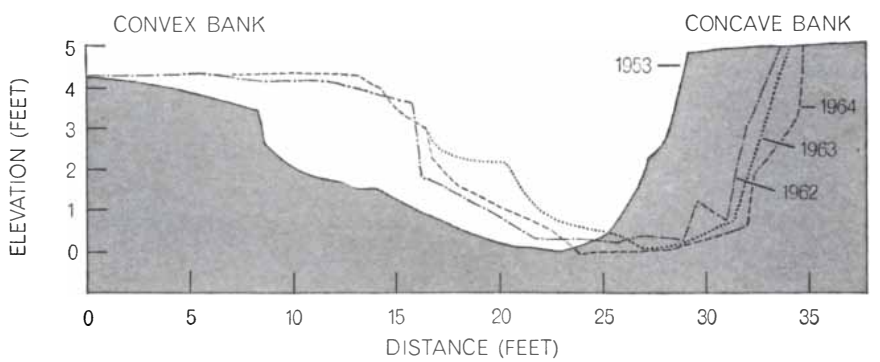
Conclusions

These data provided the key to further research, which ultimately resulted in several conclusions. First, it appears that a meandering channel more

CATASTROPHIC EXAMPLE of a sine-generated curve on a much larger scale was provided by the wreck of a Southern Railway freight train near Greenville, S.C., on May 31, 1965. Thirty adjacent flatcars carried as their load 700-foot sections of track rails chained in a bundle to the car beds. The train, pulled by five locomotives, collided with a bulldozer and was derailed. The violent compressive strain folded the trainload of rails into the drastically foreshortened configuration shown in this aerial photograph. The elastic properties of the steel rails tended to minimize total bending exactly as in the case of the spring-steel strip shown at top of these two pages, and the wrecked train assumed the shape of a sine-generated curve that distributed the bending as uniformly as possible.



IDEALIZED FLOW PATTERN of a typical meander is shown here. The left side of the illustration indicates the velocity vectors in a downstream direction for five cross sections across the curve; the lateral component of the velocity is indicated by the triangular hatched areas. The right side of the illustration shows the streamlines at the surface of the meander.



LATERAL MIGRATION of a typical meander is demonstrated in this drawing, made up of four successive cross sections surveyed between 1953 and 1964 on Watts Branch, a small tributary of the Potomac River near Washington. The lateral migration of meanders by the erosion of the concave banks and deposition on the convex banks over many years results in a river channel's occupying every possible position between the valley walls.

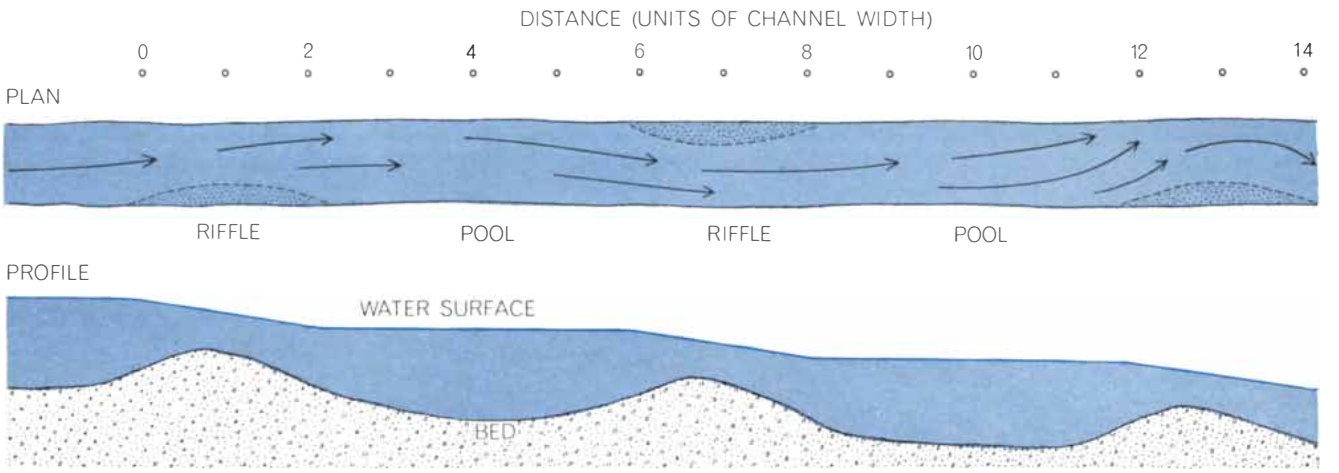
closely approaches uniformity in the rate of work over the various irregularities of the riverbed than a straight channel does. Of course the slope of the water surface is, with a slight correction for velocity, an accurate indicator of the rate at which energy is lost in the form of frictional heat along the length of the stream. Therefore a uniform longitudinal water-surface slope signifies a uniform expenditure of energy for each unit of distance along the channel.

A meander attains a more uniform rate of energy loss by the introduction of a form of energy loss not present in a straight reach, namely the curved path. It is evident that work is required to change the direction of a flowing liquid. Thus the slope of the water surface should increase wherever a curve is encountered by a river. In a meander it is at the deep pools, where the water-surface slope would be less steep than the average, that the introduction of a curve inserts enough energy loss to steepen the slope, thereby tending to make the slope for each unit of river length nearly the same. Accordingly the alternation of straight shallow reaches with curved deep reaches in a meander appears to be the closest possible approach to a configuration that results in uniform energy expenditure.

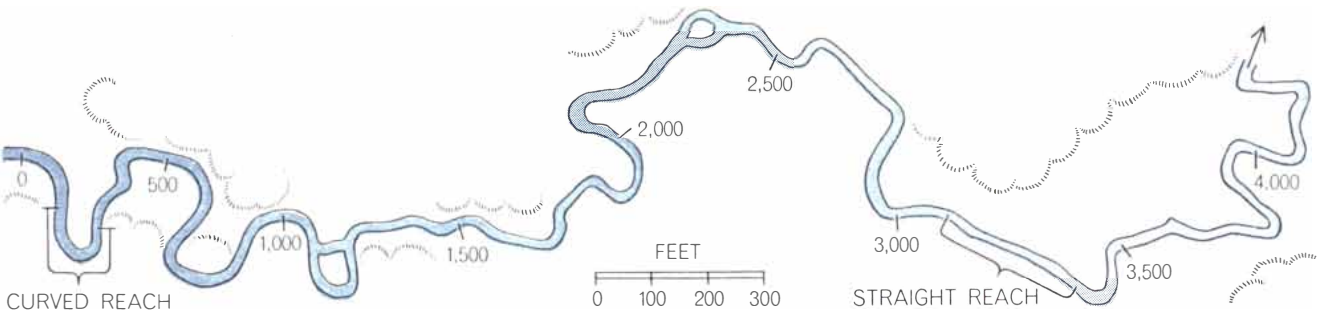
It is now possible to say something about the development of meandering in rivers. Although one can construct in a laboratory an initially straight channel that will in time develop a meandering pattern, a real meandering river should not be thought of as having an "origin." Instead we think of a river as having a heritage. When a continent first emerges from the ocean, small rills must form almost immediately; thereafter they change progressively in response to the interaction of uplift and other processes, including irregularities in the hardness of the rock.

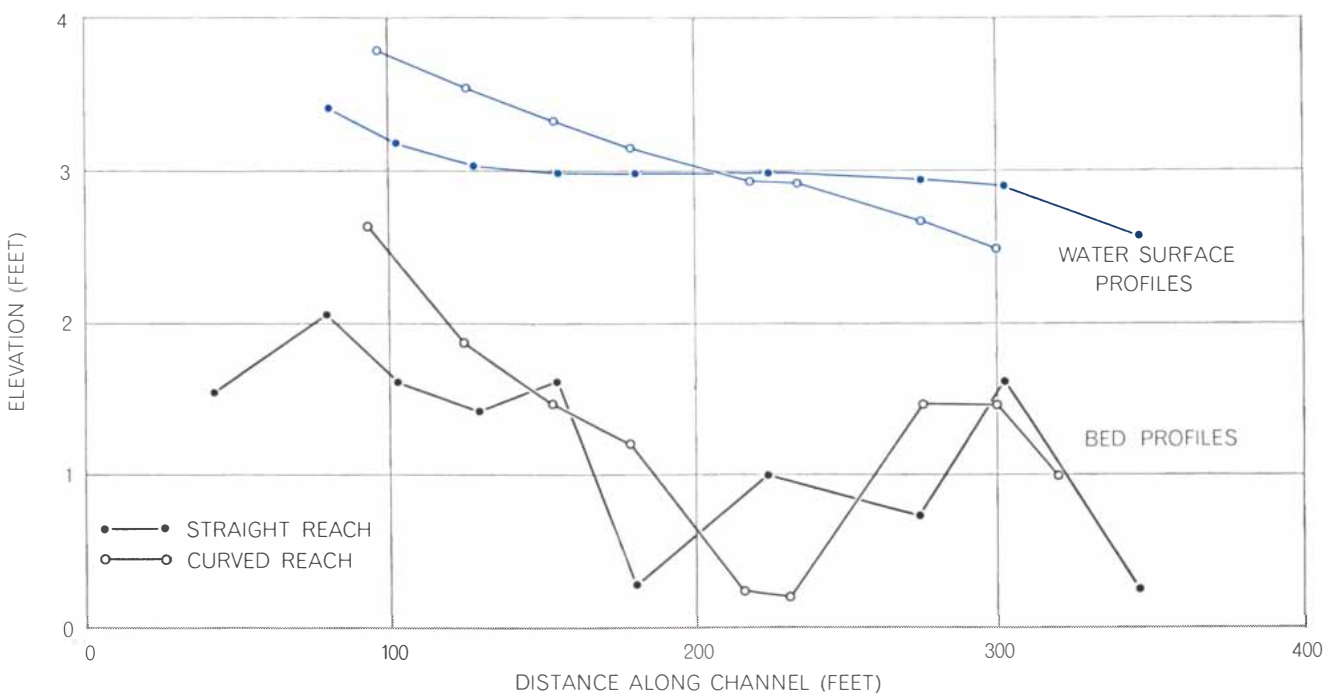
Today the continuous changes that occur in rivers are primarily wrought by the erosion and deposition of sedimentary material. As we have seen, rivers tend to avoid concentrating these processes in any one place. Hence any irregularity in the slope of a river—for example a waterfall or a lake—is temporary on a geological time scale; the hydraulic forces at work in the river tend to eliminate such concentrations of change.

The formation of meander curves of a particular shape is an instance of this adjustment process. The meandering form is the most probable result of the processes that on the one hand tend to



STRAIGHT REACH of a river has a more or less uneven bed that consists of alternating deeps and shallows, known to trout fishermen as riffles and pools. The humps in the stream bed that give rise to the riffles tend to be located alternately on each side of the stream at intervals roughly equal to five to seven times the local stream width. As a consequence the stream at low flow seems to follow a course that wanders from one side of the channel to the other, in a manner having an obvious similarity to meandering.





PROFILES of the water surface and bed of a small stream in Wyoming named Baldwin Creek were obtained by one of the authors (Leopold) and a colleague in 1959 during a period of maximum runoff from melting snow. Measurements were made in two places, a meandering reach and a straight reach, that were comparable in all outward aspects except sinuosity (*map at top*). What emerged was a quite unexpected contrast between the two reaches (*bottom*). The slope of the water surface in the meandering reach was clearly steeper than that in the straight reach; moreover, the water-surface profile of the meandering reach was nearly a straight sloping line, whereas the straight reach had a stepped profile, steep over the riffle bars and comparatively flat over the intervening pools.

eliminate concentrations of energy loss and on the other tend to reduce the total energy loss to a minimum rate. The sine-generated curvature assumed by meanders achieves these ends more satisfactorily than any other shape.

The same tendencies operate through the erosion-deposition mechanism both in the river system as a whole and in a given segment of the river. The tendency toward uniform power expenditure in the entire river leads toward a longitudinal profile of the river that is highly concave, inasmuch as uniformity in the rate of work per unit of length of channel would be achieved by concentrating the steepest slopes near the headwaters, where the tributaries and hence discharges are small. The longitudinal concavity of the river's profile also minimizes work in the system as a whole.

Such a longitudinal concave profile, however, would lead to considerable variation in the rate of energy expenditure over each unit area of channel bed. Uniformity in this rate would be best achieved by a longitudinal profile that was nearly straight rather than by one that was highly concave. Actual river profiles lie between these two extremes, and meanders must be considered in both contexts: first, as they occur within the river system as a whole, and second, as they occur in a given segment of channel.

In the context of the entire river system a meander will occur where the material constituting the banks is comparatively uniform. This will be more likely to take place downstream in a floodplain area than upstream in a headwater area. To the extent that the meandering pattern tends to lengthen the downstream reaches more than those upstream, it promotes concavity in the longitudinal profile of the system, thereby promoting uniformity in the rate of energy expenditure per unit of channel length.

In the local context of a given segment of channel the average slope of the channel is fixed by the relation of that segment to the whole profile. Any local change in the channel must maintain that average slope. Between any two points on a valley floor, however, a variety of paths are possible, any one of which would maintain the same slope and hence the same length. The typical meander shape is assumed because, in the absence of any other constraints, the sine-generated curve is the most probable path of a fixed length between two fixed points.

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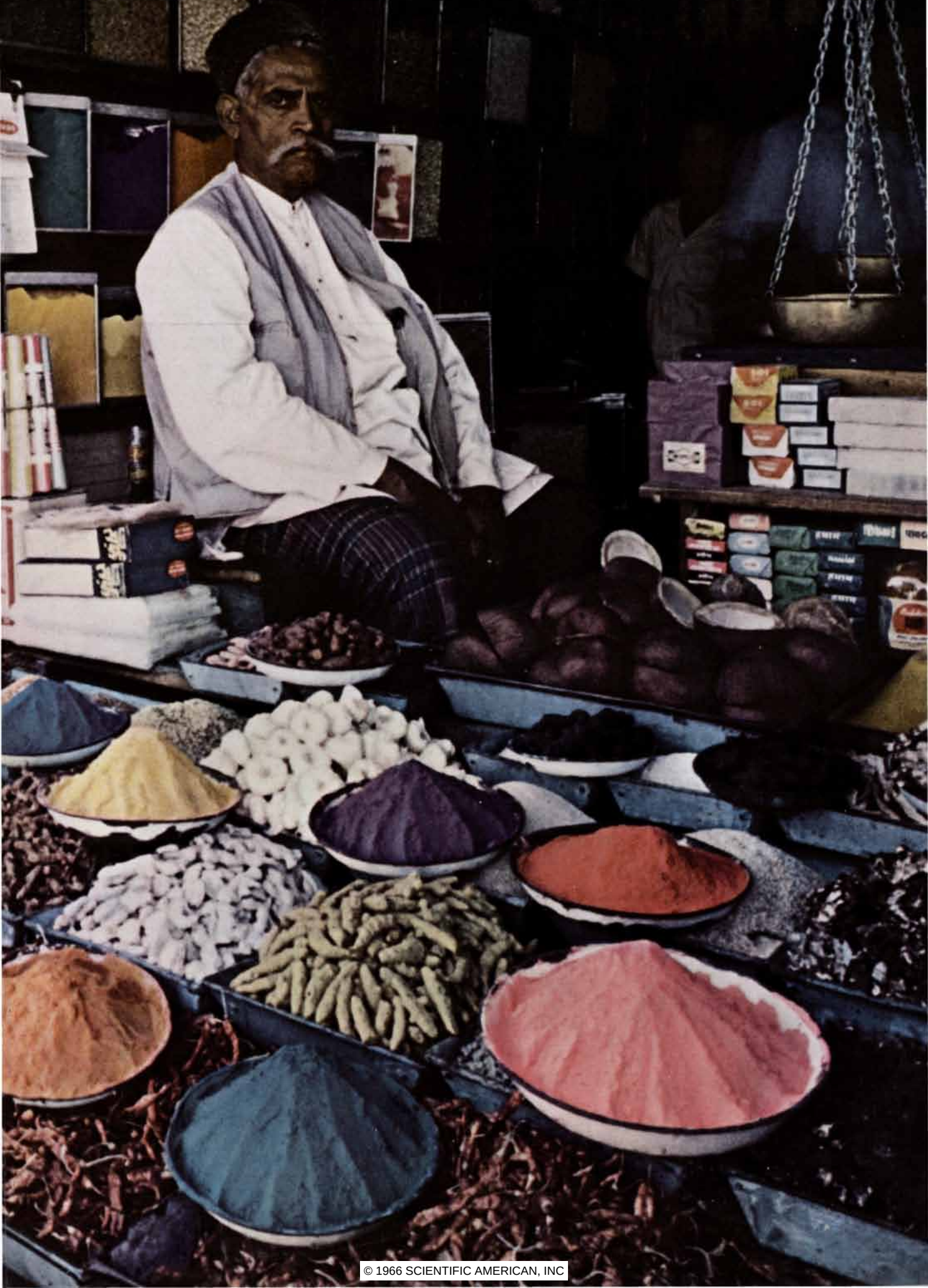
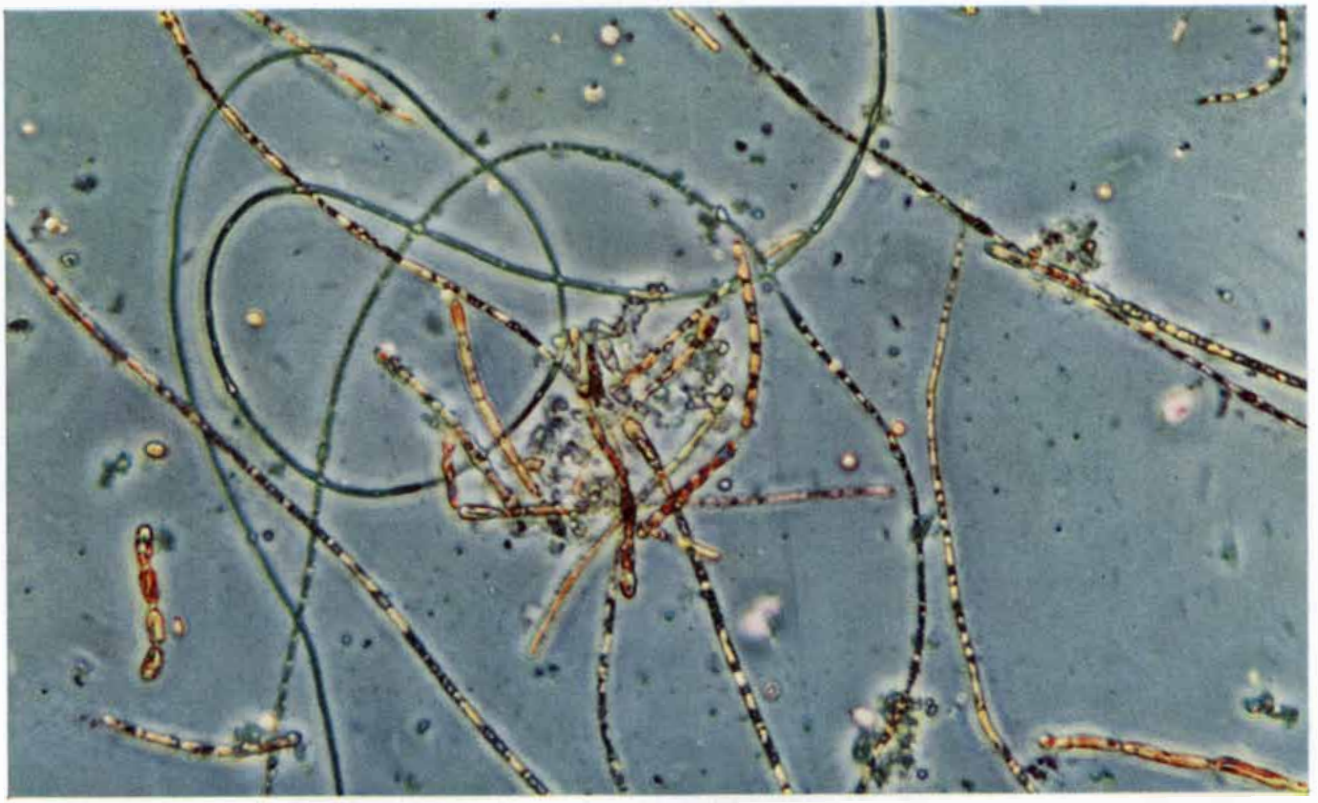
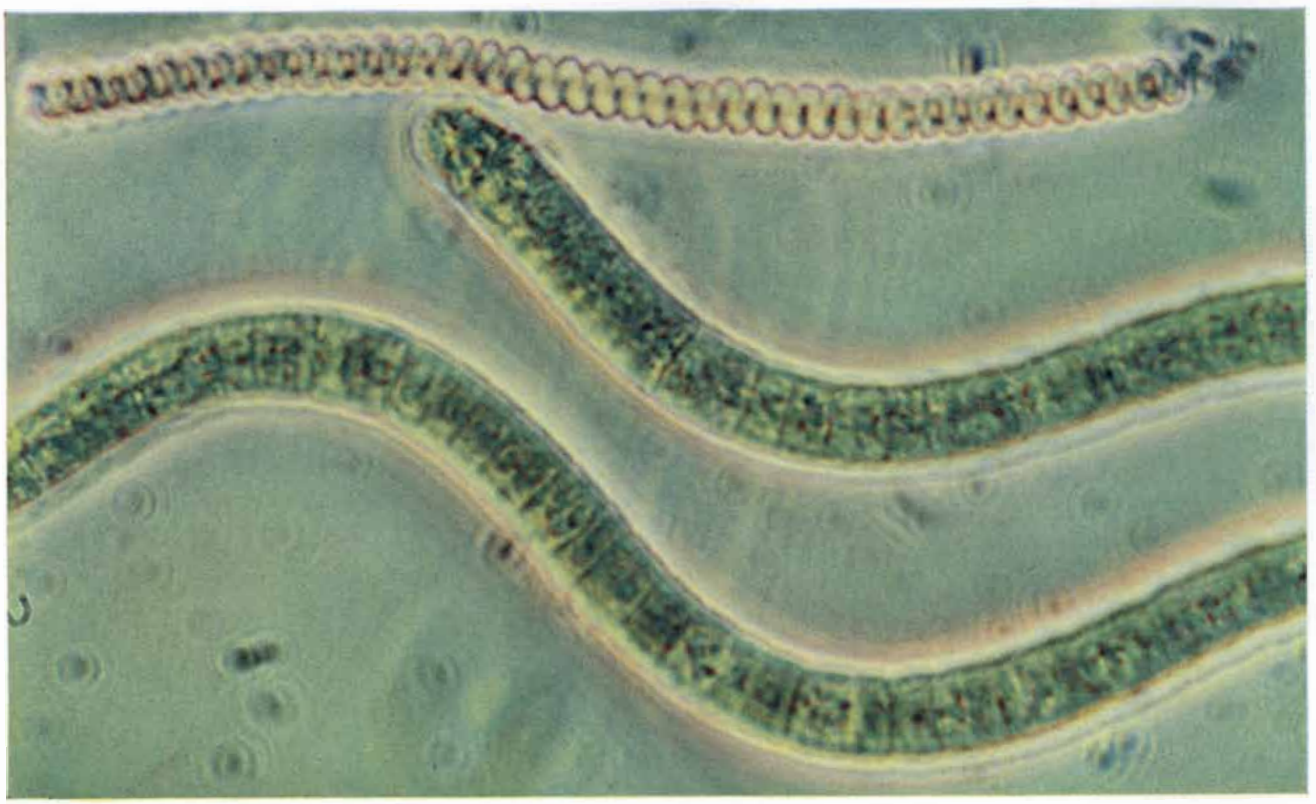




BLUE-GREEN ALGAE of the species *Gloeotrichia echinulata* consist of numbers of individual cells strung together in attenuated filaments radiating from a central point. The enlargement in this photomicrograph is about 150 diameters. Blue-green algae actually appear in a variety of colors. They were named blue-green because the first specimens to be classified were of that color.



FILAMENTOUS FORMS of blue-green algae also include the species *Spirulina versicolor* (*top*) and two filaments of the genus *Arthrospira;* the enlargement is approximately 1,500 diameters. *Arthrospira* is one of the blue-green algae responsible for the pink color often seen in flamingos; the birds acquire the color from carotenes in the blue-green algae that are part of their diet.

THE BLUE-GREEN ALGAE

These primitive plants more closely resemble bacteria than they do other algae. They live in an extraordinary range of environments, and they have both beneficial and harmful effects in human affairs

by Patrick Echlin

The algae are the simplest members of the plant kingdom, and the blue-green algae are the simplest of the algae. Indeed, the blue-green algae resemble bacteria more closely than they do other forms of algae. By this token they occupy a distinctive niche in the evolutionary order of things. They provide insights into the evolution of bacteria and algae, and also, since they are among the most primitive living cells, into the beginnings of the cell itself. Today, moreover, the blue-green algae have a considerable and increasing economic importance: they have both beneficial and harmful effects on human life.

Most of the blue-green algae are blue-green, but not all; they are found in a wide range of colors. Their name stems from the fact that the first species to be recognized as members of the group were blue-green. A few of the 2,000 species now known live as single cells of microscopic size. The cells of other species gather in colonies but still live essentially as individuals. Most species of blue-green alga, however, are filamentous: their cells are strung together in a hairlike structure. This is the form in which blue-green algae are most likely to be visible to the unaided eye, either as a mosslike growth on land or as a soft mass in water.

Whatever the form, the individual cells of blue-green algae are much alike. Each is surrounded by a gelatinous sheath. Inside the sheath is a thin membrane that encloses the cell's cytoplasm. The cell of a blue-green alga lacks a well-defined nucleus and the elaborate intracellular membranes and separate organelles of cells in advanced plants and animals. In the peripheral parts of the cytoplasm there are, however, complex lamellae, or thin sheets, that apparently form from the cell membrane [*see illustrations on page 78*].

Reproduction in most blue-green algae is a simple and asexual process. The cell merely divides. Some of the filamentous forms reproduce by a breaking of the filament, the two parts of which then grow by cell division. A few species of blue-green alga are able to reproduce by forming spores.

Like most other algae, the blue-greens manufacture their food by photosynthesis. They are distinctive, however, in that their photosynthetic pigments are distributed throughout the peripheral lamellae rather than in discrete bodies such as chloroplasts. A unique feature of certain filamentous species is the tendency to form heterocysts: large colorless cells at irregular intervals along a filament. The function of these cells is uncertain. According to various hypotheses they represent a vestigial reproductive cell, a store of food or a structure associated with either cell division or the formation of internal spores.

The blue-green algae are widely distributed over land and water, often in environments where no other vegetation can exist. They live in water that is salt, brackish or fresh; in hot springs and cold springs, both pure and mineralized; in salt lakes; in moist soils, and in symbiotic or parasitic association with other plants and animals. Most marine forms grow along the shore, fixed to the bottom in the narrow zone between the high and low tidemarks; a few float about as plankton. The largest number of species live in fresh water. Some can be found in fast-moving or turbulent waters, such as the water falling on rocks under a waterfall; others flourish in quiet waters—even in bodies of water that appear only temporarily.

On land in places of high humidity, such as gullies on the lower slopes of mountains, both tree trunks and rocks may be covered with gelatinous mats of many hues; the mats consist of single-celled blue-green algae. The filamentous algae form a feltlike growth over extensive land areas. Where high temperatures are combined with high humidity, as in the Tropics, the growth can be quite luxurious.

The wide variety of colors among blue-green algae has two main sources: the pigmentation of the gelatinous sheath and the pigmentation within the cell. The sheath, particularly in species that grow on land, is often deeply pigmented. Yellow and brown tints predominate, although shades of red and violet are also seen. The sheath coloration appears to be related to the environment—chiefly to the amount of sunlight received by the algae and to the acidity of their medium.

Within the cell are three pigments that are found in all plants capable of photosynthesis: chlorophyll, carotene and xanthophyll. In addition there are two pigments that are found only in this group of organisms: the blue pigment c-phycocyanin and the red pigment c-phycoerythrin. It is these two pigments that are principally responsible for the group's diverse coloration. The colors range from the red of the species *Oscillatoria cortiana* and *Phormidium persicinum* through the emerald green of the genus *Anacystis* to the near black of some algae that live on rocks. The color of the algae is also dependent on the age and physiological state of the organism. Healthy cultures of *Anacystis montana* are a bright emerald green, whereas an old culture is a dirty yellow. There are even a few members of the

blue-green group that are colorless; they live in such diverse habitats as the bottom of lakes, the intestines of animals and the human mouth.

Certain forms of blue-green algae have the capacity for changing color in relation to the color of the light that falls on them. The filamentous alga *Oscillatoria sancta* is green in red light, blue-green in yellow-brown light, red in green light and brownish yellow in blue light. Some deep-water algae are red, apparently for the following reason. As sunlight penetrates deeper into water its longer wavelengths, starting with the wavelengths of red light, are progressively absorbed. The last part of the visible spectrum to be absorbed is the blue. Such light could best be utilized for photosynthesis by algae with a preponderance of red pigments.

The capacity of the blue-green algae for adjusting to light of different intensities and colors means they are better adapted than other photosynthetic organisms to utilize the available light. This characteristic probably has much to do with the occurrence of these algae in so many terrestrial and aquatic habitats. Blue-green algae can grow in full sunlight and in almost complete darkness. In the Jenolan caves of Australia, for example, they grow on moist limestone near incandescent lamps that are lighted for only six hours a week while tourists pass through.

The majority of blue-green algae are aerobic photoautotrophs: their life processes require only oxygen, light and inorganic substances. The process of photosynthesis uses the energy of light to build carbohydrates (and some fats) out of carbon dioxide in the air or the water. The process of respiration then uses oxygen to "burn" these products and supply the energy needed for the rest of the alga's activities. Unlike more advanced organisms, these algae need no substances that have been preformed by other organisms.

A few forms of blue-green algae, such as a species of *Oscillatoria* that is found in mud at the bottom of the Thames, are able to live anaerobically: their life processes do not require free oxygen. They obtain their energy from inorganic compounds such as hydrogen sulfide. Other species, notably some that live in the soil, can grow in the dark if they are supplied with suitable organic nutrients. Some forms are able to fix atmospheric nitrogen in soluble salts that can then be utilized by the alga itself.

A remarkable feature of blue-green algae in water is their ability to move even though they possess no recognizable locomotory parts such as flagella and cilia. The filamentous forms can move fairly rapidly; the unicellular forms move much more slowly. All the blue-green algae exhibit a gliding movement parallel to the alga's long axis. The movement can be either forward or backward. Sometimes it is accompanied by rotation.

Several mechanisms have been put forward to explain these movements. One currently receiving attention is that the excretion of a mucilaginous substance propels the alga. Other proposed mechanisms involve osmosis, surface tension, the streaming of cytoplasm within the cell and the propagation of rhythmic waves of contraction through the cell. In connection with this last hypothesis a scalloped edge visible in electron micrographs of some species of blue-green algae may be significant. Such an edge could be associated with contractile movement.

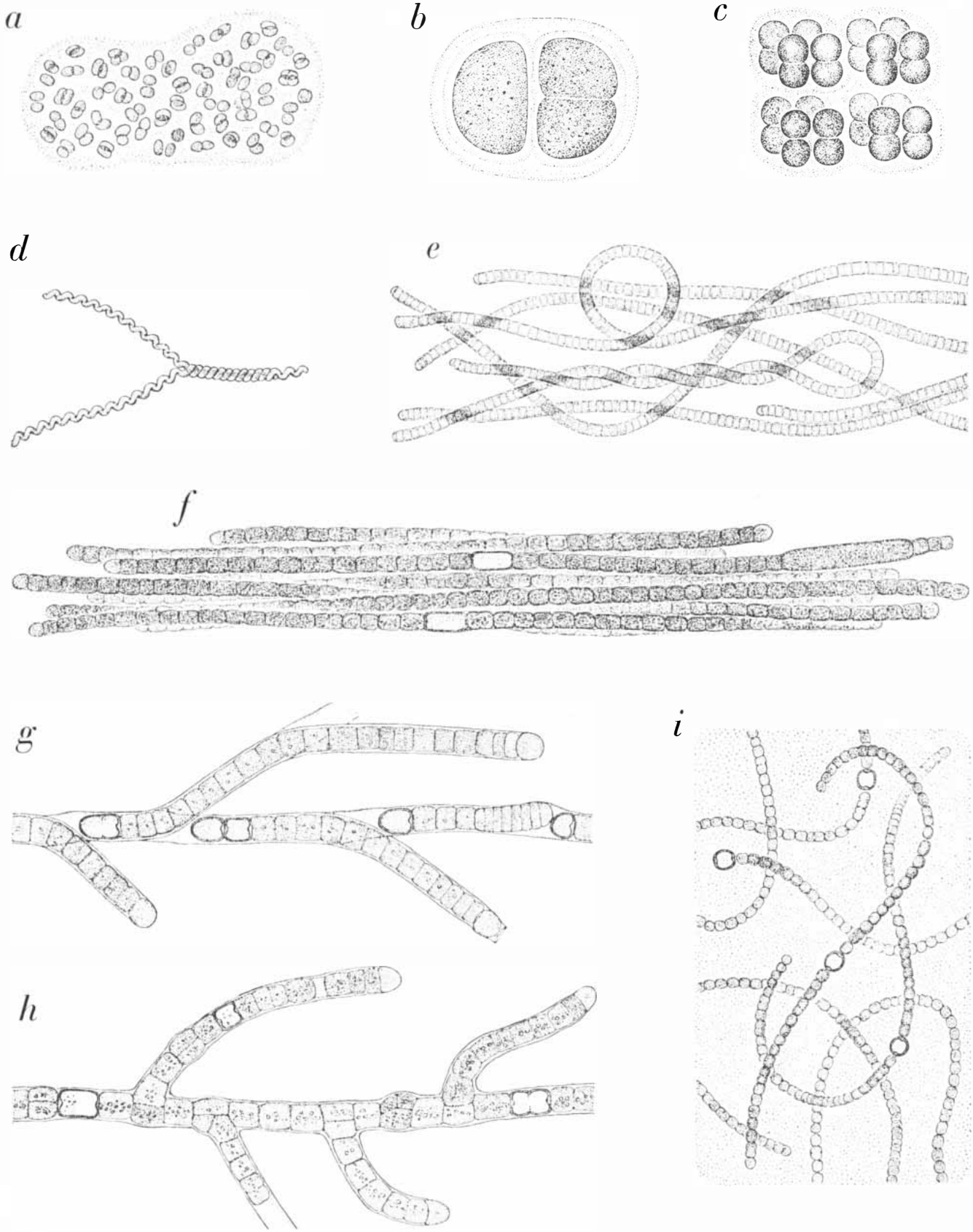
Another remarkable feature of the blue-green algae is their ability to withstand environmental extremes such as high and low temperatures and high concentrations of salt. Indeed, blue-green algae are perhaps best known to biologists as inhabitants of hot springs. Most of these "thermal" species live at temperatures of 50 to 60 degrees centigrade (122 to 140 degrees Fahrenheit); a few have been known to exist at temperatures as high as 85 degrees C. (185 degrees F.). Yet most of the thermal blue-green algae can also thrive at normal temperatures. Several species that flourish in my laboratory at the University of Cambridge at a temperature of 15 degrees C. (59 degrees F.) were collected from a hot spring in Yellowstone National Park.

As for the other end of the environmental temperature scale, blue-green algae are found in mountain streams and in Antarctic lakes. Some species live in association with lichens on bare mountain rocks in polar regions, where the surface temperature may vary in a few hours from −60 to +15 degrees C. (−76 to +59 degrees F.). In fact, the only cold environment in which blue-green algae are rare is snow.

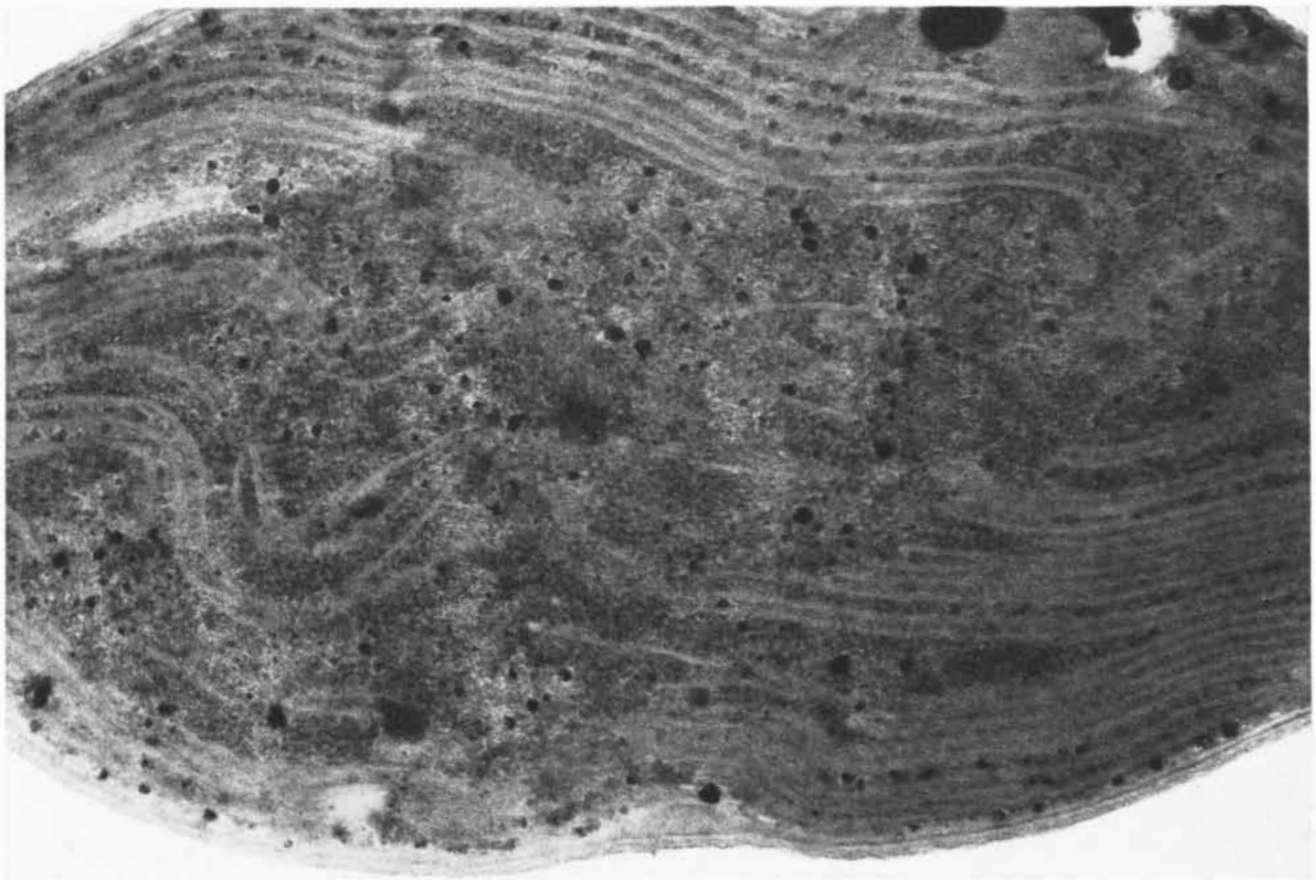
About a fifth of all the blue-green algae live in saline environments. A few

ORDER AND FAMILY	GENERA	CHARACTERISTICS
ORDER CHROÖCOCCALES	*ANACYSTIS* *CHROÖCOCCUS* *GLOEOCAPSA* *GLOEOTHECE* *MERISMOPEDIA* *MICROCYSTIS* *SYNECHOCOCCUS* *SYNECHOCYSTIS*	Unicellular and free-living, solitary or colonial.
ORDER CHAMAESIPHONALES	*CHAMAESIPHON* *DERMOCARPA*	Unicellular and free-living, solitary or colonial. Spore-producing.
ORDER PLEUROCAPSALES	*PLEUROCAPSA*	Filamentous. Growing on or in rocks.
ORDER NOSTOCALES		Filamentous, simple or branched.
FAMILY OSCILLATORIACEAE	*LYNGBYA* *OSCILLATORIA*	Simple filaments. No heterocysts.
FAMILY SCYTONEMATACEAE	*PLECTONEMA* *SCYTONEMA* *TOLYPOTHRIX*	False branching. Generally with heterocysts.
FAMILY RIVULARIACEAE	*GLOEOTRICHIA* *RIVULARIA*	False branching. Colonial.
FAMILY NOSTOCACEAE	*ANABAENA* *CYLINDROSPERMUM* *NOSTOC*	Simple filaments.
ORDER STIGONEMATALES	*FISCHERELLA* *STIGONEMA*	True branching. Heterocysts.

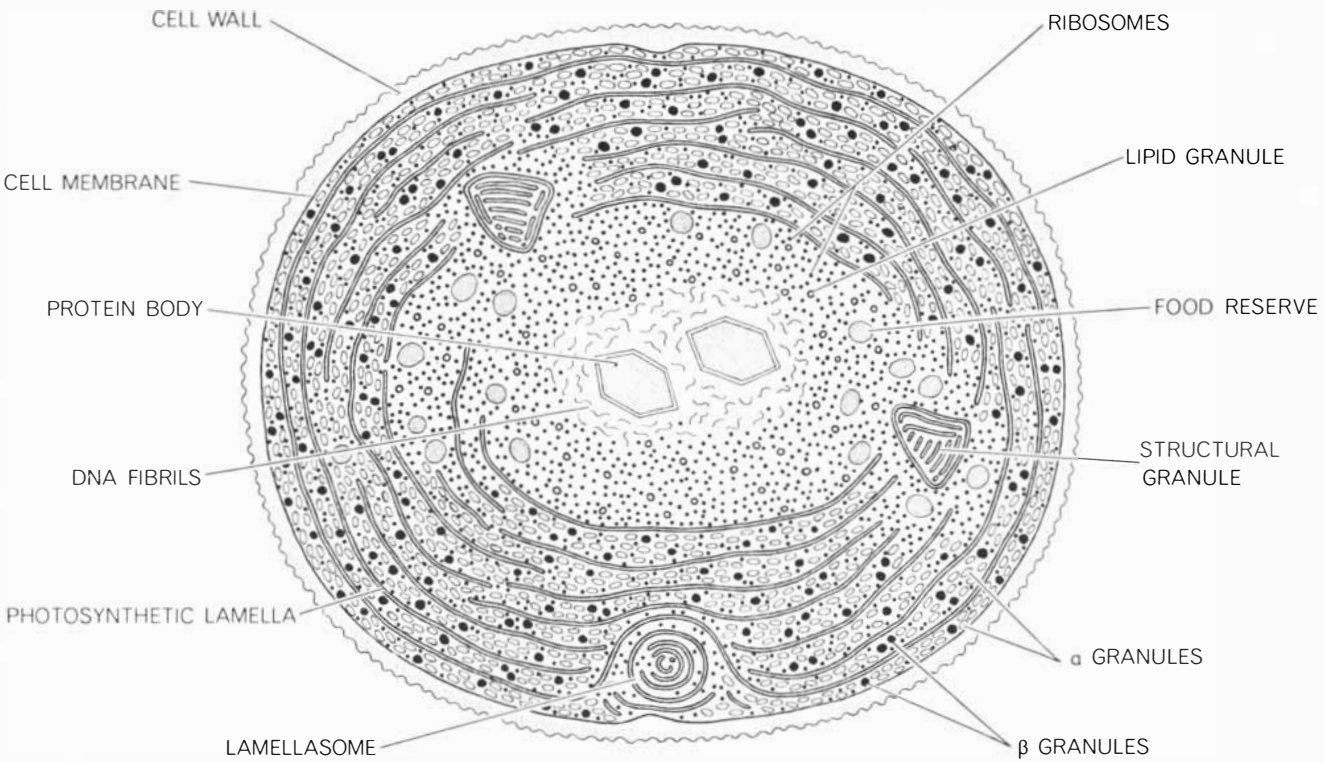
CLASSIFICATION of blue-green algae according to a system used by many botanists lists them in the division Schizophyta, class Myxophyceae (Cyanophyceae) of the plant kingdom. About 2,000 species of blue-green alga are grouped in the orders and families shown here.



TYPICAL SPECIMENS of blue-green algae include, at top, three of the unicellular and free-living variety: *a, Coccochloris* in a loosely formed colony; *b, Anacystis dimidiata* dividing; *c, Anacystis thermalis* in a compact colony. The remaining examples are of genera in which several cells exist together in a filament: *d, Spirulina,* with two intertwined filaments; *e, Oscillatoria; f, Aphanizomenon,* with two of the large, colorless cells called heterocysts; *g, Tolypothrix,* which is a genus with false branching; *h, Hapalosiphon,* which has true branching; *i, Nostoc* in a gelatinous mass. Each species is represented at an enlargement of about 500 diameters.



UNICELLULAR BLUE-GREEN ALGA is enlarged 90,000 diameters in this electron micrograph of a specimen of *Anacystis montana*. Like all species of blue-green alga, the cell lacks a well-defined nucleus. A cell of the same species is shown in detail below.



PRINCIPAL PARTS of a cell of *Anacystis montana* are identified. This genus, like other blue-green algae, lacks the highly specialized structures such as mitochondria and chloroplasts that are found in the cells of higher living forms. The function of many algal structures, including the larger ones, is unknown. Not shown is a gelatinous outer sheath characteristic of the blue-green algae.

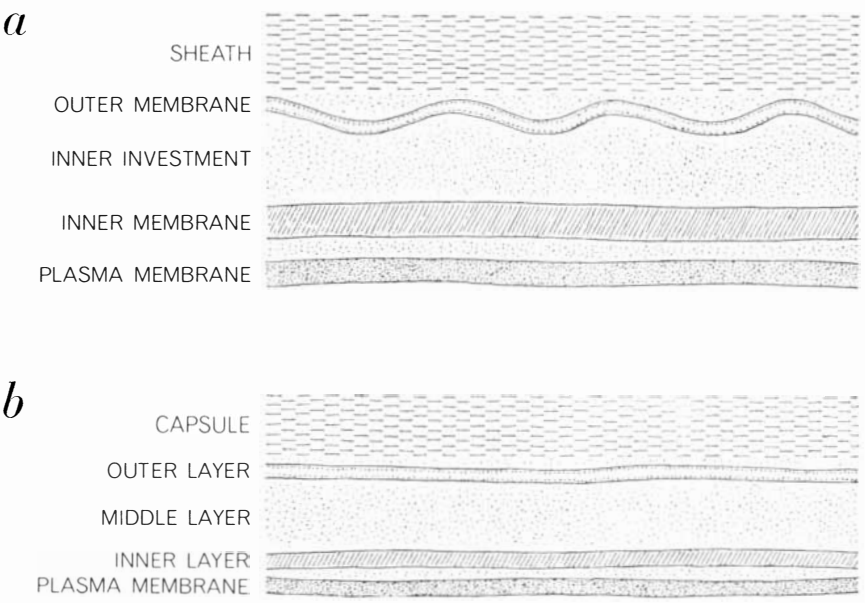
species are truly halophilic, or salt-tolerant; such species are found in southern France and in California in brines with a salt concentration as high as 27 percent. (The concentration of salt in seawater is about 3 percent.) An extreme example of high salt tolerance is the single-celled species *Gomphosphaeria,* which grows abundantly in the spring called Bitter Waters in Death Valley. The concentration of magnesium salts there is so high that the mud around the spring is encrusted with them.

From the evolutionary standpoint the algae in general are of interest because of the trends they reveal in the internal organization of the cell and the mechanism of cellular reproduction. The blue-green algae in particular, with their simple cell structure and asexual reproduction, appear to stand in close relation to the first organisms on earth. It is in this context that the similarities between the blue-green algae and the bacteria have intrigued a number of investigators.

Three features that set the blue-green algae and the bacteria apart from all other cellular organisms have been known for some time. These features are the absence of nuclei, the absence of specialized organelles and the absence of sexual reproduction. Citing the absence of certain features from two groups of organisms is, however, a rather negative way of establishing similarity between the groups. With the advances of electron microscopy in recent years it has become possible to examine the fine structure of blue-green algae and bacteria and so to find some positive similarities between them.

One such similarity is a fairly close resemblance between the cell wall of blue-green algae (not the gelatinous sheath) and the cell wall of bacteria [*see illustration on this page*]. In both cases an important component of the cell wall belongs to the class of molecules known as mucopeptides. Another similarity is that in both blue-green algae and the photosynthetic bacteria (as in other photosynthetic organisms) the essential feature of the photosynthetic apparatus is a set of membranes enclosing a space. In the blue-green algae these are the lamellae; in the photosynthetic bacteria they are called the chromatophores.

These similarities and others argue strongly for isolating blue-green algae and bacteria in a group distinct from all other organisms. I would also argue



STRUCTURAL RESEMBLANCE between blue-green algae and bacteria is typified by the similarities of their exteriors. At *a* are the sheath and cell wall of a cell of blue-green alga; at *b*, the capsule and wall of a typical bacterium. The particular similarities are in the structure of the walls. In each organism the distance between the outside of the outer membrane or layer and the inside of the inner one is between 200 and 400 angstrom units.

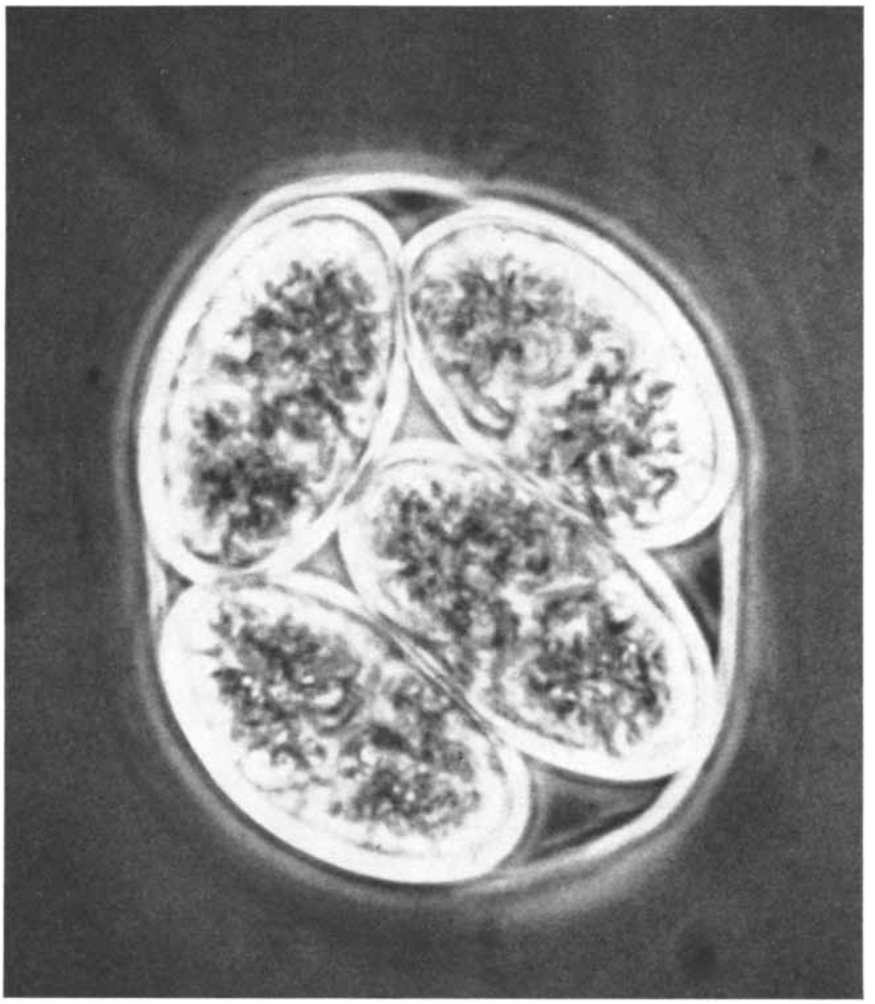
that the blue-green algae and the bacteria have probably descended from the same type of ancestral cell, although here I must rest my case more on speculation than on firm evidence. It is true that there are differences between the two types of organism. Blue-green algae are generally aerobic and photosynthetic and are more complex in form than the bacteria. The bacteria are either aerobic or anaerobic, but they are usually not photosynthetic; they require for their existence substances preformed by other organisms. In cases where bacteria are photosynthetic they differ from blue-green algae in photosynthetic mechanism, particularly in the chemical nature of the pigments.

Still, the similarities are too marked to be overlooked. It is unlikely that so many kindred features would arise independently. This is the root of the argument for a common ancestral cell. The conspicuous differences between the blue-green algae and the bacteria presumably arose at later stages in their evolution.

Perhaps the most important contribution made by the blue-green algae to human affairs lies in the fact that the nitrogen-fixing species increase the fertility of the soil. It is more than likely that this contribution can be enhanced. R. N. Singh of the Banares Hindu University in India has shown that the introduction of blue-green algae to saline and alkaline soils in the province of Uttar Pradesh increases the soils' content of nitrogen and organic matter and also their capacity for holding water. The treatment has so much improved these formerly barren soils that they can now be used to grow crops.

Other studies have shown that blue-green algae can fix enough nitrogen to support a good crop of rice and leave about 70 pounds of nitrogen in each acre after the harvesting of the rice. Astushi Watanabe of the University of Tokyo tested several species of blue-green alga in rice paddies and found that the filamentous form *Tolypothrix tenuis* yielded 1¼ tons of nitrogen per acre per year. Watanabe grew the algae in his laboratory on fine gravel soaked with a culture medium and aerated with air rich in carbon dioxide. The cultures were transferred to the experimental site in plastic bags and then inoculated into it. This kind of inoculation over a period of years increased the nitrogen in the soil by 30 percent and the yield of the rice crop by 20 percent.

Experiments conducted some years ago in Kansas, Oklahoma and Texas by W. E. Booth of the University of Kansas showed that a coating of blue-green algae on prairie soil binds the particles of the soil together, maintains a high water content and reduces erosion. Singh has envisioned the agricultural application of algal "blooms": huge shoals of algae that sometimes form in



SYMBIOTIC RELATION of blue-green algae and another organism is represented by four cells of *Glaucocystis nostochinearum*, which are enlarged some 2,200 diameters in this photomicrograph. The host cells are a green alga that has lost its chloroplasts. Inside the host cells are filaments of a blue-green alga that apparently function as chloroplasts.

bodies of water. (The Red Sea, for example, owes its occasional red color to blooms of the blue-green alga *Trichodesmium*.) Singh's proposal is to use blooms as a manure because of their high content of nitrogen and phosphorus. He found that adding dried blooms to soil in which sugarcane was growing substantially increased the crop yield. Periodic applications of fertilizers sufficient to maintain a continuous bloom of algae in fishing lakes in Alabama and Mississippi nourished the large numbers of small animals on which fish feed.

Blue-green algae are often the first plants to colonize bare areas of rock and soil. A dramatic example of such colonization is provided by the island of Krakatoa in Indonesia, which was denuded of all visible plant life by its cataclysmic volcanic explosion of 1883. Filamentous blue-green algae were the first plants to appear on the pumice and volcanic ash; within a few years they had formed a dark green gelatinous growth. The layer of blue-green algae formed in such circumstances eventually becomes thick enough to provide a soil rich in organic matter for the growth of higher plants. The algae further contribute to soil formation by acting to break down the surface of the rock.

Some of the blue-green algae that live symbiotically with other organisms undoubtedly have an economic impact, but it is difficult to measure. The best-known example of such symbiosis is provided by lichens, which are a combination of a fungus and a blue-green alga. Usually the lichen fungus can grow only if the appropriate alga is present. Lichens, like blue-green algae alone, play an important role in pioneering plant growth on bare rock. The relation between the fungus and the alga is not clearly understood. Presumably the fungus receives carbohydrates and perhaps nitrogen compounds from the alga, and the alga is able to survive in otherwise inhospitable environments because of the moist medium for growth provided by the fungus.

Several examples have come to light in which blue-green algae live parasitically within bacteria or other algae (including some blue-green species). I am currently investigating such an organism, *Glaucocystis nostochinearum*. This is a complex of two organisms: the host cell is a green alga that lacks the chlorophyll-containing chloroplasts, and within it are several filaments of a blue-green alga. Apparently the blue-green algae act as chloroplasts for the host cell.

There are many associations between blue-green algae and animals. The exact physiological relation between the partners is not known; presumably the partnership produces an essential substance that neither partner could produce by itself. In associations of this kind it seems likely that the blue-green algae originally entered the host as food but resisted digestion and stayed permanently—even, in the case of simple algae that reproduce by dividing, unto succeeding generations.

Whereas some blue-green algae act to break down rock, the species that live in hot springs actually build rock. This they accomplish by depositing salts of calcium and possibly silica within the gelatinous sheath of the algal cell wall. At Mammoth Hot Springs in Yellowstone National Park, for example, the algae deposit travertine at the rate of two feet a year. The bright colors of the basins and terraces around such hot springs are caused by the algae living in the outer layers.

As one might expect of so large and widely distributed a group of organisms, the blue-green algae have some effects inimical to the interests of man. Today their most harmful effect is undoubtedly the formation of blooms in bodies of water. When these epidemic growths occur in fresh water, they can be hazardous to human health. They choke the intakes of water-supply systems and give the water a disagreeable odor. To make matters worse, the increasing pollution of fresh waters in heavily populated areas favors the growth of algae and not of other organisms. Lake Erie, which once had white beaches and supported a prosperous fishing industry, is now seriously infested with blue-green algae. Sewage,

industrial wastes and an estimated 80 tons a day of phosphates in water running off from farmlands have turned parts of the lake into a vast tank for the culture of algae. The algae rob the water of its oxygen, and the lake becomes incapable of supporting fish life. They also wash onto the beaches and cover them with a malodorous green slime.

The measures needed to ameliorate this problem may cost the states that adjoin the lake up to a billion dollars apiece. The states have to expand sewage plants and establish tighter controls over industrial wastes. They may also have to treat the water in areas where blooms occur with such algicides as copper sulfate, which in concentrations as low as two parts per million prevent all species of blue-green alga from growing.

Under certain circumstances freshwater algae of such genera as *Microcystis, Aphanizomenon* and *Anabaena* can cause death or injury to animals. Cases of human illness associated with blue-green algae are on record, even though forms such as *Oscillospira* and *Anabaenolium* normally reside in the human gastrointestinal tract. Various gastrointestinal, respiratory and skin disorders have been traced to the ingestion or inhalation of blue-green algae or to contact with them. In South Africa in 1943 thousands of cattle and sheep were killed along a dam in the Transvaal, where the reservoir developed a poisonous bloom of *Microcystis*. The toxic substance, which was ingested by the animals when they were watered, was later identified as an alkaloid that affects the liver and central nervous system.

In general the harmful effects of blue-green algae can be controlled. The beneficial effects are open to further development. The time may come, for example, when the pressure of population on food supplies will justify mass cultivation of the blue-green algae, perhaps in conjunction with other algae. At present blue-green algae are seldom eaten by humans. There is, however, a species of *Nostoc* that forms into balls called "water plums," which have a high content of protein and oil and are eaten in parts of China and South America. Most blue-green algae are rather unpalatable, but that difficulty could be overcome by suitable flavorings or by feeding the algae to fish, poultry and cattle destined for human consumption.

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APPLICATIONS OF THE COANDA EFFECT

When a liquid or gas flows along a solid surface, it tends to stick to the surface. This effect, named for a Romanian aircraft pioneer, has potential uses in such devices as burners and hovering vehicles

by Imants Reba

Everyone knows that it is not easy to pour a liquid smoothly out of a teapot spout or the mouth of a bottle. The liquid has an annoying tendency to flow around the lip and dribble down the curved surface of the spout or the side of the bottle. What causes the flow to bend and cling to the vessel's surface? Is it simply surface tension, as has usually been supposed? The answer is not quite so simple, and it has significant technological consequences.

In the year 1910 a young Romanian-born engineer named Henri Coanda tested a new flying machine he had built himself. He had been a student of Alexandre Gustave Eiffel, designer of the Eiffel Tower and one of the pioneers of modern aerodynamics, at the École Supérieure Aeronautique in Paris,

"TEAPOT EFFECT" is a low-speed form of the Coanda effect: water poured slowly from a glass tends to stick to the side of the glass in the same way that tea sticks to the spout of a teapot. High-speed fluids similarly adhere to a surface of suitable shape.

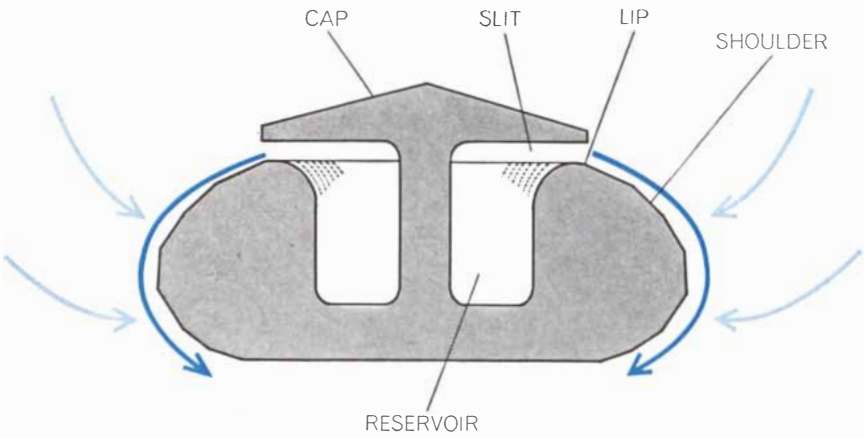
and the young engineer's approach to flying was both bold and imaginative. Coanda's machine was a kind of jet aircraft. It was equipped with an air compressor powered by a reciprocating engine; thrust was obtained by injecting fuel into the compressed air to provide a kind of afterburner. At the outset Coanda was confronted with the possibility that the flames from his two jet exhausts might set fire to the plane's fuselage, which was made of plywood. He therefore installed metal plates to deflect the exhaust flames away from the fuselage.

Coanda took his vehicle out for a test run on a field at Issy-les-Moulineaux, a Paris suburb. As he taxied across the field he saw with dismay that the deflecting plates, instead of diverting the exhaust away from the body of the plane, were actually sucking the flames toward it! Preoccupied with this surprising development and with handling the engine throttle, Coanda did not notice until the last moment that he was approaching the Paris city wall at high speed. He jerked back on the control stick, became airborne long enough to clear the wall, then crashed.

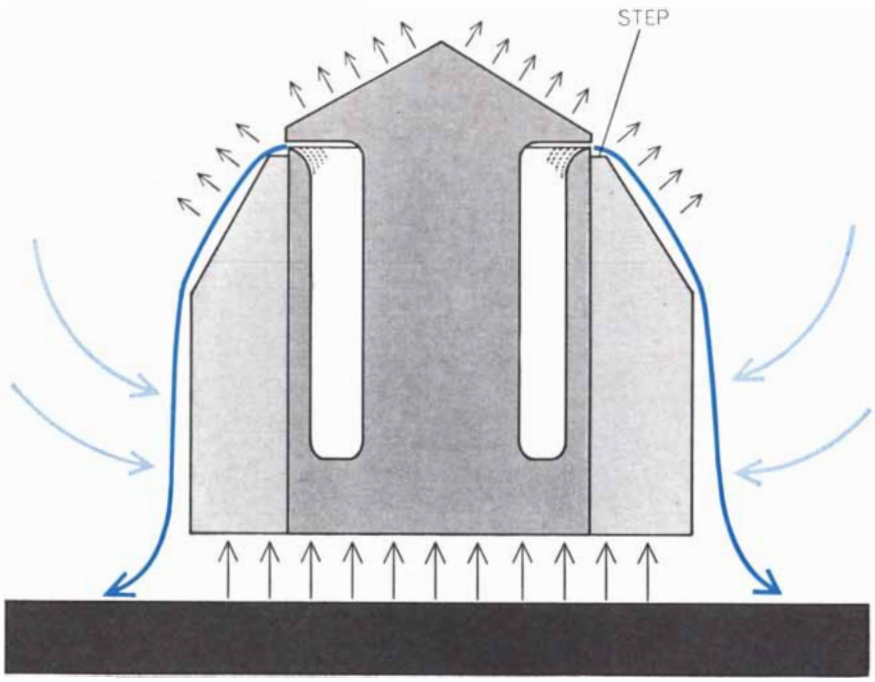
As far as is known, this was the first flight of a jet airplane. Reflecting on the incident, however, Coanda was less interested in the takeoff than in the strange phenomenon of the wrong-way bending of the jets by his deflector plates. At the first opportunity he discussed the event with Theodor von Kármán, the foremost theorist of aerodynamics, who was then working at the University of Göttingen. Von Kármán realized that the phenomenon was a new discovery and named it the Coanda effect.

Twenty-five years or more passed before any other investigator gave serious attention to the Coanda effect. Coanda himself went to work as chief engineer of the Bristol Aeroplane Company in Britain and became involved in various technical researches having nothing to do with this subject. In his spare time, however, he carried on experiments to examine the basic features of the effect and its possible uses.

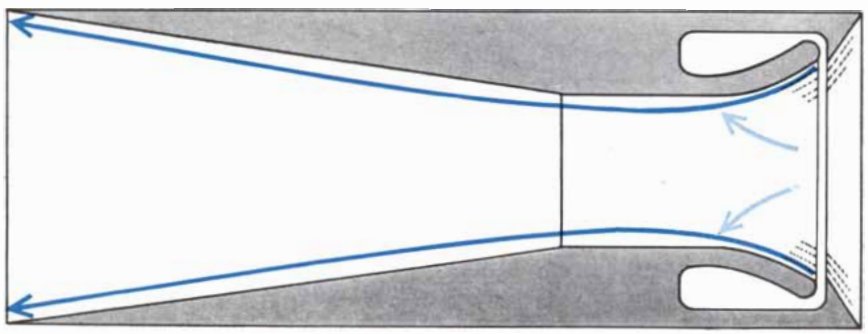
Consider a sheet of fluid (gaseous or liquid) that is discharged through a slit onto an extended and rounded lip. As in the case of the teapot spout, the sheetlike stream will attach itself to the curved surface and follow its contour. Coanda found that by constructing a shoulder composed of a series of



COANDA EFFECT was named for the tendency of a fluid, either gaseous or liquid, to cling to a surface that is near an orifice from which the fluid emerges. In this representation air from the reservoir emerges through the slit and, as shown by the dark color, closely follows the sides of the vessel. An important part of the effect is the tendency of the primary flow of air to entrain, or draw in, more air (*light color*) from the environment.



EXTERNAL NOZZLE was designed by the author in early tests of the Coanda effect as a means of generating lift. Pressure over the upper portion proved to be less than atmospheric; hence a vehicle with the shape of such a nozzle could be lifted by low pressure at top and higher pressure at bottom. Step near slit proved to be crucial in maintaining good lift.



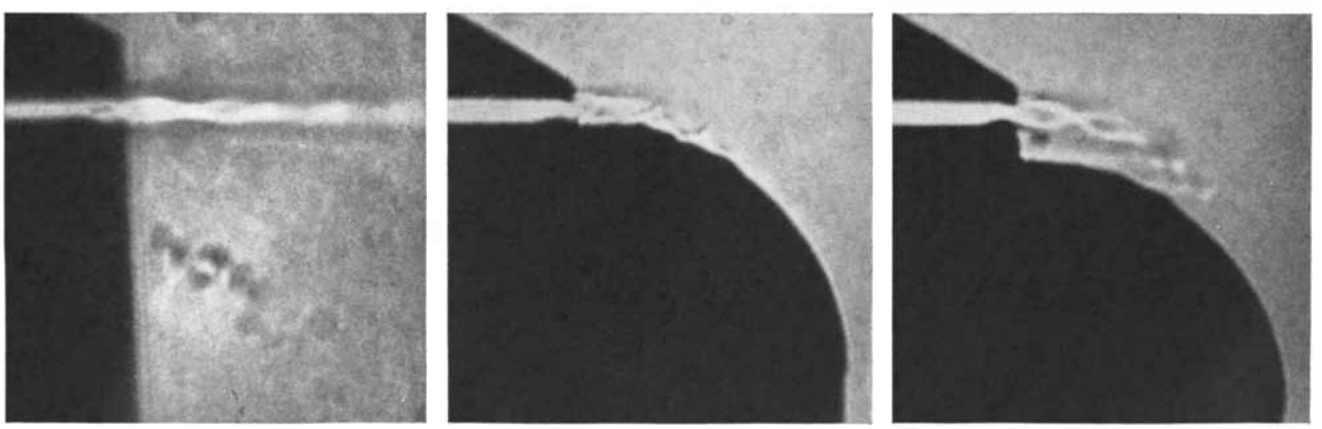
INTERNAL NOZZLE takes its name from the fact that the flow of air is through the inside of the nozzle. Otherwise the Coanda effect is the same as that in the external nozzle.

short, flat surfaces, each at a certain angle to the one before and each with a certain length, he could bend a jet stream around an arc of 180 degrees [*see top illustration on preceding page*]. Moreover, by experimenting with air blown through the slit he discovered that the deflected airstream sucked in air from the surroundings. As the jet flowed around the shoulder it entrained up to 20 times the amount of air in the original jet. Coanda measured the air pressure at various points along the surface over which the stream was flowing, and he established the significant fact that the pressure on the surface was less than atmospheric pressure: in other words, it represented a relative vacuum. Near the slit the existence of this vacuum accelerated the flow of the jet after it emerged from the slit.

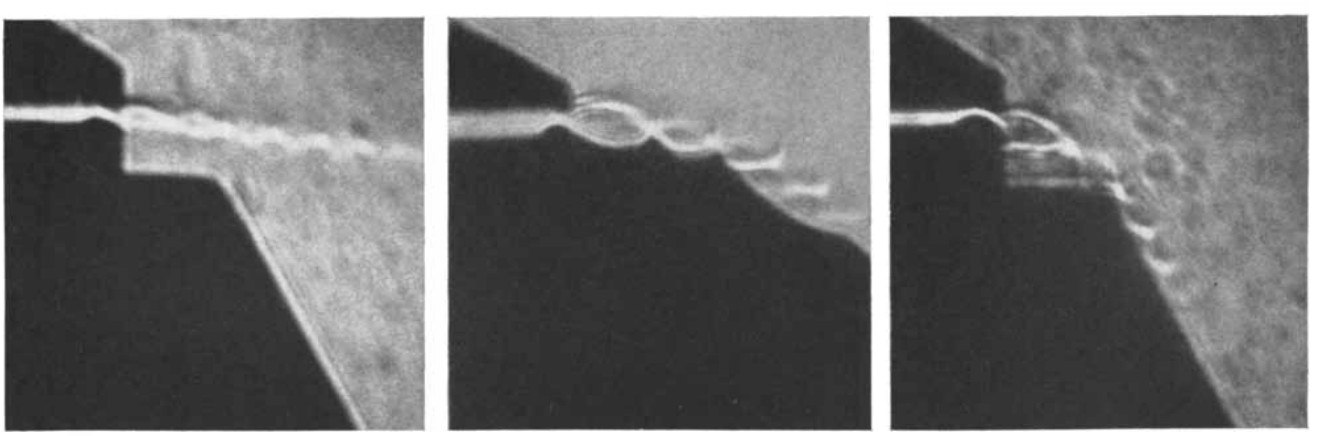
From his experiments and calculations Coanda derived a remarkable conclusion. The Coanda effect, he argued, could lift and propel a vehicle by a process that was the reverse of that in conventional propulsion systems. Instead of applying force at the rear of the vehicle (such as a rocket or a boat) to propel it against the resistance of the air or water in front, one could use the Coanda effect to generate a vacuum at the front, so that the higher pressure at the rear would impel rather than propel it. Similarly, a Coanda-generated vacuum above the vehicle would provide lift. In conventional aircraft-propulsion systems the necessary vacuum above the wings is generated by driving the vehicle forward at high speed; the Coanda system would accomplish the same purpose without any forward motion or moving parts simply by blowing air over a rounded shoulder.

In aerodynamics the problem of propulsion is reduced to the problem of overcoming drag, a resistance whose components are high pressure at the nose of the vehicle and low pressure at the tail. Coanda's proposal, to put it briefly, consists of propelling the vehicle by means of "negative drag": low pressure at the nose and higher pressure at the rear. This suggestion is so completely contrary to ordinary concepts about the flow of a fluid around moving bodies that it has understandably met with great skepticism among aerodynamicists.

Undismayed by skeptics or by the general lack of interest in his ideas, Coanda proceeded to construct various nozzles embodying his effect and to design vehicles to be propelled by them. The fact that some of his designs took the shape of flying saucers has not helped matters. The Coanda effect might have been dismissed as an eccentric notion had it not attracted the attention of the team of Allied scientists that was assigned to investigate the German wartime research after the liberation of Paris in World War II. It was alleged that the Germans had conscripted Coanda into their jet-propulsion research. In any case, the Allied scientists examined Coanda's devices and suggested that the Coanda effect merited seri-



IMPORTANCE OF GEOMETRY in optimizing the Coanda effect is demonstrated by these shadow photographs. At left is the flow of an undeflected jet of air. With a curved surface outside the slit (*middle*) the air tends to follow the surface, but with distortions. A step at the exit of the slit (*right*) produced a better flow but not an ideal one because the air impinged on the surface.



FURTHER MODIFICATIONS showed (*left*) that too high a step can cause the flow to separate from the surface. With a grooved surface (*middle*) the flow was undistorted. A well-balanced geometry (*right*) provided an ideal flow that was tangent to the surface.

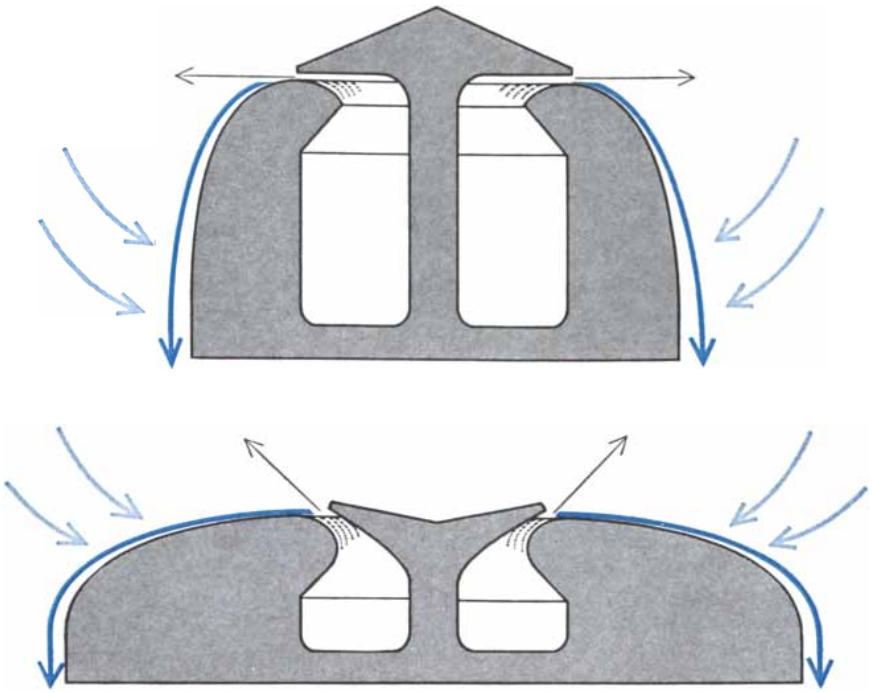
ous study. A theoretical analysis by von Kármán in 1949 and experiments at the Cornell Aeronautical Laboratory in 1952 supported Coanda. Several other investigators, however, reported that his claims could not be confirmed, and this discouraged a thoroughgoing evaluation of his ideas.

Happily unaware of the controversy among the experts, I was attracted to Coanda's concept by an article about him in a popular magazine in 1956. As a student at the Polytechnic Institute of Brooklyn, I was particularly interested in propulsion systems, and the unorthodox Coanda approach seemed exciting. When I went on to graduate studies at the institute, working as a research assistant in its newly established Rocket Propulsion Laboratory, I had the good fortune to obtain more technical information about the Coanda effect from T. Paul Torda, director of the laboratory, who had worked with von Kármán on the theoretical analysis.

I set out to test the effect with a nozzle of my own design. Coanda had experimented with both "external" and "internal" nozzles. In the former the deflecting shoulders were outside a tube; in the latter, inside [*see middle and bottom illustrations on page 85*]. My nozzle was of the external type: a roughly cone-shaped arrangement in which air blown outward through a slit circling the body would cascade over a shoulder angled 60 degrees from the slit. This form of the device was inspired by the thought that the Coanda effect might be applied to a "ground-effect machine," the type of vehicle that moves over the ground on a thin cushion of air. For such a machine one of the main problems is steering and related control, since it has no traction with the ground. It seemed that Coanda nozzles might provide such controls.

The first tests of the nozzle were successful. With a nozzle positioned upright in a model ground-effect machine, the Coanda phenomenon caused the model to take off and rise to a height of several inches when a fast stream of air was blown through the slit. Emerging from the slit at the speed of sound, the air accelerated to supersonic speed as soon as it began to flow over the shoulder.

In 1961, having joined the Armour Research Foundation, now the IIT Research Institute associated with the Illinois Institute of Technology, I was provided with funds for an investigation of the possible use of the Coanda effect for propulsion. Coanda had said that a Coanda nozzle, by increasing the momentum of the gas flow, could produce twice as much thrust as an ideal straight nozzle with the same input of energy. Experimenters testing his claim had failed to achieve any augmentation of thrust by means of the Coanda effect. Their test devices, however, were quite simple in design, whereas Coanda had developed rather sophisticated nozzles of complicated geometry. It therefore remained possible that with proper design a gain in thrust could be demonstrated.



REORIENTATION OF SURFACES was necessary to progress from nozzle-like applications of the Coanda effect (*top*) to the wide-based shape (*bottom*) desirable for a ground-effect machine. The changes involved much experimentation with different configurations.

As a start in our testing program I designed a one-piece nozzle six inches in diameter with a shoulder in the form of a series of successively angled flat surfaces, according to Coanda's original design. The results of its first test were most disappointing. The airstream from the slit did not flow around the shoulder contour; it promptly detached itself unless the slit opening was made very small or the flow was very gentle and undisturbed. I went home from the laboratory frustrated and discouraged. But my assistant, Edward Wohlthausen, stayed on and carefully went over every feature of the nozzle's construction. He discovered a seemingly trivial difference, which turned out to be crucial, between this model and the one I had built originally at Brooklyn Polytech. My first model had had a small step down from the mouth of the slit. This small step at the aperture, only about a thirty-second of an inch deep, made the difference between the airstream's clinging to the shoulder and separating from it. With such a step the new model also worked.

We then proceeded to extensive testing of some 30 different shoulder configurations. With the help of shadowgraph photography that showed details of the flow, we obtained several interesting insights into the Coanda effect [*see illustrations on opposite page*]. The small step at the very lip of the slit is important because it turns the flow from the slit into an eddy, or vortex, which in this device rings the entire nozzle and therefore forms what is called a ring vortex. It is the vortex—or rather the low pressure generated within it—that causes the stream from the slit to bend and thus follow the contour of the shoulder. The curving of the stream around the shoulder produces a force directed radially outward; this force, tending to pull air away from the shoulder surface, apparently accounts for the relative vacuum, or suction, next to the surface. To maintain the suction, which prevents separation of the stream from the surface and causes the flow to accelerate, the stream must hug the

shoulder surface closely without actually impinging on it or adhering to it.

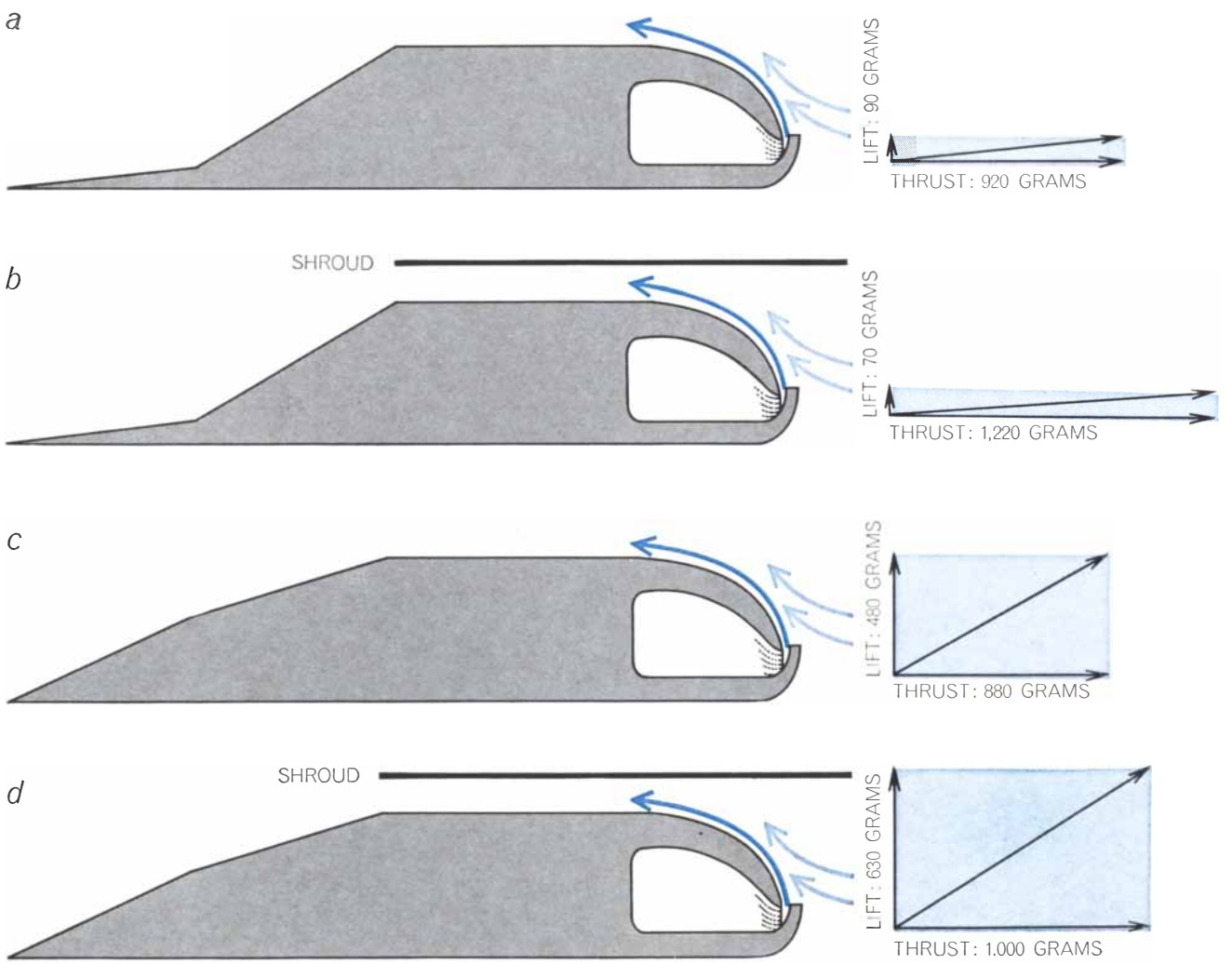
Our experiments showed clearly that the creation of a stable Coanda effect depends on the appropriate adjustment of many factors: the diameter of the slit, the strength of the jet, the depth of the step and various other details of the shoulder contour. Particularly crucial is the ratio of the slit diameter to the diameter of the nozzle as a whole. If the slit is too wide in relation to the shoulder breadth, the stream will tend to detach itself from the surface; if it is too narrow, the stream will tend to stick to the surface. Also important is the texture of the surface: a properly roughened surface helps to prevent distortion of the stream flow. In short, it takes a complex set of arrangements to produce a useful Coanda effect. It is no wonder that most investigators of the effect had found it to be an elusive phenomenon.

Obviously the effect depends primarily on the maintenance of a balance between the centrifugal force and the suction force as the stream flows around the shoulder and afterbody of the nozzle. We found by experiments that the efficiency of the effect could be enhanced by certain adjustments of the orientation of the slit and the slope of the shoulder; these controlled the distribution of pressure within the stream so that it did not separate from the surface.

Although we obtained high thrust efficiencies with such devices, we were not able to produce the gain in thrust (over the theoretical capabilities of conventional jet devices) that Coanda had said should be achievable. At this juncture, in the spring of 1963, Coanda himself visited my laboratory. (He was then 77 years old.) He examined the model with which I was working, bent over it and cupped his hands around the nozzle. The fluid in a manometer attached to the model promptly rose, showing an increase in the suction pressure. By simply forming a shroud around the nozzle with his hands Coanda had increased the device's production of thrust!

The shroud, Coanda explained, guides the streamlines of the entrained flow in a direction parallel to the surface of the model and thus enhances the suction pressure. Coanda went on to emphasize also the importance of proper design of the afterbody, or tail, beyond the shoulder. A suitably tapered afterbody, he said, would cause the flowing stream to exert a positive pressure on the rear of the body and thereby add to the propulsive thrust.

Not entirely convinced of this last argument, because it was so contrary to accepted ideas in aerodynamics, I nevertheless proceeded to build



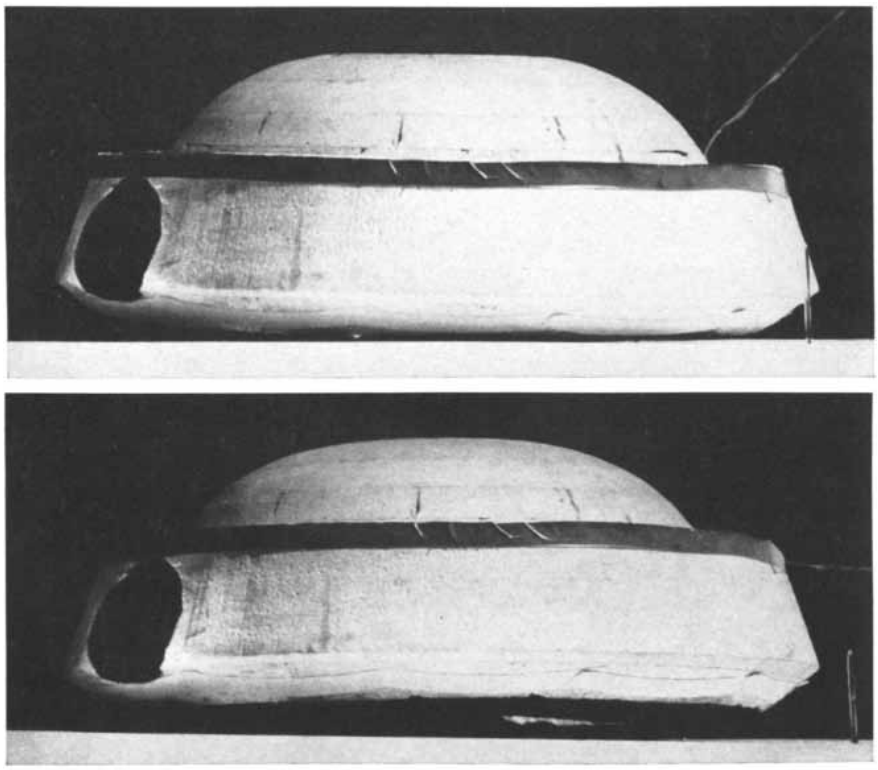
CONFIGURATION AND SHROUDING affect the performance of an airfoil. At *a* the Coanda effect over the airfoil at left produces the forces represented at right. At *b* the result of placing a shroud over the same airfoil is shown. An airfoil of different geometry appears unshrouded at *c* and shrouded at *d*. In each instance the data were obtained from an airfoil that was fixed rather than moving.

several models based on Coanda's recommendations. The shroud concept immediately proved its value in enhancing thrust. The afterbody theory, on the other hand, turned out to be harder to confirm. At length, after more than a year of experimenting with various afterbody configurations, we finally produced one that bore out Coanda's prediction [*see illustration on opposite page*]. This nozzle, with a shroud and a steeply tapered tail, produced a thrust 19 percent greater than that of an ideal jet lacking the augmentation of the Coanda effect.

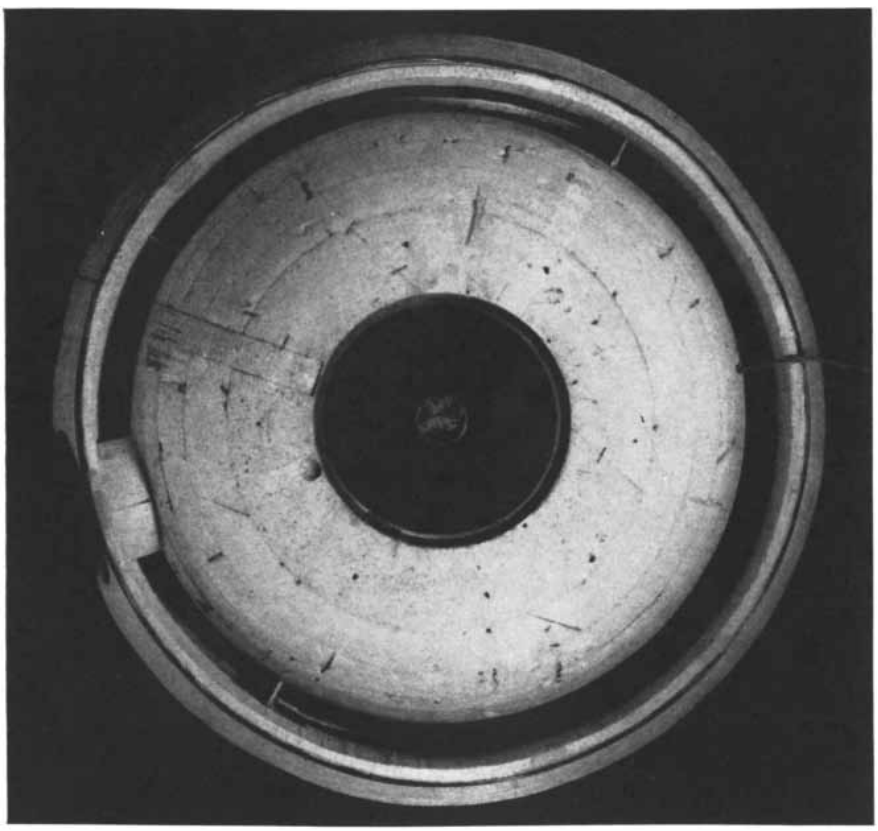
Independent studies at the University of Toronto's Institute of Aerospace Science, at Pennsylvania State University and at the Research Center of the Huyck Corporation in Stamford, Conn., have also verified that Coanda nozzles are capable of augmenting thrust. Gains of up to 38 percent have been reported. Indeed, it can be said that Coanda's hypothesis of propulsion by negative drag has been confirmed.

This is not to say that the Coanda effect is fully understood. There is no doubt that the gain in thrust with the Coanda type of nozzle derives from the fact that a jet sheet flowing around a curved wall entrains more outside fluid than a straight jet stream does. But the mystery remains: Why does it do so? The answer probably lies in the turbulences set up within a curving jet sheet; presumably they promote vigorous mixing of portions of the fluid and so increase the rate of entrainment at the outer edge of the sheet. In any case, we now know from experiments that the Coanda effect does work to augment thrust, and we therefore have a sound basis for exploring possible useful applications of the phenomenon. Indeed, it has already shown its usefulness in another field, namely the device known as the fluid amplifier, whose functioning depends on the Coanda effect [see "Fluid Control Devices," by Stanley W. Angrist; SCIENTIFIC AMERICAN, December, 1964].

The first device we built to test the practical application of Coanda thrust was a small model called GEM (for ground-effect machine). This dome-shaped model, two feet in diameter, has a ring slit at the top, a shoulder configuration in the form of an ellipse with its major axis parallel to the ground and a short, collar-shaped shroud around the lower part [*see illustrations at right*]. The slit is inclined at an angle of 45 degrees from the horizontal, so that the jet is directed upward—contrary to all



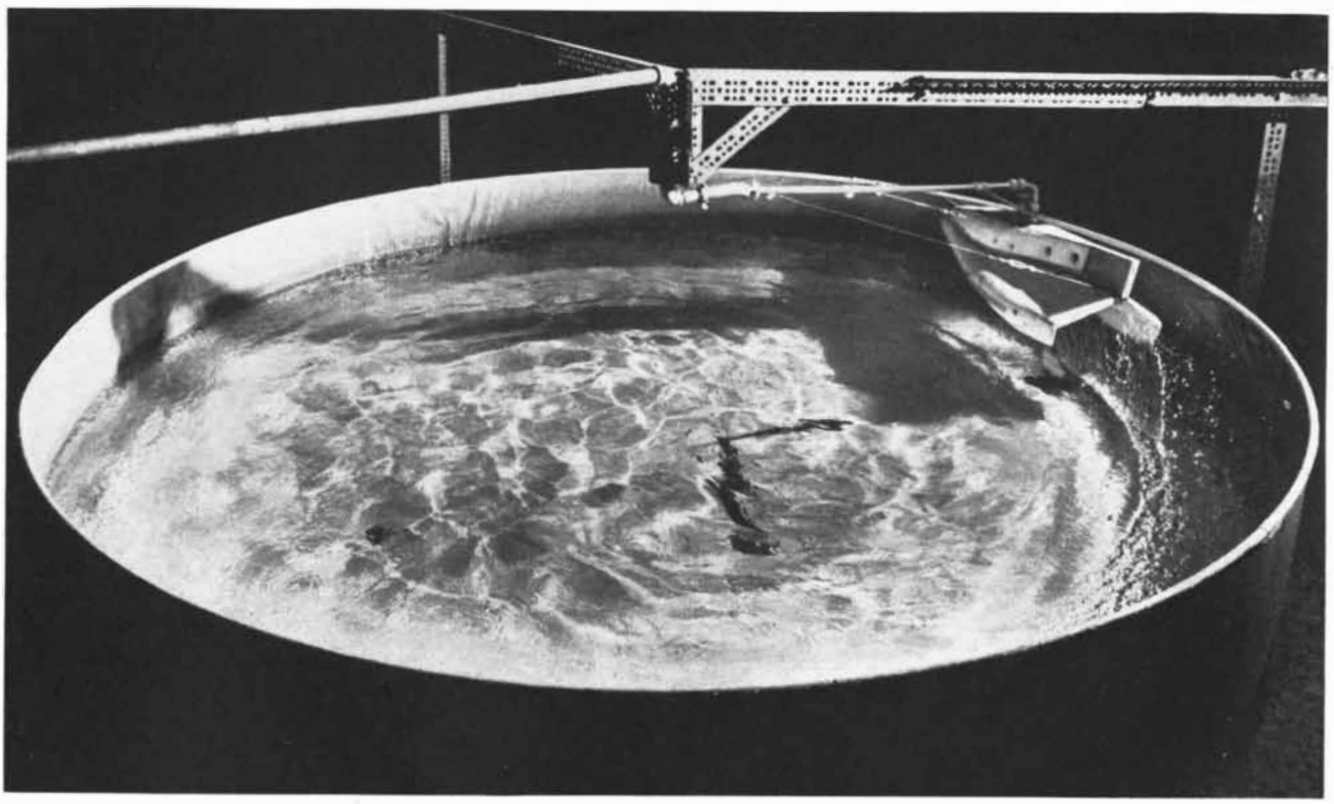
GROUND-EFFECT MACHINE, which is known by the acronym GEM, rests on a table at top and rises from the table at bottom. It achieves lift by means of air, but in an unusual way. Because of the Coanda effect the pressure at GEM's top is less than atmospheric. With this negative drag, or reduced resistance, over the upper portion of the surface, the higher pressure at the bottom lifts or drives the vehicle. The hole on the left side is the air intake.



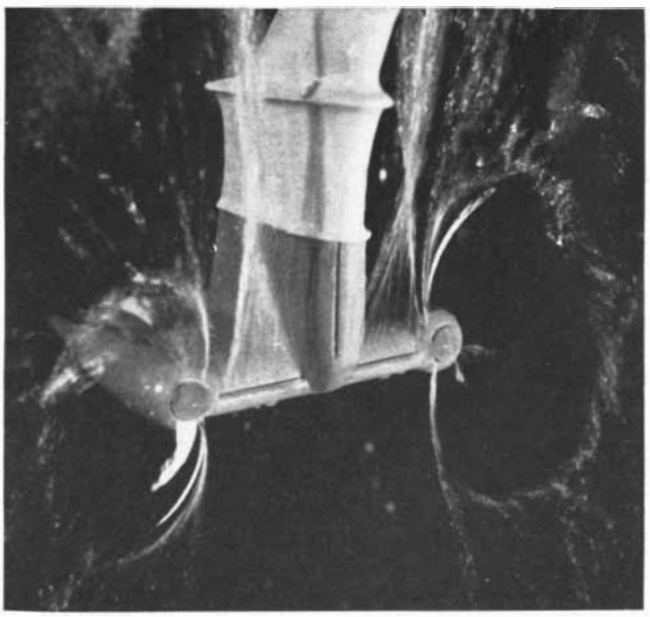
TOP VIEW of the GEM shows the slit from which the air emerges. The slit is the thin light circle near the outer edge of the dark central area. The dark circle just outside the slit is the step. This model, designed by the author, is approximately two feet in diameter.

conventional uses of jet thrust to generate lift. This vehicle is raised from the ground simply by the jet of air that produces a vacuum at the upper surface, flows around the shoulder and emerges at the bottom, thus producing the ground effect: pressure higher than that of the environment. The primary jet, generated by a small ducted fan, represents a comparatively modest application of power, the strength of the jet amounting to a pressure of four inches of water.

The cover hooding the slit at the top of the model can be tilted so that the slit is widened on one side and narrowed on the other; this maneuver, by skewing the distribution of force over the top surface, serves as a means of banking the vehicle in the air. By a simple modification of the vehicle's



HYDROFOIL CRAFT using the Coanda effect has achieved speeds of more than 19 knots in this pool. The model is about four feet long. The wings on the hull are for stabilizing the craft and for generating a ground effect; propulsion is from an underwater foil.



KEY PART of the hydrofoil is this foil with several slits for achieving the Coanda effect. Water emerging from the slits (*right*) tends to curve around the foil because of the Coanda effect, thereby creating a negative drag similar to that in the airborne GEM.

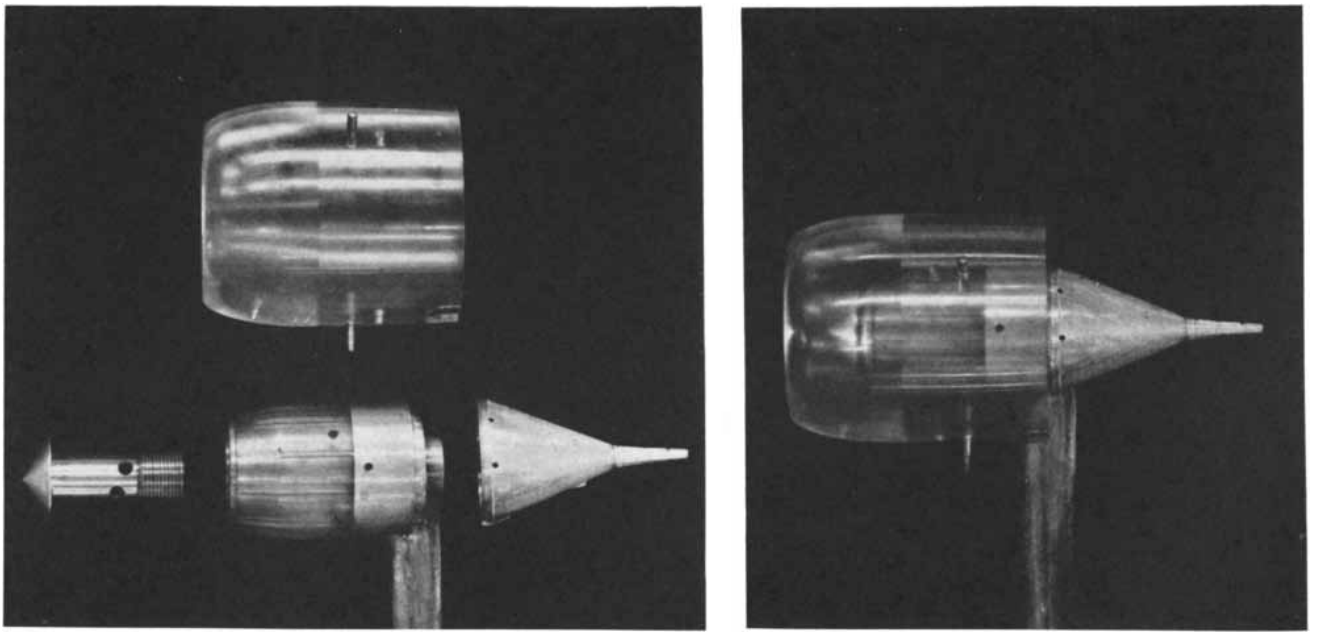
form it has been endowed with forward propulsion. In this model the configuration of the body is asymmetrical, and the resulting asymmetrical distribution of forces in the jet sheet provides forward thrust to the vehicle.

The Coanda system offers several improvements over the present versions of ground-effect machines. It should reduce the amount of power needed for propulsion, reduce the weight of the machine, permit steering of the vehicle by banking and make it easier to mount slopes.

The estimated lift efficiency of the present rather crude model is about 25 pounds of lift per horsepower for a lift-off height of about a twentieth of the diameter of the vehicle. This performance is comparable to that of ground-effect vehicles operated by conventional means. It remains to be seen, however, if a vehicle of the Coanda type will retain comparable lift efficiency when it is scaled up to full size.

Another vehicle currently under development in our laboratory is a boat of the hydrofoil type, that is, a craft in which the foil lifts the hull out of the water. In this case, employing the Coanda effect, the hydrofoil is self-propelling: it provides not only the lift and controls but also the propulsion of the craft. Nozzles that emit jets of water are incorporated in the leading edges of the foil, the strut and water-intake pods. The craft has a hull with downswept wings that I have designed to minimize drag, improve the craft's stability on the water and provide some additional lift by the ground effect [*see illustrations on opposite page*].

Our present model, four feet long and weighing 22 pounds, cruises at better than 20 miles per hour at the end of a tether in a circular pool 10 feet in diameter. It can lift its hull out of the water and ride on the hydrofoil at very low speed and without using any more power than is required for cruising. Control of the craft is accomplished by means of surfaces that do not protrude into the flow. Thanks to the large entrainment of fluid from the vicinity of the nozzles, the foil generates essentially no wake, very little spray and little noise. We believe the use of a "ventilating flow"—achieved by injection of small amounts of air—will minimize undesirable effects caused by cavitation (the formation and collapse of bubbles around the foil). If we are right, a full-scale version of the craft should be capable of speeds of more than 80 knots,

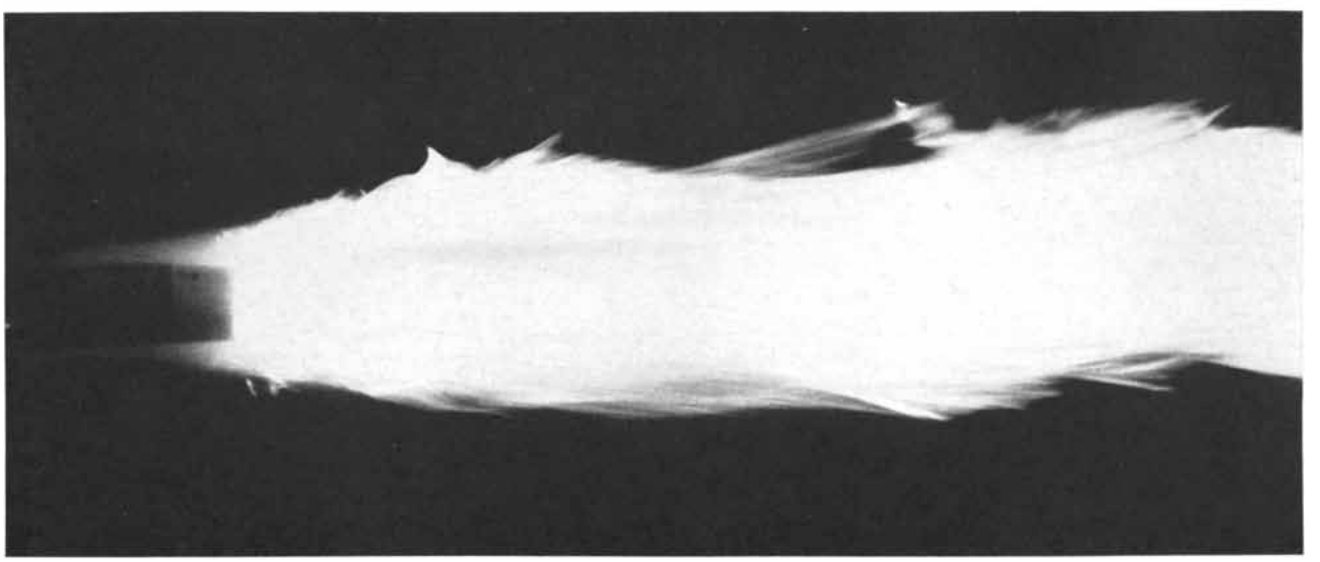


COANDA NOZZLE is shown disassembled at left and assembled at right. The plastic part is a shroud that enhances the Coanda effect. The conical part is the afterbody; pressure over it is slightly above atmospheric when the nozzle is operating to achieve thrust.

with a considerable saving of power over conventional high-speed hydrofoil boats.

Aside from the uses of the Coanda effect for propulsion systems, which are still in a highly experimental stage of development, there is another type of application in which the principle has already proved its value. Nozzles based on this principle are extraordinarily efficient as components of burners [*see illustration below*]. When properly shrouded, they produce an almost invisible flame with no smoke and essentially complete combustion of the fuel. In some applications most of the air for combustion is supplied by the nozzle's entrainment of air. In addition the nozzle can be used as a pump to recirculate unburned gases and thus produce blue-flame, smokeless combustion. To these advantages are added mechanical simplicity, compactness, comparatively low cost and the absence of moving parts. Attempts are now being made to adapt the Coanda nozzle to the burning of heavy fuel oils. Nozzles of this kind might also be employed in vehicle-propelling engines, and this possibility is now being considered.

It is in the field of propulsion, of course, that the prospects for employing the Coanda effect look most attractive. The promise of attaining a propulsion system that would produce its own dividend of power from the very nature of its design, that would have no moving parts such as propellers or fans, that could be blended into the contour of a vehicle without wasting space or significantly disturbing aerodynamic characteristics, that would be smaller, lighter and quieter than present engines—is indeed an incentive to further exploration of the Coanda effect.



TYPICAL FLAME in a burner using a Coanda nozzle is blue, smokeless, quiet and well concentrated when the nozzle is properly shrouded. Almost total combustion of fuel is achieved. Much of air for combustion comes from entrainment of air by the Coanda effect.

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Pigs in the Laboratory

Similarities between the physiology of swine and of men suggest that if pigs were smaller, they would make excellent experimental animals. The problem of size has now been solved by breeding miniature pigs

by Leo K. Bustad

The pig is a greatly underappreciated animal. For thousands of years it has been a mainstay of civilization and a versatile servant of man. It is easily domesticated, and it can be raised in pens or allowed to fend for itself in the field or the woods, since it will eat almost anything, including man's leavings. The pig is the world's most bounteous supplier of meat and fat. What is not commonly realized is that it is capable of serving, and has served, in many capacities besides providing food. It was long employed as a beast of burden. In ancient Egypt it was used for treading seeds into the ground, its small hoofs planting them at the right depth in soft soil. The Polynesians, making use of the pig's sensitive nose, employed it to search out lost burials; other cultures trained the pig to grub for truffles and to retrieve game. In England pigs became popular substitutes for the hunting dog. A celebrated sow named Slut developed such proficiency in hunting that her accomplishments were recorded in 1807 in the periodical *Rural Sports:* "Slut was ... trained ... to find, point and retrieve Game as well as the best Pointer. ... When called to go out Shooting, she would come home off the Forest at full Stretch, and be as elevated as a Dog upon being shown the Gun."

The subject of this article is not, however, the pig's aptitudes or its domestic history; it is the pig as a servant of science. In anatomy and physiology the pig is remarkably like man. Its heart and circulatory system, its diet, its alimentary tract and even its teeth are very similar to those of a human being. Like man, the pig has comparatively little hair on its body. It has a tendency to be sedentary and fat. It develops stomach ulcers and cardiovascular diseases resembling man's. In almost every way the pig offers a closer analogy to man than do those laboratory favorites, the rat and the dog.

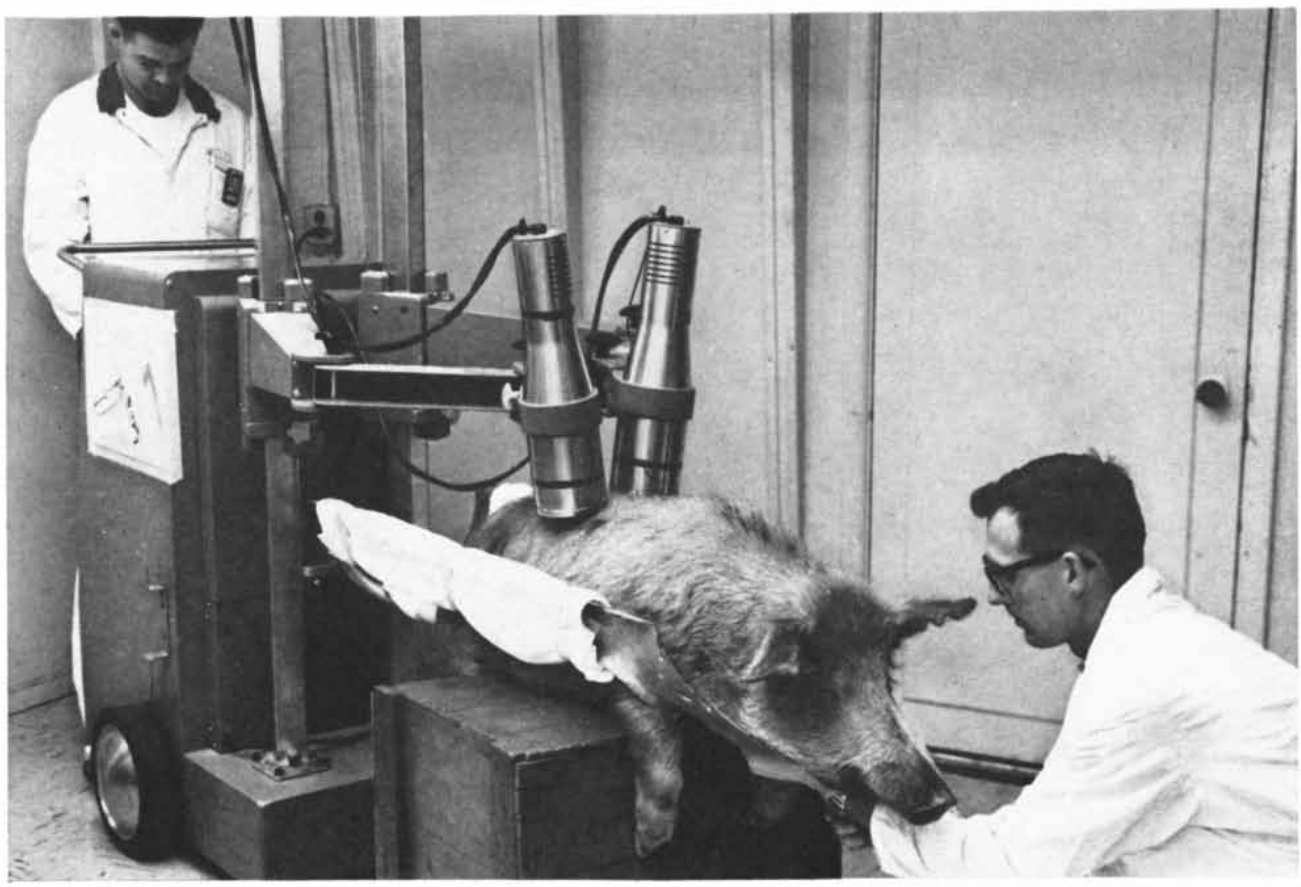
The potential usefulness of the pig as an experimental animal was recognized in a general way centuries ago. Leonardo da Vinci studied the cyclic motions of the pig's heart. The 18th-century investigator John Hunter, one of the most brilliant men of medicine Britain has produced, declared the pig to be the most useful of all animals for physiological studies. An anecdote in John Kobler's recently published biography of Hunter (*The Reluctant Surgeon*) has a pig as its hero. The Margrave of Baden Dierlach was stricken with an apparent heart disturbance, and his court physicians decided a poultice should be applied over the heart. They fell into dispute, however, about exactly where the heart was located in the chest. "To settle the issue to the Margrave's satisfaction, they dissected a pig before his eyes in the belief—and it is true—that the situation of a pig's heart is the same as that of a prince's. The Margrave finding this logic admirable, they applied a poultice accordingly a little to the left of his median pectoral line."

Notwithstanding such recommendations, until recently the pig had won no enthusiastic admittance to laboratories. The great Russian physiologist Ivan Pavlov tried experimenting with pigs but gave it up when he found that as soon as a pig was placed on the table it began to squeal at the top of its lungs and squirm so that work was impossible; Pavlov concluded that pigs were inherently hysterical. Work with pigs was handicapped by a general lack of knowledge about the care, feeding and handling (including anesthesia) of these animals in the laboratory. Most forbidding was the pig's size (pigs weigh as much as 800 pounds); there simply was not room for such a subject in most laboratories.

All of this has now changed. Over the past decade several laboratories have succeeded in breeding miniature pigs that grow little larger (150 to 200 pounds) than the average weight of a man. These animals not only are more manageable but also make possible more significant physiological investigations, because they are more closely scaled to the human body. As a result the pig has at last come into its own in biological research. A report by the United Kingdom Agricultural Research Council lists 3,094 publications and current research projects with pigs as the subjects, and the Battelle-Northwest Laboratory of the Atomic Energy Commission has issued a selected list of more than 1,500 articles that have been published in the past five years on studies of pigs in biology and medicine alone.

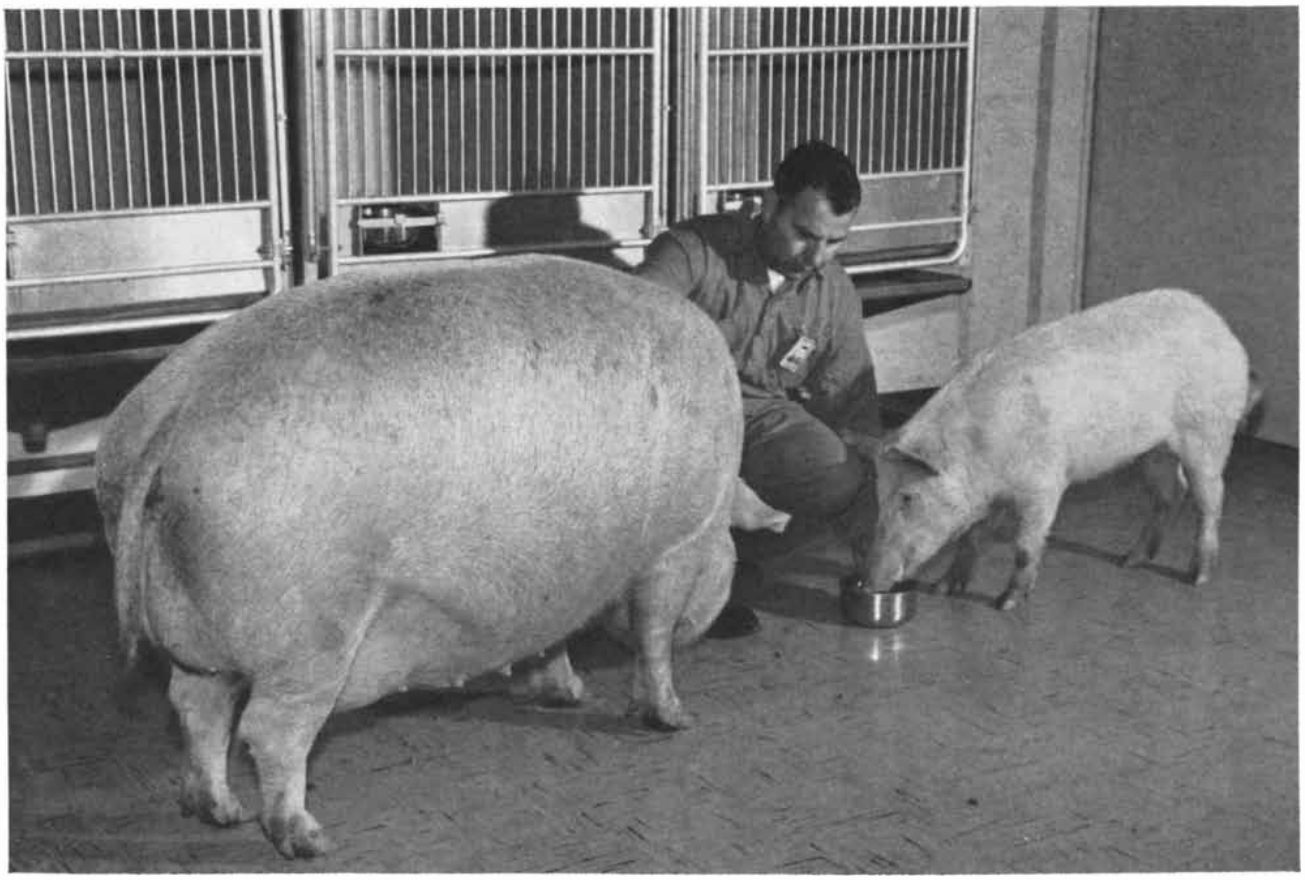
My interest in pigs goes back to my boyhood on a farm in a Norwegian community in western Washington. I never ceased to be amazed at how much pigs resembled people. They were temperate at the trough, neat and clean if given a chance, dignified in courtship and conjugality. It was as a graduate student at Washington State University in the late 1940's that I developed an enthusiasm for the pig's research possibilities. There, working under Tony J. Cunha and Eugene Ensminger, who introduced me to the use of the pig as an experimental animal, I began with studies of the effects of vitamin deficiencies. In the course of these investigations I attempted the difficult task of raising pigs from birth without their mother, so that we might have subjects uncontaminated by colostrum

MINIATURE PIG lies anesthetized and ready for surgery after experimental contamination with plutonium at the Battelle-Northwest Laboratory of the Atomic Energy Commission. Here the author and his colleagues bred a strain of miniature pigs for experiments.



RADIATION DETECTORS are used to study a miniature pig's kidney function after experimental radiation damage. The instrument over each of the pig's kidneys measures the concentration and movement of a substance labeled with a radioactive iodine isotope.

EARLY MINIATURE PIG, bred at the Pitman-Moore division of the Dow Chemical Company, feeds next to a standard Palouse pig, a breed developed at Washington State University that often weighs 800 pounds. A mature miniature pig weighs less than 200 pounds.



HANFORD MINIATURE, also shown with a standard Palouse pig, was bred from Pitman-Moore miniatures, crossed with the Palouse strain to obtain the latter's white color. These pigs are being crossed with a Mexican strain to obtain a more hairless skin.

(the milk secreted immediately after delivery). I learned a great deal about pigs as I lived with them night and day for weeks, feeding them around the clock every two or three hours. When I returned some of the piglets to their mother after a few days, they embarrassed me somewhat by squealing and running to me in preference to their mother (in consequence of their early imprinting) whenever they heard me approaching. The experiment, however, succeeded only in breaking up happy pig families (besides putting a severe strain on my own); under the given conditions and in the time allowed I did not manage to keep viable any litter that had been removed at birth from its mother.

Much as I would have liked to continue my work with infant pigs, exploring problems in nutrition, I was more strongly attracted to the field of radiation biology, and so I joined the Hanford Laboratories of the General Electric Company (now the Battelle-Northwest Laboratory); there investigations of the effects of ionizing radiation were being carried out on experimental animals. These studies began with sheep, but we soon extended them to swine, anticipating that the effects on the pig would provide a firmer basis for extrapolation to man. We used a standard breed of swine, called Palouse, that was developed at Washington State University. These animals grew to a weight of between 600 and 800 pounds, even on a restricted diet. They were costly to feed and maintain, were unwieldy and developed arthritis; moreover, their size made it questionable that they could accurately be compared with man. As we ran short of feed, housing and patience we began to wish for a smaller pig.

I learned that a friend from my graduate school days, David England, was conducting a project in breeding a small pig for research purposes at the Hormel Institute of the University of Minnesota. He and his associates William E. Rempel and Almut E. Dettmers had started the crossbreeding program with three wild pig varieties: a guinea hog from Alabama, a wild boar from Catalina Island and a hog from the piney woods of Louisiana. Later a fourth variety, a swine called Ras-N-Lansa from Guam, was introduced. Most recently a white domestic pig, the Tamworth, was bred into the line to give it a light color. The Minnesota group's breeding efforts produced a comparatively small pig (adult weight about 180 pounds) called the Hormel miniature. In the 15 years since they first created this breed they have reduced its weight by roughly a third.

The Hormel Institute provided us with some castrated miniature pigs for experiments. It was the institute's policy at the time not to release any animals in its breeding program that were capable of reproducing. Since we wanted to raise our own miniatures we had to look elsewhere for a breeding stock. We found that the Pitman-Moore Company of Indiana, a veterinary pharmaceutical firm, was breeding another strain of miniature swine from a small, wild Florida hog of mixed ancestry; it was descended from pigs Columbus had brought to the New World and that had interbred with Caribbean swine. The Pitman-Moore Company generously presented the Hanford Laboratories with some of its best stock of this breed. With these animals as the basis, my associates—V. G. Horstman, M. E. Kerr and W. J. Clarke—and I began in 1957 to breed a new strain. We particularly wanted white pigs, to facilitate studies of the effects of radiation on the skin; hence we crossed the Pitman-Moore breed with white swine of the Palouse strain. Later we crossed the offspring with a Labco pig, a sparsely haired, gentle swine from Mexico, and so produced an animal that not only is white but also has a smooth skin with very little hair. The weight of the Hanford miniatures at present runs from 150 to 200 pounds.

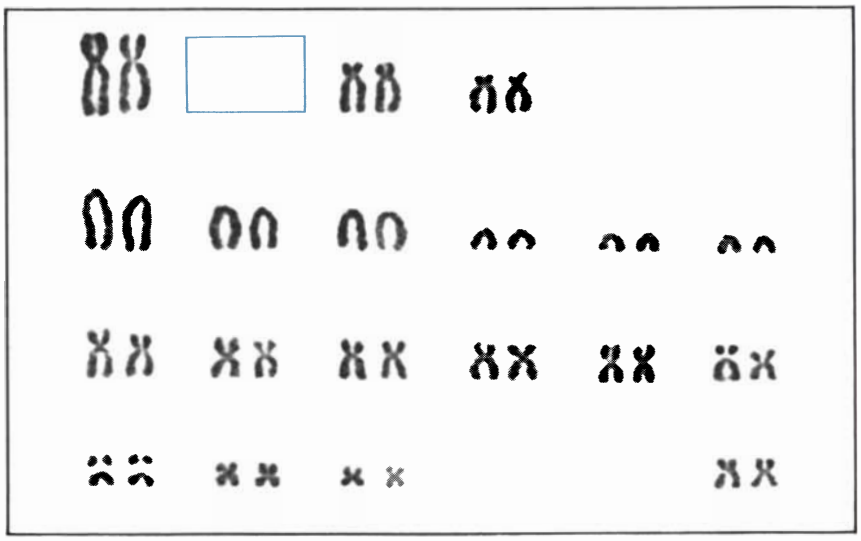
From the stocks I have mentioned and from others, several institutions are now engaged in breeding small pigs for research; among them are the Battelle-Northwest Laboratory, the Hormel Institute, the University of Nebraska, the U.S. Food and Drug Administration, the Vita Vet Laboratories, Labco and laboratories in France and Germany. One goal is to produce a pig smaller than a man—about 60 pounds or less—that would require no more space or food than a dog and would be a better subject than the dog for many biological investigations.

Let us review some of the recent research in which pigs have served as the experimental animals. It would take volumes to survey the vast field of these wide-ranging studies; I can only report here the highlights of a few particularly interesting investigations.

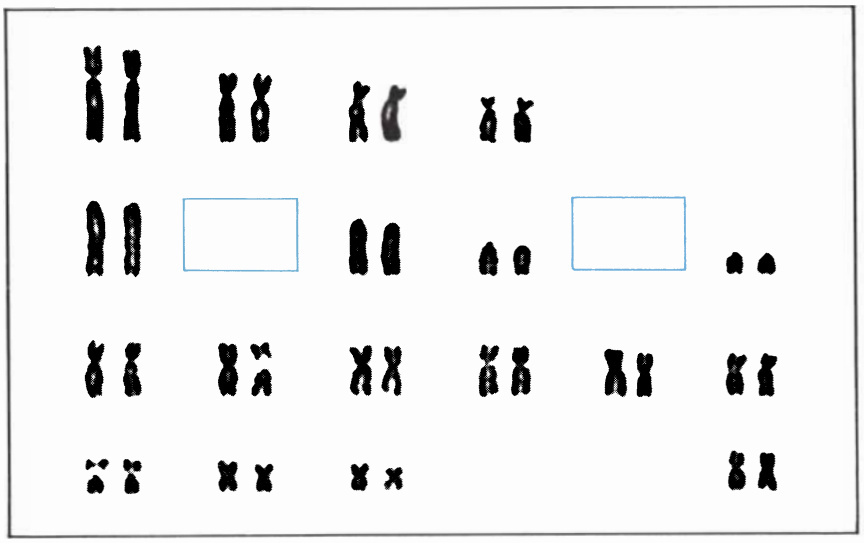
Chief among the inquiries in which the pig has been used so far is the study of nutrition. The pig's alimentary tract and metabolism are so similar to man's that it has yielded a wealth of information bearing on human nutritional problems. The pig provides a standard for the feeding of infants and young children. It has been found that a young pig has more stringent food requirements than a human baby; consequently one can be sure that a diet that provides healthy growth in a piglet will be adequate for a baby. Experiments with pigs have also shed light on the protein-deficiency disease of children called kwashiorkor. Wilson G. Pond and his associates at the Cornell University Graduate School of Nutrition produced the symptoms of this disorder in young pigs by feeding them a low-protein diet containing only 3 percent protein and 20 percent or more of fat. Curiously they found that on the same low ration of protein young pigs did not develop as severe symptoms and showed normal activity if the fat content of the diet was reduced. On the low-protein, high-fat regime infant pigs suffered severe liver damage, anemia, gross edema and in addition permanent losses of learning ability.

Several investigators, among them Jerome C. Pekas of the Battelle-Northwest Laboratory and Donal F. Magee of the Creighton University School of Medicine, have shown that the pig is a particularly convenient animal for studying the functioning of the pancreas and other elements of the digestive system. An operation on the gastrointestinal tract of the pig is the same as the corresponding operation in a human subject; a given dose of a drug or other substance produces very nearly the same degree of response in a pig as it does in a man, and presumably the various digestive juices secreted by the pig are about the same in quantity and composition as those secreted by man. The pig's pancreatic juice is rich in enzymes. Pekas has found that the animal can be excited to a high rate of pancreatic secretion by a continuous infusion of secretin, the pancreas-stimulating hormone. Looking into the functioning of the young pig's pancreas, he has observed that the animal sometimes shows a congenital failing, marked by inefficient metabolism of soybean protein, that parallels a similar disorder in human infants.

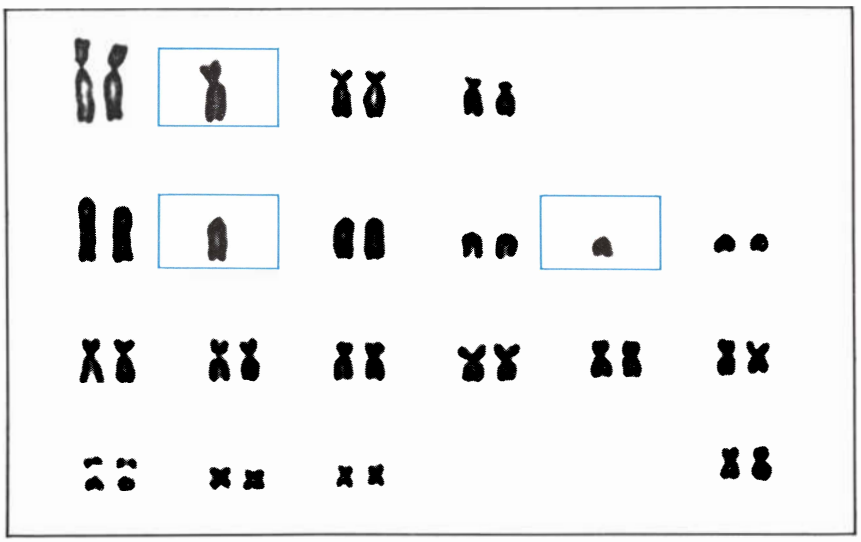
Other investigators of the pig's gastrointestinal tract have discovered that it occasionally develops spontaneous ulcers similar to those in man. Experimenters at Purdue University have produced a high incidence of ulcers by



DOMESTICATED PIG has 38 chromosomes, arrayed here in four rows. This and the karyotypes below are from the Agricultural Research Laboratory of the University of Tennessee.



EUROPEAN WILD PIG has only 36 chromosomes. One pair that the domestic animal lacks is in the first row; two present in the domestic are missing in the second row.



HYBRID PIG has 37 chromosomes. Single chromosomes occupy each of the three karyotype positions in which either the domestic animal or the wild one lacked a pair.

feeding pigs gelatinized cereal products.

In the course of the studies at Washington State University in which we tried but failed to raise pigs from birth without the mother we noticed that the pigs usually succumbed to infection. This fact and other observations suggested to us, as it had to other investigators, that the pig might be a good subject for studies of immunology. In recent years a number of investigators have found that the young pig is indeed uniquely suited for studies of the development of immunity.

A newborn pig has very little gamma globulin (the principal antibody protein) in its serum. Apparently it acquires gamma globulin and other immunoglobulins from its mother's colostrum when it begins to suckle. Diego Segrè of the University of Illinois found that baby pigs deprived of colostrum remained deficient in gamma globulin for weeks and showed little of the normal antibody response to antigens. He concluded that colostrum provides the young with the basis for developing the immune mechanism. Experimenting further, he found that colostrum-deprived baby pigs acquired immunological capability when he injected an antigen together with a small amount of a specific antibody or large amounts of gamma globulin. These results supported the theory that the antigen-antibody complex, rather than the antigen alone, is the usual stimulus for the production of an antibody.

Somewhat different results emerged from experiments by Dennis W. Watson, Y. B. Kim and S. Gaylen Bradley at the University of Minnesota Medical School. They took infant pigs from the mother prematurely by surgery and kept them without colostrum and under germ-free conditions. The piglets proved to be completely free of any detectable immunoglobulins or antibodies. Yet these immunological "virgins," unlike Segrè's, showed an excellent ability to produce antibodies against antigens soon after birth.

The development of the miniature pig proved invaluable for our studies of radiation effects at the Hanford Laboratories. These studies were prompted by the need for detailed information about tolerances and treatment for people exposed to radioactive substances. For such investigation the miniature pig has many useful characteristics as an experimental animal. Its body size and skeletal mass are about the same as man's; its general similarity to human beings in diet and digestion per-

mits meaningful tests of experimental diets; its life-span (15 to 20 years) is long enough to allow measurement of the effects of radiation in shortening life and in causing malignancies.

One of the Hanford investigations, still under way, is exploring the effects of strontium 90, a long-lived and potentially hazardous constituent of nuclear fallout, which is deposited principally in the bones. Strontium 90 at various levels of dosage is fed daily to experimental pigs. Leukemias have already developed in animals receiving the very high levels of dosage in the program. No bone tumors have appeared as yet, but this form of malignancy is known to have a long latent period of development.

Roger McClellan and his associates at Hanford's successor laboratory, Battelle-Northwest, extended the strontium-90 studies to other radioactive substances that could be used in power generators with minimal hazard to man. Power generators of the thermoelectric type with radioactive isotopes as their energy source are being developed for small portable units on the earth and in space. An important factor in determining the safety of such devices is the extent to which the radioactive material in them would be taken up by the body if it were accidentally ingested. McClellan found that when strontium in the form of a titanate is ingested into the pig's digestive tract, less than .5 percent is absorbed into the body. This is only about a tenth of the amount absorbed when more common chemical forms of strontium are ingested. Still smaller is the absorption of the radioactive substances cerium 144 and promethium 147: less than .01 percent of the oral dose of those isotopes is absorbed into the pig's tissues.

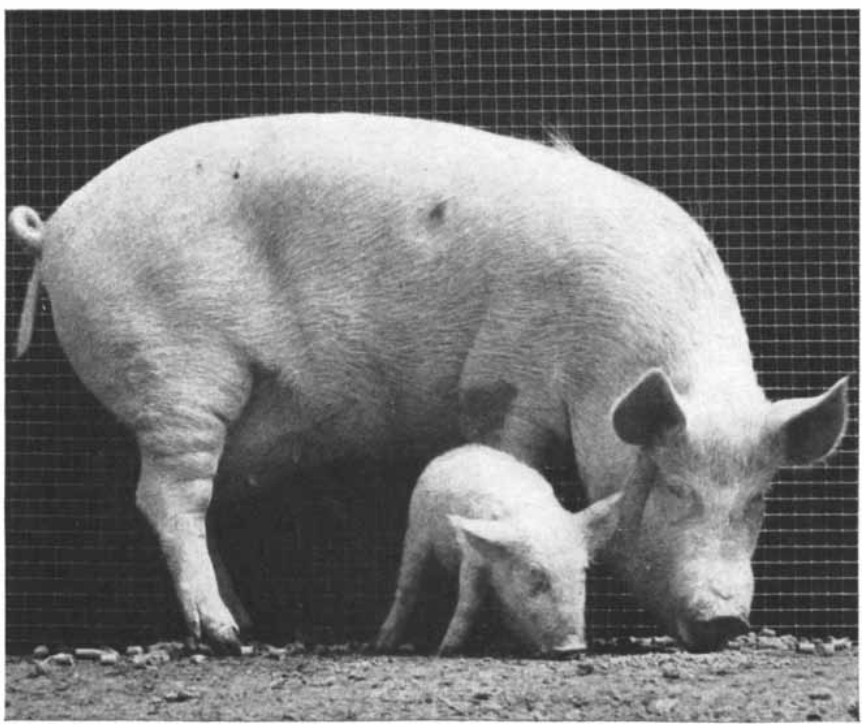
Our miniature pigs enabled other investigators at Hanford and Battelle-Northwest to examine the toxic effects of plutonium and to test methods of treatment. It was found that certain chelating agents, including DTPA (diethylenetriaminepentaacetic acid), are effective in helping the body to eliminate plutonium that has been absorbed.

Using a standard breed of pig, the U.S. Navy Radiological Defense Laboratory made detailed tests of the results of high doses of radiation. The investigators found that the 50 percent lethal dose resulting in death within 30 days was 400 roentgens. Surprisingly, they also learned that a sublethal dose endowed pigs with considerable resistance to later heavy exposure. After the animals had received a dose of about 265 roentgens and had been allowed three weeks for partial recovery, it took a dose 70 percent greater than the usual one to cause a 50 percent death rate.

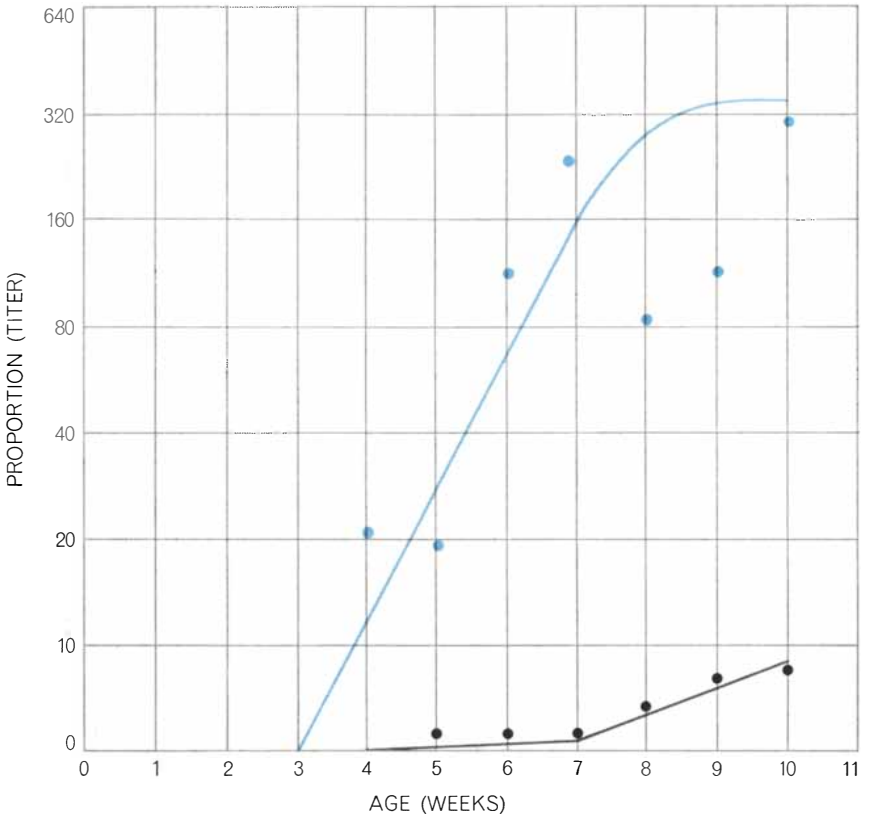
The largest study utilizing swine in radiobiology is one that has been conducted since 1959 at Iowa State University with Atomic Energy Commission support. D. F. Cox and his associates are measuring the effects of radiation on the fertility of male pigs and the genetic effects on their offspring. The standard procedure consists in giving the male's testes an X-ray dose of 300 roentgens and breeding the male later after germ cells subjected to the radiation have developed. As was expected, the irradiation reduces the amount of sperm by about 20 percent; this does not, however, significantly impair the pig's reproductive capacity. So far more than 15,000 baby pigs have been sired by the irradiated males. In one of the breeds under test (the Duroc breed) a peculiar result has been noted: the litters fathered by irradiated males tend to be slightly larger than normal. This result was not observed in the Hampshire breed. No explanation of the phenomenon has yet been found.

The Battelle-Northwest group has studied the effects of radiation on the karyotype (chromosome pattern) by examining the white blood cells of miniature pigs fed radioactive strontium. Investigators in other laboratories have found the pig to be an exceptionally useful animal for analysis of the various forms of chromosome in the cell nucleus. The domestic pig normally has 38 chromosomes—19 pairs. Six of these pairs have characteristic, readily identifiable shapes, and the rest can be classified in small groups. R. A. McFeely of the University of Pennsylvania is making a detailed study of abnormalities in pig chromosomes. This inquiry carries special interest because pigs have an extraordinarily high rate of embryonic death—about 30 to 40 percent—and it is known that chromosome aberrations are sometimes associated with embryonic death in human beings.

Robert Murphree and A. F. McFee of the Agricultural Research Laboratory of the University of Tennessee have found a distinctive complement of chromosomes in a pig resulting from a cross between a domesticated swine and a European wild sow. The parents have 38 and 36 chromosomes respectively, and the offspring turns out to have an odd number: 37. Apparently it is completely fertile, and its chromosome number should be a good marker for research purposes. This case of an odd number of chromosomes is not altogether unique: a cross between two breeds of European ponies has been known to



ADAPTABILITY OF PIGS in experimental situations is shown by the response of a pair of normal pigs, raised from the same litter at the University of Cambridge, to different diets. They are a year old; the larger pig weighs more than 200 pounds, the underfed pig 11 pounds.



PROTECTIVE ROLE OF COLOSTRUM is demonstrated by the comparative rate of antibody production on the part of two piglets after injections of diphtheria toxin. The normally suckled animal (*color*) quickly produced antibodies but the animal that had been deprived of its mother's colostrum by bottle-feeding from birth (*black*) was a late and low producer.

produce a fertile offspring with 65 chromosomes.

Among the institutions that have used our Hanford miniature pigs for research is the University of Oregon Dental School. There E. B. Jump, M. E. Weaver and their associates have found the animal highly useful for studying dental problems. The pig's teeth are nearly the same size as man's (approximately a fourth larger) and are of the same types, consisting of molars and cutting teeth. Moreover, the general growth pattern is the same: the pig starts with deciduous teeth and sheds them as its permanent teeth develop. Hence the pig's mouth and jaw provide a model that makes possible experimental studies on many of the dental problems of children. Douglas L. Buck and other Oregon investigators have used it to look into the details of tooth growth and development, the basic movements of the teeth in biting and chewing and the functioning of orthodontic appliances.

Probably the field in which the pig will make its greatest contribution to human health and longevity is that of research on the heart and circulatory system. In this area the parallels between the pig and man are striking, to say the least. The pig's rearing as an item for the table has produced an animal that is a counterpart, even a caricature, of the overfed, physically lethargic human population. Coupled with this similarity of nurture and disposition is a porcine cardiovascular system that also is remarkably parallel to the human system. The pig's heart and coronary arteries, unlike the dog's, have much the same pattern as man's. Its blood-clotting mechanism is like that of man.

Investigators have found the pig particularly valuable for the study of atherosclerosis. H. C. Rowsell and his associates at the Ontario Veterinary College have used it to examine the effects of diet. Since the pig likes all man's foods (from peanuts and popcorn to a steady diet of eggs), Rowsell's group has tested pigs with high-cholesterol diets, including foods such as eggs, butter and lard. They find that in pigs such a diet indeed accelerates the development of atherosclerosis, and the signs and symptoms of the disorder are like those in man. Rowsell also used the pig to test anticoagulant drugs administered in certain human cardiovascular diseases. He found that a small dose of dicumarol or heparin was worse than ineffective: it actually had a coagulating effect on the blood. The finding emphasized the importance of proper dosage in the use of these drugs.

D. K. Detweiler and Hans Luginbuhl at the University of Pennsylvania have been analyzing the progressive stages of the development of atherosclerosis. For this purpose they had the good fortune to gain access to a herd of 2,000 breeding sows of various ages that have been raised on garbage (that is, essentially a human diet). In these animals, ranging up to 14 years in age, they have made detailed analyses and tests of the atherosclerotic lesions, the blood vessels and the blood. At Iowa State University, Robert Getty, studying the development of atherosclerosis from another point of view, has found that the characteristic deposits on the artery walls commonly start in the first year of the pig's life and are present in most animals by the second year.

G. D. Lumb and his associates at the Warner-Lambert Research Institute in Canada are studying how blood is supplied to the heart under adverse conditions. It is well known that when the major coronary arteries in man are partly blocked or constricted, this stimulates the development of an auxiliary or substitute circulation to nourish the heart. Lumb's group, using a plastic constrictor to narrow the pig's coronary vessels gradually, demonstrated that the animal, like man, develops a bypass system of circulation. Lumb also found that vessel-dilating drugs could improve the survival of pigs whose coronaries had been occluded.

A joint group at the University of Colorado and Colorado State University (C. A. Maaske, N. H. Booth and T. W. Nielsen) is using the pig to study congestive heart failure, a complex disorder that involves the functioning of the heart as a pump, the mechanisms controlling the heart and secondarily the functioning of the kidneys and lungs. They have found that the pig is a much better subject than the dog for an investigation of this matter. A single operation on the pig's main pulmonary artery produces the symptoms of a gradual development of cardiac failure.

All in all, although the pig is only a newcomer to the laboratories of basic biology, there can be little doubt that it will become, along with the primates, a most important contributor to knowledge about the biology of man.

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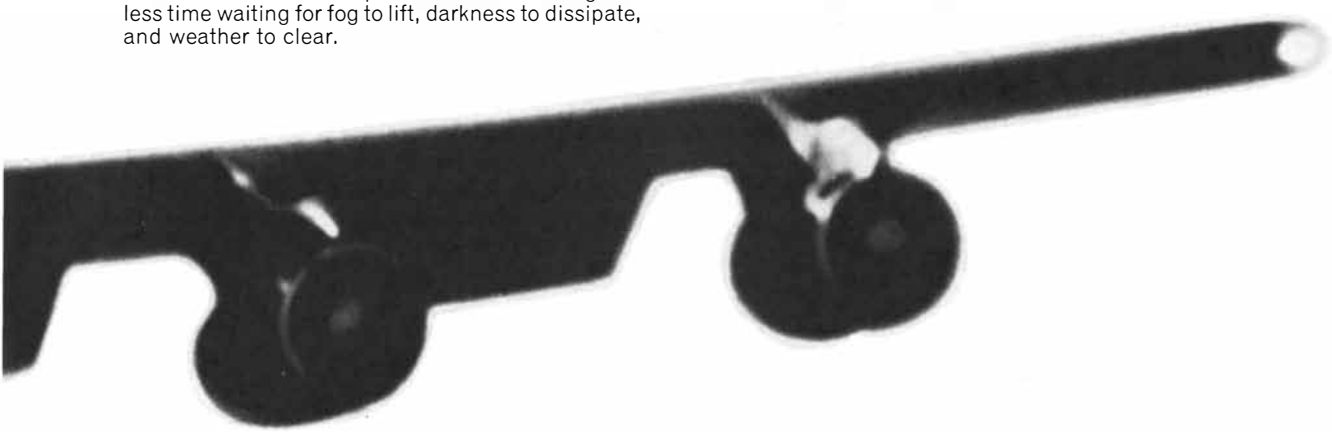

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Elephant-hunting in North America

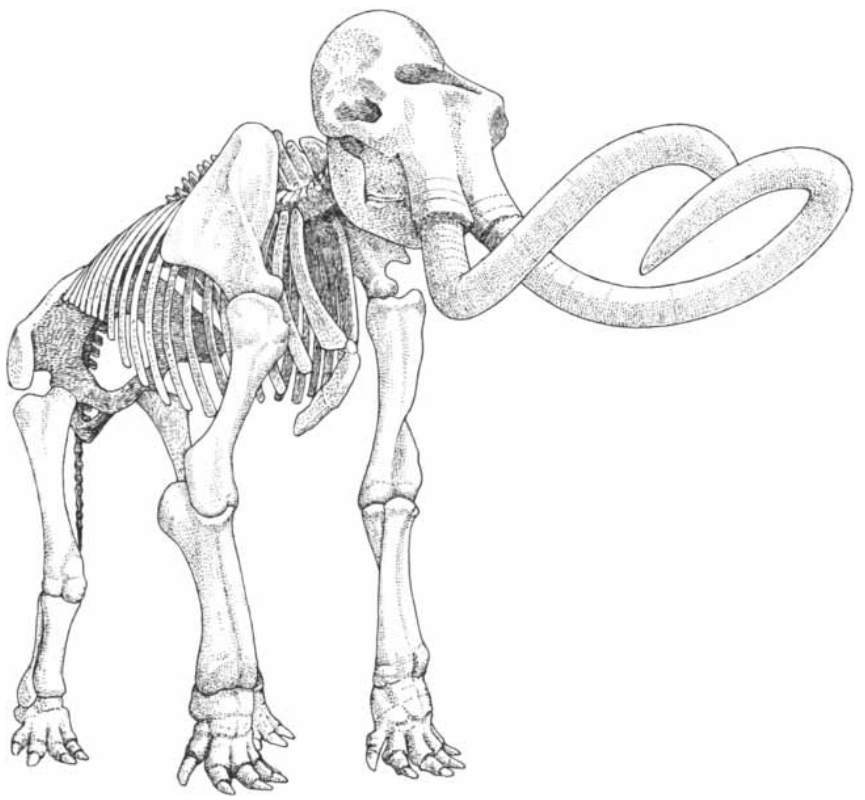
Bones of elephants that vanished from the continent 10,000 years ago are found together with the projectile points early men used to kill them. Indeed, the hunters may have caused the elephants' extinction

by C. Vance Haynes, Jr.

Elephant-hunting today is a specialized activity confined to a handful of professionals in parts of Africa and Asia; 11,000 years or so ago it provided a living for one of the earliest groups of humans to inhabit the New World. At that time hunting bands whose craftsmen made a particular kind of stone projectile point by the thousands ranged across North America from the east coast to the west coast, as far north as Alaska and as far south as central Mexico. Two generations ago such a statement would have been hard to support. Since 1932, however, the excavation of no fewer than six stratified ancient sites of mammoth-hunting activity in the western U.S. and the discovery of scores of significant, if less firmly documented, sites elsewhere in North America have proved its validity beyond the possibility of challenge. It is the purpose of this article to present what we know of the lives of these mammoth-hunters and to suggest when they arrived in the New World.

The first evidence that man had been present in the New World much before 2000 B.C. touches only indirectly on the history of the mammoth-hunters. This was a discovery made near Folsom, N.M., by an expedition from the Denver Museum of Natural History in 1926. Careful excavation that year and during the next two seasons uncovered 19 flint projectile points of unusual shape and workmanship lying 10 feet below the surface among the bones of 23 bison. The bison were of a species that paleontologists had thought had been extinct for at least 10,000 years. The Denver Museum excavation at Folsom thus made it plain that as long ago as 8000 B.C. hunters armed with a distinctive type of flint point had inhabited what is now the western U.S. The association of the projectile points with the bison bones made it almost certain that the bison were the hunters' prey; any doubts on this score were settled when Frank H. H. Roberts of the Smithsonian Institution, digging at the Lindenmeyer site in Colorado, found a Folsom point firmly lodged in a bison vertebra.

In 1932 a cloudburst near Dent, Colo., hastened the erosion of a gully near the South Platte River and exposed a large concentration of mammoth bones. Investigators from the Denver Museum went to work at the site; the bones proved to represent 11 immature female mammoths and one adult male. Along with the animal remains they found three flint projectile points and a number of boulders that were evidently not native to the surrounding accumulation of silt. In the 1930's the carbon-14 technique of dating had not yet been invented, but the geologists in the party estimated that the Dent site was at least as old as the Folsom site and perhaps older. Certainly the projectile points found at Dent, although they bore a general resemblance to those found at Folsom, were cruder in work-



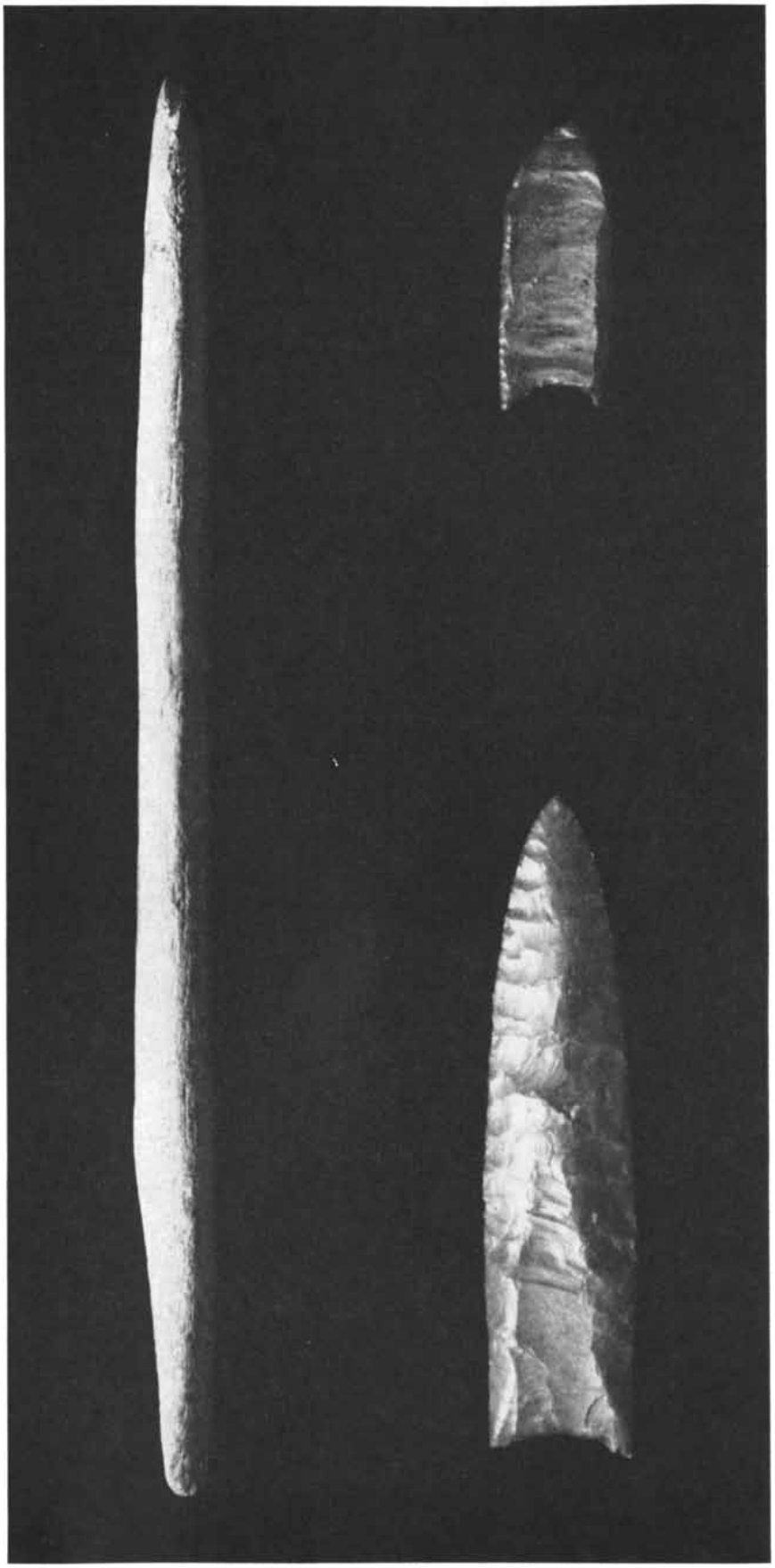
AMERICAN ELEPHANTS were all of the genus *Mammuthus*. They included the woolly mammoth, which also ranged the Old World, and the imperial, confined to North America. This skeleton of one imperial variety, the Columbian, is 12 feet at the shoulder.

manship. In any case, the excavation at Dent made it evident that early hunters in western North America had preyed not only on extinct bison but also on the mammoth.

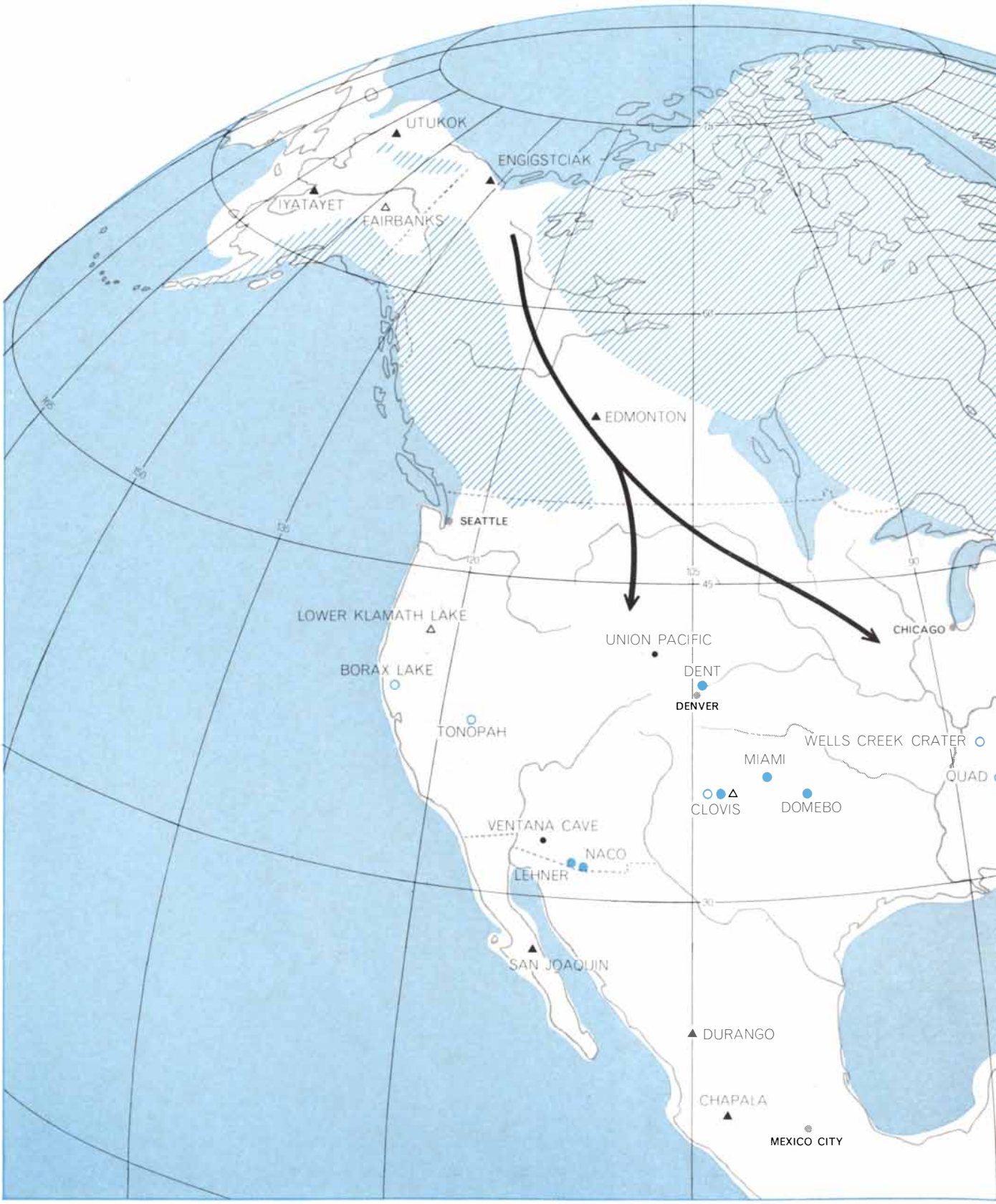
Beginning in 1934 John L. Cotter of the Academy of Natural Sciences in Philadelphia excavated a site known as Blackwater Draw near Clovis, N.M., which proved to contain the answer to the relative antiquity of the Folsom and Dent finds. In the Clovis sediments projectile points like those from Folsom were found in the upper strata associated with bison bones. Below these strata, associated with the remains of two mammoths, were four of the cruder, Dent-style projectile points and several flint tools of a kind that could have been used for butchering. Also found at Clovis was an entirely new kind of artifact—a projectile point fashioned out of bone. At the completion of nearly two decades of work at the site by investigators from the Philadelphia Academy and other institutions, students of New World prehistory were generally agreed that two separate groups of hunters had once inhabited western North America. The earlier group, using flint projectile points of the type found in the lower Clovis strata, had been primarily mammoth-hunters; the later group, using Folsom points, had been primarily bison-hunters.

The most obvious characteristic that Clovis and Folsom points have in common is that they are "fluted." After the flint-knapper had roughed out the point's general shape he beveled its base; then, with a deft blow against the beveled base, he detached a long flake, leaving a channel that extended a third or more of the point's length [*see illustration at right.*] The fluting, on one or both sides of the point, gave the point a hollow-ground appearance. It has been suggested that the flute channels facilitated the bleeding of the prey, as do the blood-gutters of a modern hunting knife. A more plausible explanation is that the fluting made the point easier to fit into the split end of a wooden shaft. The assumption that the points were hafted in this manner is strengthened by the fact that their edges are generally dulled or ground smooth for a distance from the base about equal to the length of the flute channel. If a sinew lashing was used to mount the point in a split shaft, it would be mandatory to have dull edges where the lashing was wrapped; otherwise the flint would cut through the taut sinew.

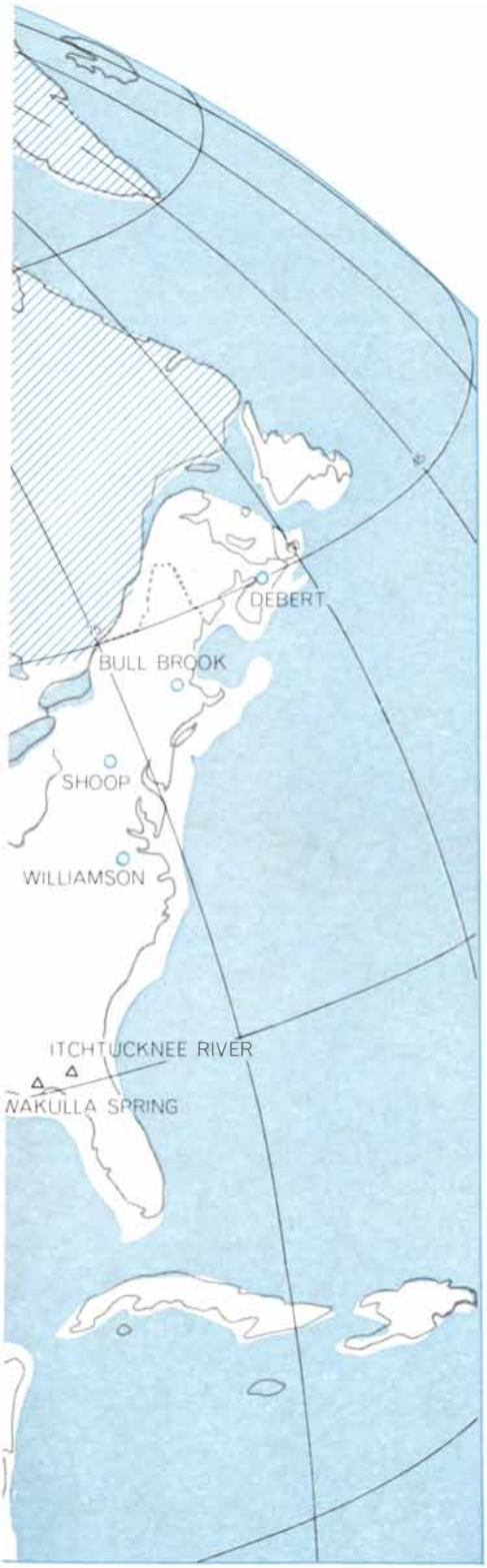
To judge from the ease with which



PROJECTILE POINTS used by early hunting groups in North America include one of bone (*left*) and one of flint (*lower right*) found near Clovis, N.M., in the mid-1930's. These artifacts were used to kill mammoths. The smaller flint point (*upper right*) was made by a later group that hunted bison. The first of these were found near Folsom, N.M., in 1926.



ICE-FREE CORRIDOR in western Canada may have opened some 12,000 years ago. The author suggests that the mammoth-hunters who made both the characteristically fluted flint projectile points and the needle-like bone ones left the Bering Strait area earlier than that and reached the unglaciated part of North America some 11,500 years ago. Symbols by the names distinguish among campsites, kill



▲ ISOLATED FINDS OF FLUTED FLINT POINTS

sites and significant isolated finds. In the northeast Debert and Bull Brook probably include non-Clovis Paleo-Indian material.

a few self-taught flint-knappers today can turn out a classic Clovis or Folsom point in a matter of minutes by striking raw flint with a "baton" of deer antler or hardwood, it is reasonable to believe that the early hunters also used this technique of baton percussion, at least in roughing out their points. There are even indications that such roughed-out blanks were produced at various flint quarries and then carried back to campsites for the finishing touches. Detaching the channel flake or flakes was obviously the crucial step; once successfully fluted, the point was finished by sharpening the tip, trimming the edges either by rasping or by pressure-flaking, and dulling the lower edges where the lashing would be wrapped around. If the tip of a point broke off, the point might be sharpened again [*see top illustration on page 109*].

Although the points from any one site exhibit a considerable range in size and appearance, it is usually not difficult to distinguish between Folsom and Clovis points. The fluting of a Folsom point is typically a single channel that extends all the way to the tip of the point or nearly so, and the edges of the point are delicately chipped. A Clovis point is typically larger, with coarsely chipped edges; usually more than one flake has been removed to produce the flute channel and these have "broken out" less than halfway to the tip in what is called a "hinge" fracture. In some cases the hinge fracture broke inward rather than outward, snapping the unfinished point in half. If early man used profane language, such an incident must surely have inspired an epithet or two.

Carbon-14 dating has now established the antiquity of four of the six sites in which mammoth bones are associated with Clovis points. Two of the sites are Clovis itself and Dent; the others are Domebo Canyon in Oklahoma, where a single mammoth was found together with three Clovis points and an assembly of flint butchering tools, and Lehner Ranch Arroyo in New Mexico, where among the bones of nine immature mammoths Emil Haury of the Arizona State Museum uncovered 13 Clovis points and eight butchering tools in 1955 and 1956. It was charcoal from a campfire hearth at the Lehner site that in 1959 yielded the first Clovis carbon-14 dates to be determined; they averaged $11,260 \pm 360$ years before the present, or a little earlier than 9000 B.C. The carbon-14 dates from Dent, Clovis and Domebo fall in this same time interval, as do the dates of two other early sites in the western U.S. that may or may not have Clovis connections. These are Union Pacific, Wyo., where mammoth bones and flint tools are found, and Ventana Cave in Arizona, which has no mammoth remains. The other two stratified Clovis sites that contain mammoth bones—Miami in the Texas Panhandle and Naco, Ariz., where Haury and his associates uncovered the bones of a single mammoth in 1951 with five out of eight Clovis points concentrated in its chest area—have not been dated by the carbon-14 method.

These and other carbon-14 determinations, together with geological analyses, have established a general framework for North American prehistory in the Rocky Mountains, the Great Plains and the Southwest. The earliest period ends about 10,000 B.C.; its fossil fauna include the mammoth and extinct species of camel, horse and bison, but there are no artifacts associated with their remains that positively indicate man's presence. There follows a gap of about 500 years for which information is lacking. In the next period, between 9500 and 9000 B.C., the early fauna is still present and Clovis projectile points are frequently found in association with mammoth remains. In the following period, between 9000 and 8000 B.C., mammoth, camel and horse have all disappeared; only the extinct bison species remains, and the artifacts found among the bison bones include Folsom projectile points rather than Clovis. The next cultural complexes overlap Folsom somewhat and are dated between 8500 and 7000 B.C. Several sites in this span of time are assigned to the Agate Basin complex. Finally, between 7000 and 6000 B.C., the Agate Basin complex is replaced by the Cody complex. These later "Paleo-Indian" cultures do not concern us. What is interesting is that, in spite of their wide geographical distribution, all the dated Clovis sites apparently belong to the same relatively narrow span of time.

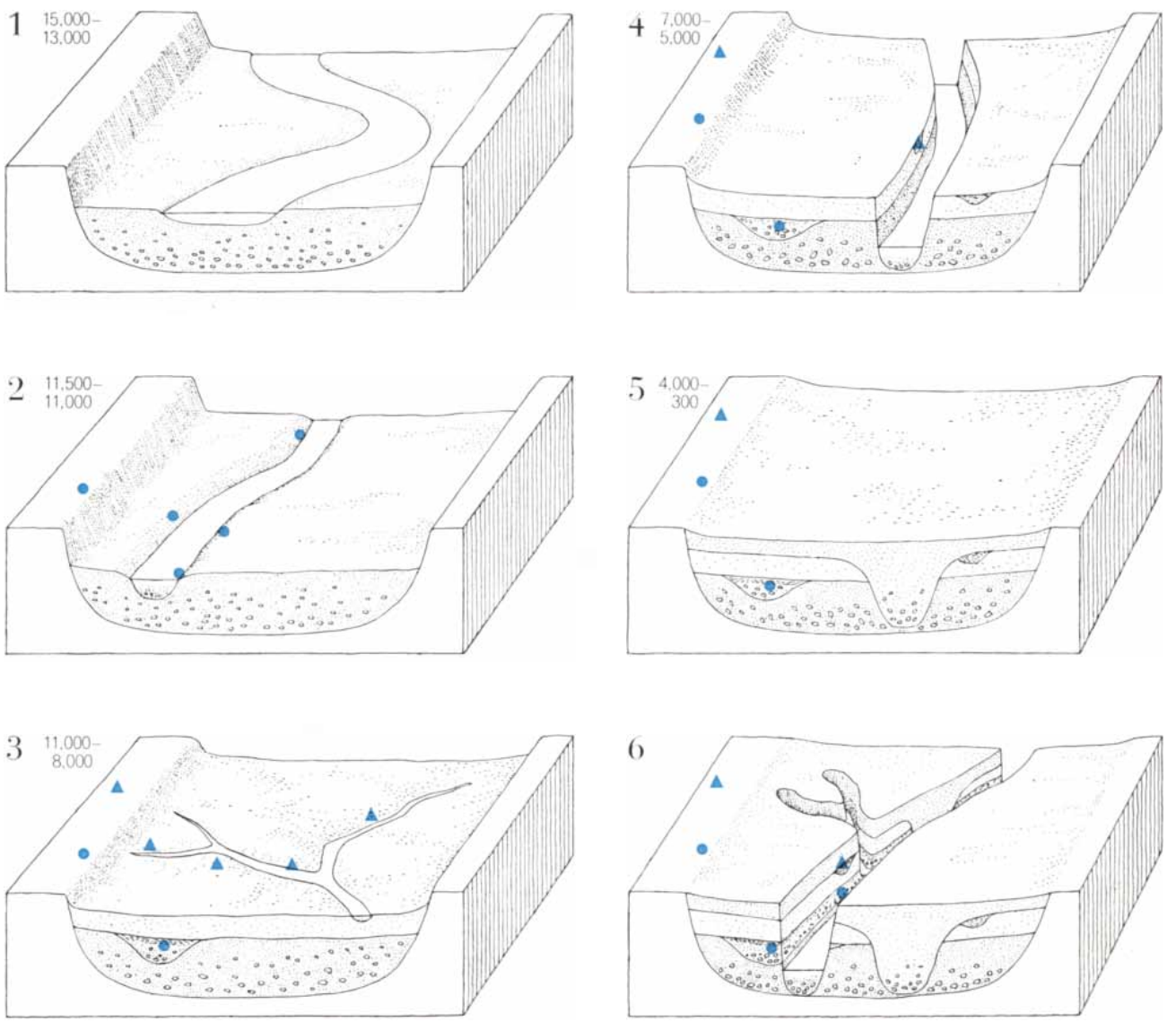
Although the Clovis sites mentioned thus far are all in the western U.S., it would be a mistake to think that the mammoth-hunters were confined to that part of North America. Clovis points have been found in every one of the mainland states of the U.S. and there are more Clovis points at any one of three eastern sites than at all the stratified western sites combined. The trouble is that, with a very few exceptions, the eastern Clovis artifacts are found on the surface or only inches below the

surface; it is impossible to assign dates to them with any degree of reliability. An example of the complexity of the problem is provided by the Williamson site near Dinwiddie, Va., where Clovis points and Civil War bullets are found side by side in the same plowed field.

In spite of the problem of dating the eastern discoveries, no grasp of the vigor and extent of the mammoth-hunters' culture is possible without consideration of its maximum range. In addition to the sites in the western U.S. already mentioned, Clovis points—flaked from obsidian rather than flint—have been unearthed at Borax Lake, a site north of San Francisco. Here, unfortunately, the stratigraphy is disturbed and artifacts of various ages are mixed together. Another western Clovis site is near Tonopah, Nev., where fluted points were found on the surface around a dry lake, together with flint scrapers, gravers and perforators. Neither the site nor the artifacts have been described in detail, however, and the Tonopah material is not available for study. (It is in a private collection.)

Projectile points made of bone and ivory, nearly identical with the ones found at Clovis, have also been found elsewhere in the West. Two come from deposits of muck in central Alaska that contain mammoth bones. Unfortunately the Alaskan muck is notorious for its mixed stratigraphy, and the relative ages of artifacts and animal remains in it are not easily determined. The other bone points have been found at Klamath Lake in California, in deposits as yet undated. These deposits also contain mammoth bones, but the artifacts and animal remains are not in direct association.

In the eastern U.S. large numbers of similar bone points have been found underwater at two locations in Florida: the Itchtucknee River and Wakula Spring. The latter site has also yielded mammoth remains. Something of the difficulty facing investigators who wish to assign dates to such underwater discoveries as the 600 bone points from Wakula Spring can be appreciated when one considers that the same six-foot stretch of sandy bottom may yield a bone point, a mammoth tooth and a



SEQUENCE OF DEPOSITS at a hypothetical valley site shows how a sediment-filled river valley (*1*) was inhabited by the Clovis mammoth-hunters (*2*). Dates are given in number of years before the present. Next (*3*) the Clovis valley sites are covered by fresh sediments on which the later Folsom bison-hunters camped. Both the Clovis and the Folsom campsites on the terrace above the valley escape burial; surface sites of this kind are difficult to date. Later cycles of erosion and deposit (*4 and 5*) leave the Clovis and Folsom valley sites deeply buried. Finally (*6*), today's situation is shown; erosion has now bared two superposed kill sites (*center*).

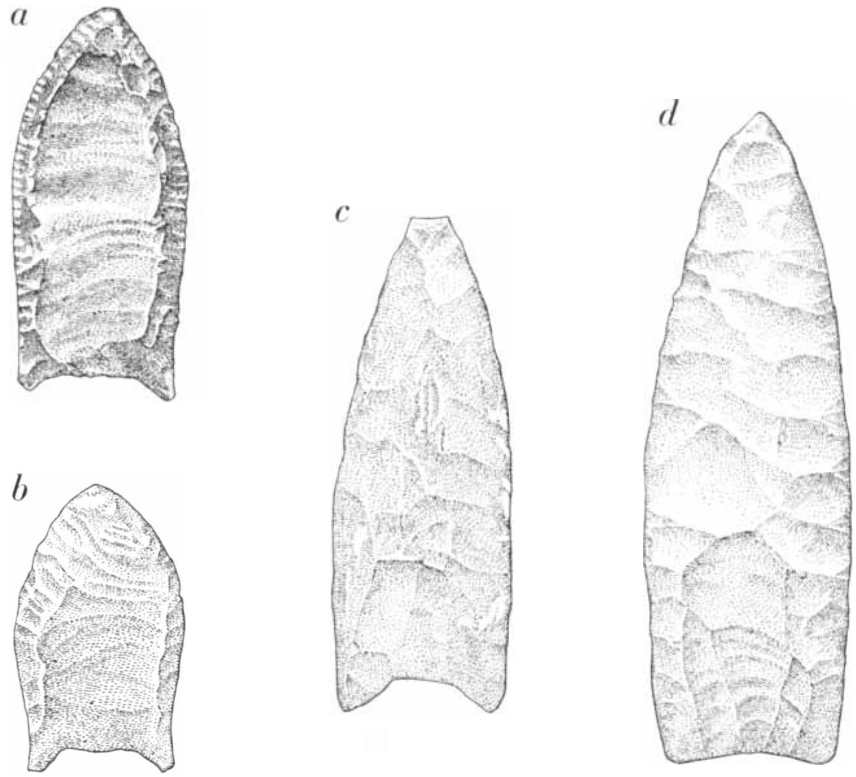
soft-drink bottle. The prospect of dating the abundant Clovis finds elsewhere in the East is in most instances not much brighter. Nevertheless, thanks to amateur archaeologists who have taken pains to report the exact location of their surface discoveries, it is now apparent that the greatest concentration of fluted projectile points is centered on Ohio, Kentucky and Tennessee. When the places in which Clovis points have been discovered are plotted on a map, the distribution of the points corresponds closely to that of mammoth fossils and those of the other New World proboscid, the mastodon.

The curious fact remains that, with one possible exception, no Clovis point in the eastern U.S. has ever been found in association with animal bones. The possible exception is a Clovis point found in 1898 at Big Bone Lick in Kentucky, where mammoth bones have also been uncovered. At the time, of course, the point was not recognized for what it was, and there is no evidence that the point was found in association with the mammoth bones.

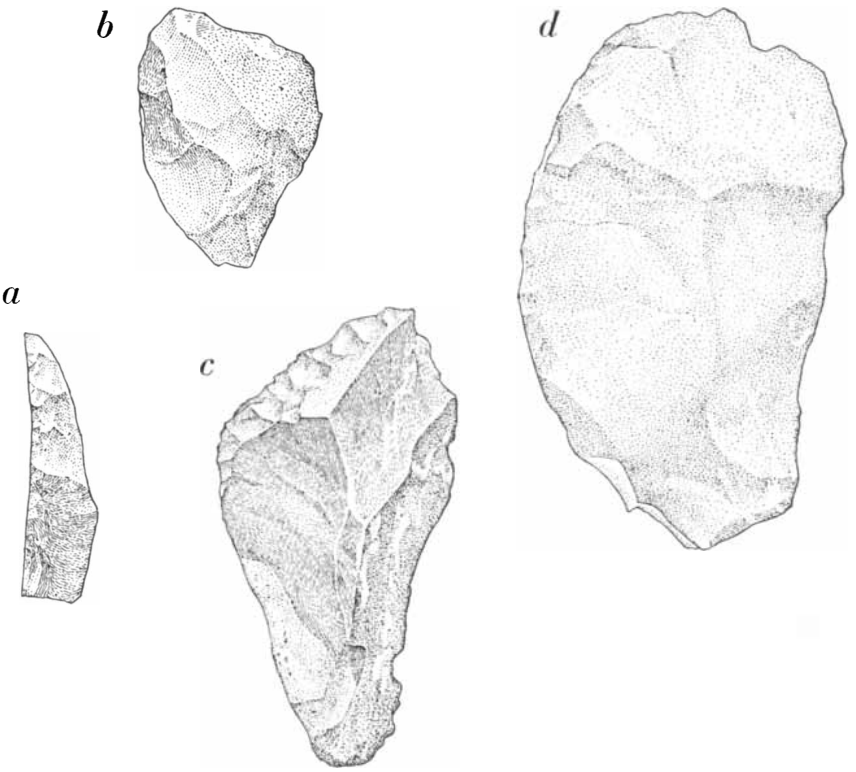
The major surface discoveries of Clovis artifacts in eastern North America have been made at the Williamson site in Virginia, at the Shoop site near Harrisburg, Pa., at the Quad site in northern Alabama and at Wells Creek Crater in Tennessee [*see illustration on pages 106 and 107*]. To judge from the hundreds of Clovis points and thousands of other flint tools that have been picked up at these locations, each must represent a large campsite.

The same is probably true of Bull Brook near Ipswich, Mass.; hundreds of fluted points from this site have been analyzed by Douglas S. Byers of the R. S. Peabody Foundation in Andover, Mass. Unfortunately the stratigraphy at Bull Brook is disturbed. No campfire hearths or clear-cut levels of human habitation are known; four charcoal samples that may or may not be associated with the flint points yield carbon-14 dates that range from 4990 ± 800 B.C. to 7350 ± 400 B.C. It is evident that the Bull Brook deposits cover a considerable span of time.

The only other significant stratified site in eastern North America that has yielded carbon-14 dates is near Debert in the Canadian province of Nova Scotia. Debert is being studied by investigators from the R. S. Peabody Foundation and the National Museum of Canada. Here fluted projectile points have been found that are neither Clovis nor Folsom in style. The average of



CHARACTERISTIC DIFFERENCES between Folsom (*"a" and "b"*) and Clovis (*"c" and "d"*) projectile points include the Folsom point's long neat flute scar, produced by the detachment of a single flake, and the delicate chipping of its cutting edges. Clovis points tend to be coarser and larger; flute scars are short and often show the detachment of more than one flake. The shorter of the Folsom points may have been repointed after its tip broke off.



STONE TOOLS found at the Lehner site in New Mexico include keeled scrapers (*a*) and a variety of sidescrapers (*"b," "c" and "d"*). The latter were made from large flakes of flint knapped on one side. Choppers suitable for butchering were also found at this Clovis site.

carbon-14 dates at Debert is 8633 ± 470 B.C., or roughly 1,000 years later than the Clovis sites in the western U.S.

East or west, buried or exposed, most Clovis discoveries can be classified either as campsites or sites where animals were killed. A campsite is characterized by the presence of a wide variety of flint implements in addition to fluted points. A kill site is characterized by the presence of animal bones together with fluted points and a few flint butchering tools or no other tools at all. Recent excavations at Clovis itself indicate that the area around an extinct lake that attracted game to the site was used by the mammoth-hunters for both killing and camping. Not only butchering tools but also flint scrapers, gravers and knives have been discovered in the lower strata of the Clovis site. Apart from Clovis, however, the only other campsites in the western U.S. appear to be Tonopah, with its mixture of points and other artifacts, and Borax Lake.

Fortunately the major Clovis sites in the eastern U.S. provide abundant evidence of camp life. Some contain literally thousands of flint implements in addition to the characteristic fluted points; these include choppers, gravers, perforators, scrapers and knives made out of flint flakes. The locations of these sites show the kind of place the mammoth-hunters preferred as a camp. Shoop, Williamson, Quad and Wells Creek Crater are all on high ground, such as a stream-cut terrace or a ridge, overlooking the floodplain of a river or creek.

Analysis of the kill sites, in turn, reveals something about the Clovis people's hunting techniques, although many questions remain unanswered. The number of points found with each kill, for example, is inconsistent. At the Dent site only three Clovis points were found among the remains of a dozen mammoths. At Naco the skeleton of a single mammoth was associated with eight points. One interpretation of this seeming contradiction is that the Naco mammoth may have been one that got away, escaping its hunters to die alone some time after it was attacked. The 12 mammoths at Dent, according to the same interpretation, were butchered on the spot and the hunters recovered most of their weapons. One piece of negative evidence in support of this interpretation is that no butchering tools were found at Naco. Such tools, however, are also absent from Dent.

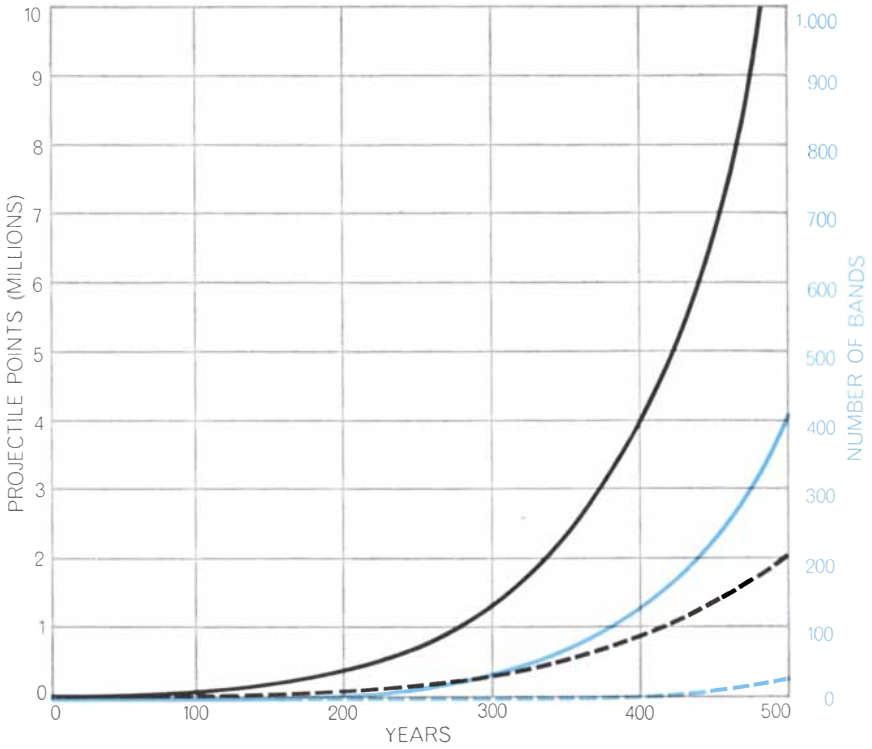
The Dent site affords a reasonably clear picture of one hunt. The mammoth bones were concentrated at the mouth of a small gully where an intermittent stream emerges from a sandstone bluff to join the South Platte River. It seems plausible that here the Clovis hunters had stampeded a mammoth herd over the edge of the bluff. Some of the animals may have been killed by the fall; others may have es-

STAMPEDED MAMMOTHS were unearthed near Dent, Colo., in 1932 by workers from the Denver Museum of Natural History. Among the bones of 11 immature female elephants and one adult male elephant they found several boulders and three typical Clovis projectile points. Photographed at the site were (*left to right*) Rev. Conrad Bilgery, S.J., an unidentified Regis College student, two Denver Museum trustees (W. C. Mead and C. H. Hanington) and Frederick Howarter of the museum's paleontology department.

caped. Those that were too badly hurt to fight free of the narrow gully may then have been stunned with boulders—an assumption that helps to explain the presence of these misplaced stones among the mammoth bones—and finally dispatched with spear thrusts. The bag of 11 cows and one bull would have constituted a highly successful day's work, but it may also have been the result of several hunts.

All six mammoths found at Clovis could also have been taken by stampeding a herd, in this case into shallow water where the footing was treacherous. Whether this actually happened, or whether the animals were simply surprised while watering, is impossible to determine. Clovis nonetheless affords a tantalizing glimpse into another of the mammoth-hunters' thought processes. One of the springs that fed the lake contains hundreds of flint flakes and a number of intact flint tools, including three Clovis points. Did the ancient hunters deliberately toss waste chips and usable artifacts into the spring? If not, how did these objects accumulate?

The concept of cutting a herd—separating the young and less dangerous animals from the more formidable adults—may be what is demonstrated by the remains at the Lehner site, where all nine mammoths were immature or even nurslings. At Lehner, as at Domebo (where only a single adult was killed), the animals apparently had been attacked while watering along a spring-fed stream.



POPULATION INCREASE among the mammoth-hunters in the course of 500 years is calculated on the assumption that an original 30-member hunting band multiplied by a factor of 1.2 or 1.4 each 28-year generation (*color*). Black curves show the total number of Clovis points produced during 500 years, assuming that one person in four made five each month.

Although the way in which the hunters' fluted projectile points were mounted seems clear, the kind of haft on which they were mounted remains unknown. That the points were used as arrowheads seems unlikely; the bow reached the New World or was independently invented there at a much later date. The Clovis points must therefore have been mounted on spears or darts. Whether launched from the hand or propelled by a spear-thrower, neither may have been a weapon of much effectiveness against an infuriated mammoth. It seems possible that, when the prey showed fight, most of the hunters devoted their efforts to keeping the mammoth at bay while a daring individual or two rushed in to drive a spear home to its heart from behind the foreleg.

The analysis of kill sites provides one further fact about the Clovis hunters. Although they were evidently specialists in the pursuit of mammoths, they were not unwilling to take other kinds of quarry. At two of the sites—Clovis and Lehner—bison bones are also found.

The fluted projectile point is a highly specialized artifact that must have passed through a considerable period of development, yet no precursors are known in the New World or elsewhere. Obviously the archaeological record is incomplete, and perhaps it will remain so. For the time being, however, this absence of evident precursors suggests that the Clovis people arrived in the New World, already equipped with their specialized tool kit, between 12,000 and 13,000 years ago. Carbon-14 dates obtained during the past 15 years have built up a reasonably consistent picture of the way in which the New World was peopled during the final stages of the Pleistocene ice age. When the most recent glacial period was at its peak, 14,000 to 20,000 years ago, a large portion of the earth's water supply was stored in the Northern Hemisphere's ice sheets. The so-called land bridge between Alaska and Siberia in the area of the Bering Strait, exposed by the low level of the earth's oceans at that time, was no narrow isthmus but a broad land mass joining Asia and North America in a single continent.

The Bering land mass, however, was not a thoroughfare from the Old World to the whole of the New. The Cordilleran ice cap covered the Canadian Rockies from Vancouver to eastern Alaska, and the Laurentide ice cap covered most of the rest of Canada and much of the northern U.S. These two glacial formations merged at the foot of the Canadian Rockies, leaving central Alaska, the Bering land mass and eastern Siberia unglaciated but cut off from the more southerly Americas by an ice barrier.

A little more than 12,000 years ago there occurred a marked period of glacial retreat known as the Two Creeks interval. Carbon-14 dates indicate that the warm interval came to an end scarcely more than a century or two later, or about 9900 B.C.; another glacial advance began soon thereafter. As we have seen, Clovis points make their first appearance in western North America in 9500 B.C., or roughly half a millennium after the Two Creeks interval. A tenable hypothesis connecting the two events is that the Two Creeks glacial retreat opened a trans-Canadian corridor between the Cordilleran and the Laurentide ice caps. The progenitors of the Clovis people, confined until then to central Alaska but already specialists in big-game hunting, could thus make their way down an ice-free corridor into a world where big game abounded and

CLOVIS BONE POINT, partly cleared of surrounding matrix at lower right, lies in direct association with the bones of a mammoth foreleg. Unearthed at Clovis, this evidence of early man's hunting ability is displayed at the Philadelphia Academy of Natural Sciences.

had scarcely been hunted until that time.

This, of course, is no more than a hypothesis, but it is a useful one on two counts. First, it provides a logical explanation for the abrupt appearance of Clovis points in North America at about 9500 B.C. Second, it is easily tested. All that is needed to destroy the Two Creeks hypothesis, for example, is the discovery of a Clovis site more than 12,000 years old located south of the ice sheet. Thus far no such Clovis site has been found. Meanwhile the Two Creeks hypothesis can also be tested indirectly in demographic terms.

Assuming that the first Clovis people passed through northwestern Canada some 12,000 years ago, they would have had to travel at the rate of four miles a year to reach the most southerly of their western U.S. sites, 2,000 miles away, within 500 years. Is such a rate of human diffusion realistic? Edward S. Deevey, Jr., of Yale University has noted that, under conditions of maximal increase in an environment empty of competitors, mankind's best efforts produce a population increase by a factor of 1.4 in each 28-year generation [see "The Human Population," by Edward S. Deevey, Jr.; SCIENTIFIC AMERICAN, September, 1960]. James Fitting of the University of Michigan has recently investigated a prehistoric hunting camp in Michigan; he suggests that Paleo-Indian family hunting bands numbered between 30 and 60 individuals.

Making conservative use of these findings, I have assumed that the first and only Clovis band to pass down the corridor opened by the Two Creeks interval numbered about 30, say five families averaging six persons each: two grandparents, two parents and two offspring. I have assumed further that one in four knew how to knap flint and produced Clovis points at the rate of five a month. In case Deevey's growth factor of 1.4 is too high, I have also made my calculation with a smaller factor—1.2—on the grounds that a plausible extrapolation probably lies somewhere between the two.

Applying these production rates, I find that in 500 years an original band of 30 mammoth-hunters evolves into a population numbering between 800 and 12,500, comprised of 26 to 425 hunting bands. In the same 500 years the bands' flint-knappers will have made—and left scattered across the land—between two million and 14 million Clovis points. Assuming that the demographic model is a reasonable one, the Clovis hunters could easily have spread across North America from coast to coast in the brief span of time allotted to them. Indeed, if the higher figure is in any way realistic, the rapid increase in the number of mammoth-hunters could easily be one of the main reasons why these animals became extinct in North America sometime around 9000 B.C., leaving the succeeding Folsom hunters with no larger prey than bison.

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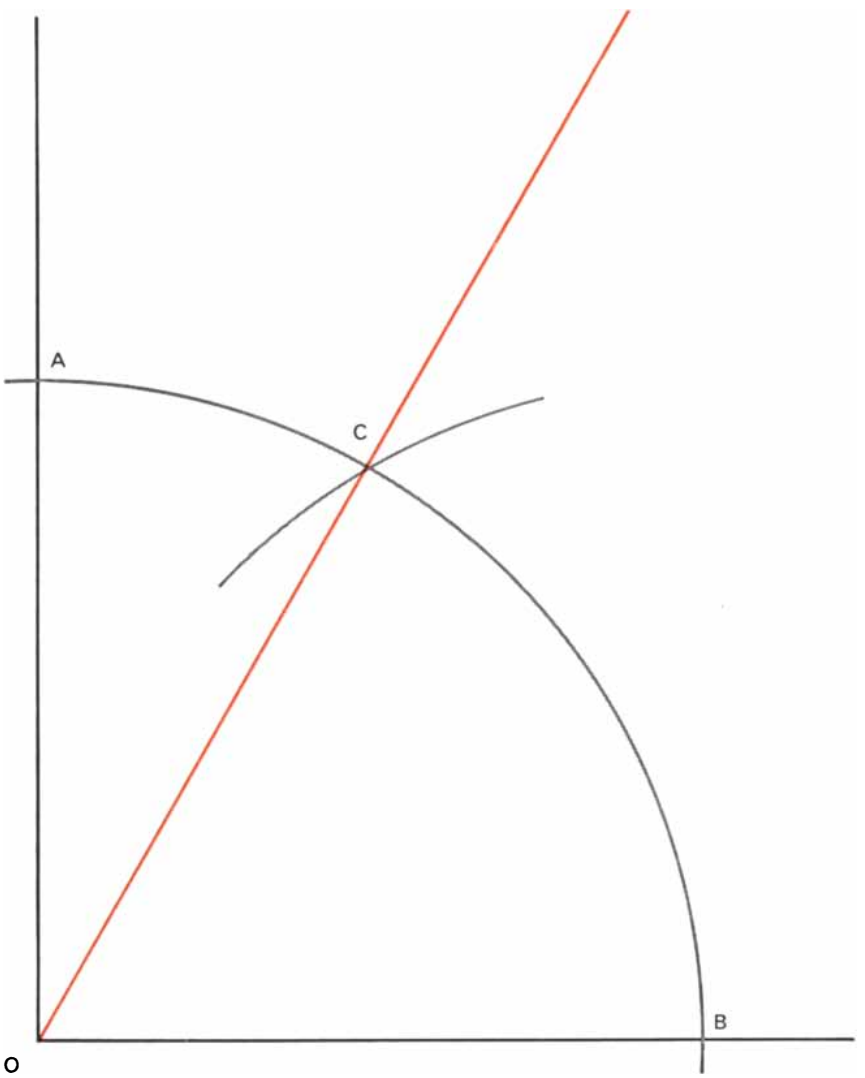
MATHEMATICAL GAMES

The persistence (and futility) of efforts to trisect the angle

by Martin Gardner

Two of the first compass-and-straightedge constructions a child learns in plane geometry are the bisection of an angle and the division of a line segment into any desired number of equal parts. Both are so easy to do that many pupils find it hard to believe there is no way in which the two instruments can be used to trisect an angle. Indeed, it is usually the student who is most gifted mathematically who takes this as a challenge and immediately sets to work trying to prove the teacher wrong.

Something like this happened among mathematicians in the "childhood" of geometry. As far back as the fifth century B.C. geometers devoted a large share of their time to searching for a way of using straight lines and circles to obtain an intersection point that would trisect any given angle. They knew, of course, that certain angles could be trisected. The right angle, for instance, is ridiculously easy. One has only to draw the arc *AB* [*see illustration on this page*] and then, without altering the compass opening, place the compass point at *B* and draw an arc that intersects the other arc at *C*. The line from *O* through *C* trisects the right angle. (Readers are invited to brush up on their plane geometry by proving the trisections mentioned in this article. All have simple proofs.) The 60-degree angle in turn trisects the straight angle of 180 degrees, and by bisecting the 30-degree angle one obtains the angle that trisects the 45-degree angle. An infinity of special angles obviously can be trisected under the classical restraints, but what the Greek geometers wanted was a general method applicable to any given angle. Together with doubling the cube and squaring the circle, finding it became one of the three great construction problems of ancient geometry.



How to trisect a right angle

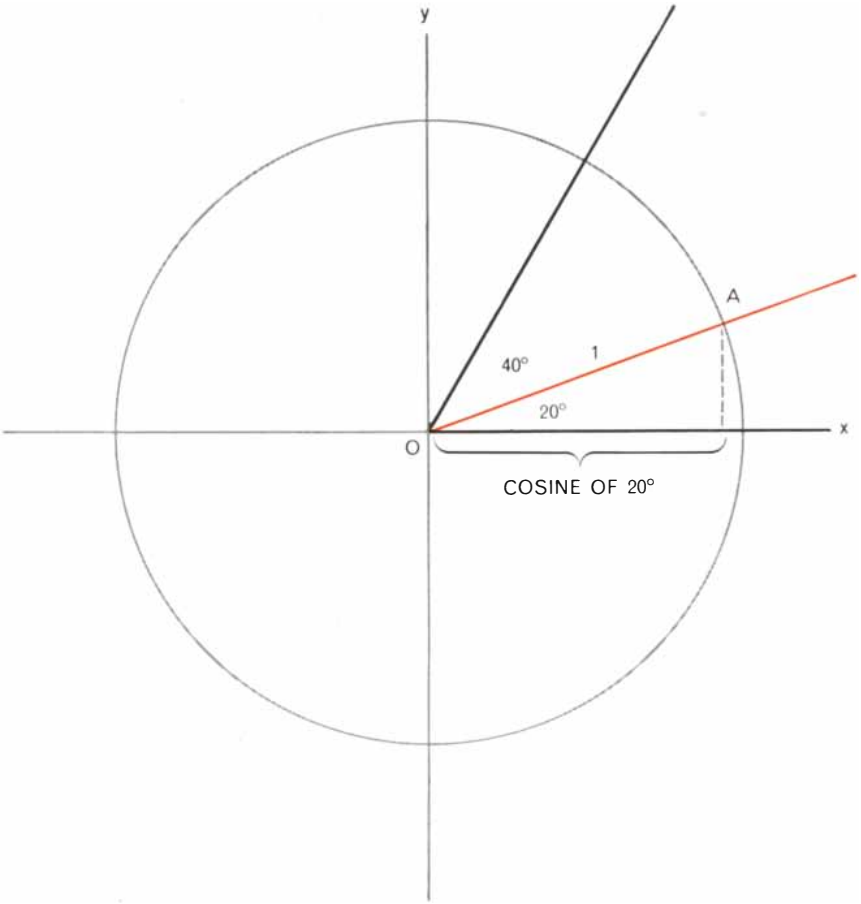
It was not until 1837 that a French mathematical journal published the first completely rigorous proof, by P. L. Wantzel, of the impossibility of trisection. His proof is much too technical to explain here, but the following remarks suggest its main lines. (The fullest and best nontechnical exposition of such a proof can be found in *What Is Mathematics?*, by Richard Courant and Herbert Robbins, pages 127–138.) Consider a 60-degree angle with its vertex at the origin of a Cartesian coordinate plane [*see illustration at top of opposite page*]. Draw a circle with its center at *O* and assume that the circle's radius is 1. The trisecting line of the 60-degree angle will intersect this circle at *A*. Is it possible, using only compass and straightedge, to locate point *A*? If not, at least one angle cannot be trisected and therefore there will be no general method.

Because straight lines on the Cartesian plane are graphs of linear equations and circles are graphs of quadratic equations, it can be shown that there are five, and only five, operations that can be performed on given line segments by using only a compass and straightedge. The segments can be added, subtracted, multiplied and divided, and their square roots can be extracted. Given any line segment *n*, one can use compass and straightedge to find the square root of *n*. The same operation can be repeated on the square root of *n* to obtain *its* square root, which is the

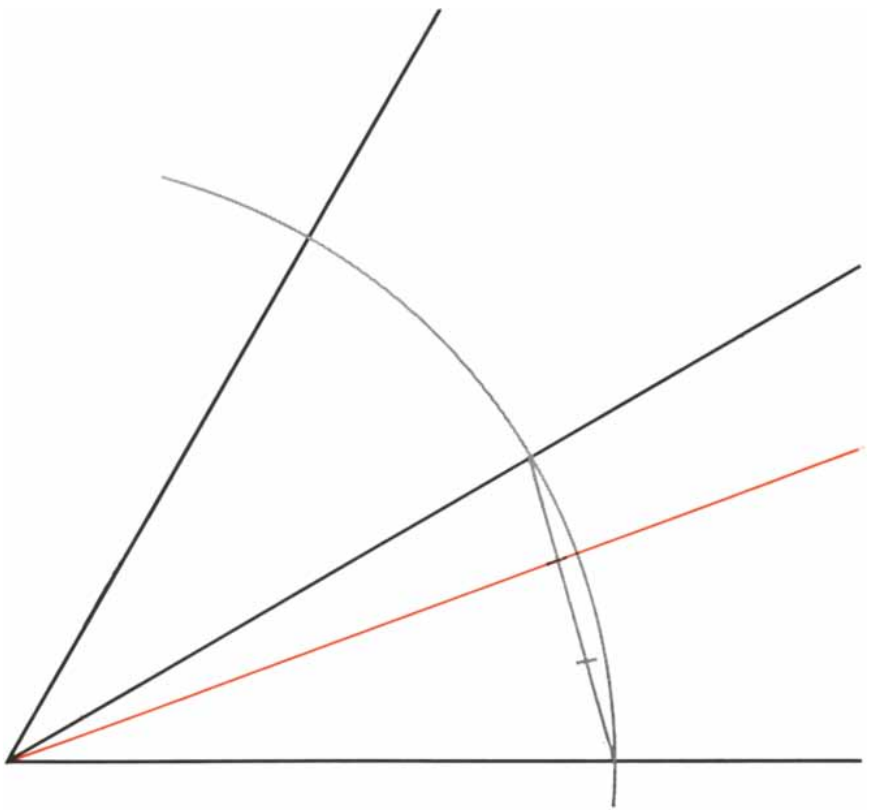
same as the fourth root of n. Thus by repeating the operation of square root extraction a finite number of times one can find any root in the doubling series 2, 4, 8, 16... It is not possible, with compass and straightedge, to find the cubic root of any line segment, because 3 is not a power of 2. All of this, together with arguments in analytic geometry and the algebra of what are called "number fields," establishes that the only "constructible" points on the plane are those with x and y coordinates that are the real roots of a certain type of equation. It must be an algebraic equation that is irreducible (cannot be factored into expressions with lower exponents), has rational coefficients and is of a degree that is a power of 2, that is, with its highest exponent in the 2, 4, 8... doubling series.

Consider now the x coordinate of point A in the top illustration at the right, the point that trisects the 60-degree angle. It measures the base of a right triangle whose hypotenuse is 1, and so it is equal to the cosine of 20 degrees. A bit of juggling with some simple trigonometric formulas shows that this cosine is the irrational root of an irreducible cubic equation: $8x^3 - 6 = 1$. The equation is of degree 3, therefore point A is not constructible. Since there is no way to find point A with compass and straightedge, the 60-degree angle cannot be trisected under the classic restrictions. Similar arguments prove there are no general methods by which compass and straightedge can divide any given angle into fifths, sixths, sevenths, ninths, tenths or any other number of equal parts not in the 2, 4, 8, 16... series. Among the infinity of angles that *can* be trisected are those equal in degrees to $360/n$ where n is an integer not evenly divisible by 3. Among the infinity that cannot be trisected are those equal to $360/n$ where n is an integer divisible by 3. An angle of 9 degrees can be trisected. Its trisector, the 3-degree angle, cannot—which is the same as saying that there is no way to construct a unit angle with compass and straightedge. Nor can a 2-degree angle be constructed.

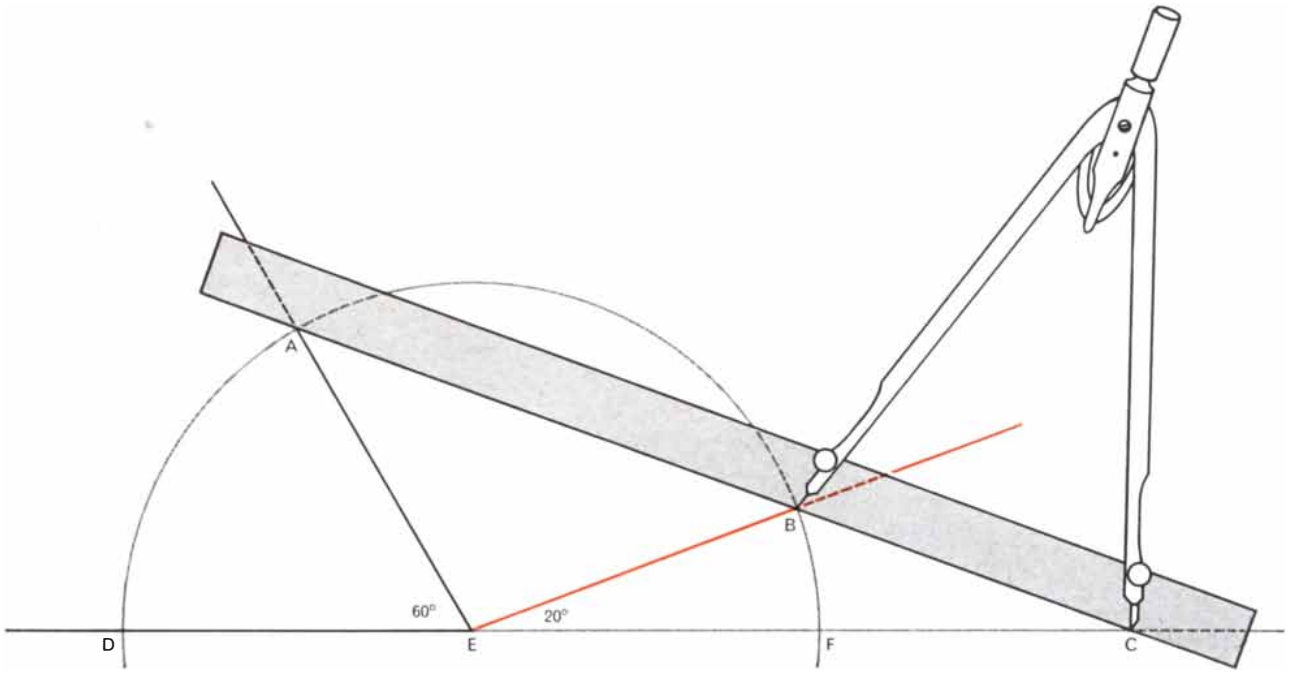
There are, of course, many ways to trisect the angle approximately. One of the simplest (given by Hugo Steinhaus in his *Mathematical Snapshots*) is applied to a 60-degree angle in the bottom illustration at the right. First the angle is bisected, then a chord of a half-angle is trisected. This provides a point for trisecting the original angle with an error less than the inevitable inaccuracy that occurs in the drawing. Dozens of



Point A is not "constructible" with compass and straightedge



A simple way to (almost) trisect any angle



Archimedes' method of trisection by cheating

still better approximations have been published, but most of them require considerably more work.

Absolutely precise trisections are achieved only by breaking one of the traditional restraints. Many noncircular curves such as the hyperbola and parabola will produce perfect trisections. Other methods assume an infinite number of construction steps with the trisecting line as a limit. The simplest way, however, to evade the restraints is to mark two points on the straightedge. This can even be done without actually putting marks on it: by using the ends of the straightedge to mark a line segment, by using its width or merely by pressing the legs of the compass firmly against the edge. One of the best trisections obtainable by this kind of cheating is found in the writings of Archimedes. The angle to be trisected is *AED* in the illustration above. Draw a semicircle as shown, then extend *DE* to the right. With the compass still open to the semicircle's radius, *DE*, hold the legs against the straightedge and place the straightedge so that it passes through point *A*. Adjust the straightedge until the points marked on it by the legs of the compass intersect the semicircle and its extended base at points *B* and *C*. In other words, make *BC* equal to the radius. The arc *BF* is now exactly one-third of the arc *AD*.

A great variety of curious mechanical devices have been invented for angle-trisecting. (Twenty are pictured in the standard Italian work on recreational mathematics, *Matematica Dilettevole e Curiosa*, by Italo Ghersi, current edition, pages 476–489.) As Leo Moser, a University of Alberta mathematician, once pointed out in an article, the ordinary watch is such an instrument. If the minute hand is moved over an arc equal to four times the angle to be trisected, the hour hand moves through an arc that is one-third the given angle. A whimsical linkage designed by Alfred Bray Kempe, a London lawyer, is based on theorems involving crossed parallelograms—parallelograms "folded" so that two opposite sides cross [*see top illustration on opposite page*]. The three crossed parallelograms in the linkage are similar. A long side of the smallest is a short side of the middle one, a long side of which is in turn a short side of the largest one. The device trisects automatically, as shown. The principle can be extended, by adding more crossed parallelograms, to make an instrument that will divide angles into any desired number of equal parts.

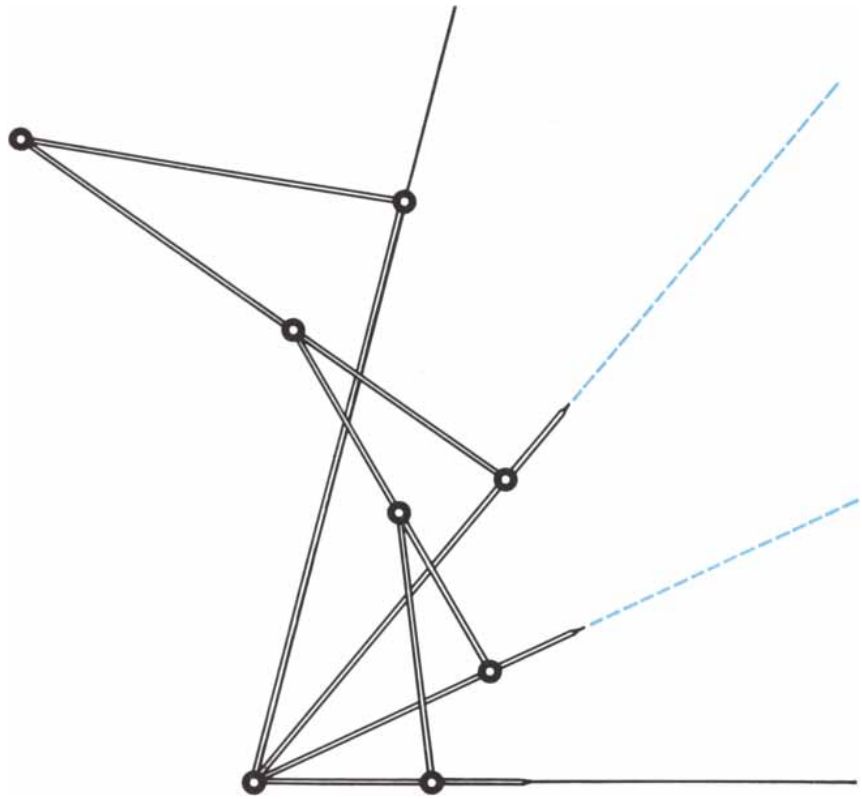
An easy-to-make cardboard trisecting device called the "tomahawk" has no moving parts, requires no preliminary construction lines and is unconditionally guaranteed to trisect instantly and accurately [*see bottom illustration on opposite page*]. Its top edge *AD* is cut into thirds by points *B* and *C*. The curved edge is the arc of a semicircle with a radius *AB*. The tomahawk is placed with corner *D* on one arm of the angle, the semicircle tangent to the other arm and the right edge of its handle crossing the angle's vertex. Points *B* and *C* trisect the angle. If an angle is too acute for the tomahawk to fit, you can always double it one or more times until it is large enough, trisect the larger angle, then halve the result as many times as you doubled it.

Although the proof of trisection impossibility by compass and straightedge is completely convincing to anyone who understands it, there are still amateur mathematicians all over the world who delude themselves into believing they have discovered a method that meets the classic requirements. The typical angle-trisector is someone who knows just enough plane geometry to work out a procedure but not enough to follow the impossibility proof or to detect the flaw in his own method. His trisection is often so complicated, and his proof has so many steps, that it is not easy for even the expert geometer to find the error that is certain to be there. Professional mathematicians are always being favored with such proofs. Since it is both time-consuming and unrewarding to search for errors, they usually mail the material back quickly without trying to analyze it. This invariably confirms the trisector's suspicion that the professionals are engaged in an organized conspiracy to prevent his great discovery from becoming known. After his method has been rejected by all the mathematical journals to which he sends

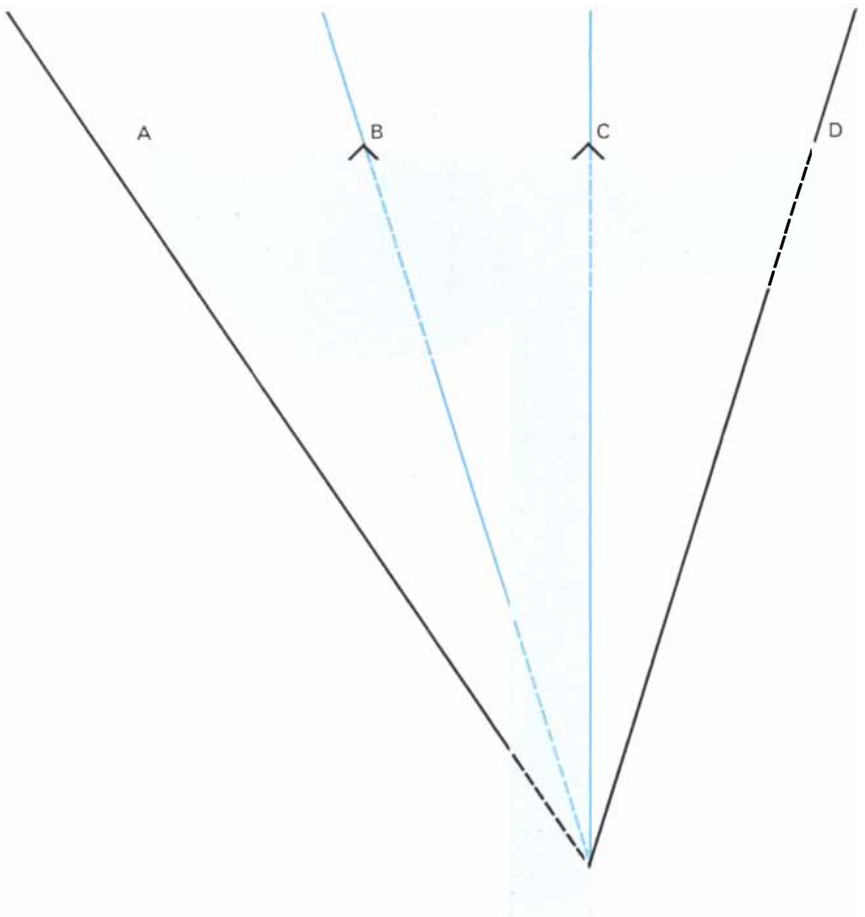
it, he often explains it in a book or pamphlet printed at his own expense. Sometimes he describes his method in an advertisement in a local newspaper, adding that his manuscript has been properly notarized.

The last amateur mathematician to be given widespread publicity in the U.S. for angle-trisecting was the Very Reverend Jeremiah Joseph Callahan. In 1931, when he was president of Duquesne University in Pittsburgh, he announced that he had solved the trisection problem. The United Press sent out a long wire story, written by Father Callahan himself. *Time* ran his picture with a favorable account of his revolutionary discovery. (That same year Father Callahan published a 310-page book called *Euclid or Einstein,* in which he demolished relativity theory by proving Euclid's famous parallel postulate, thereby showing the absurdity of the non-Euclidean geometry on which general relativity is based.) Reporters and laymen expressed shock when the establishment mathematicians, *without even waiting to see Father Callahan's construction,* declared unequivocally that it could not be correct. Finally, at the end of the year, Duquesne published Father Callahan's booklet *The Trisection of the Angle.* "The mathematicians were right," says mathematician Irving Adler, who tells the story in his entertaining book *Monkey Business.* "Callahan had not trisected the angle." He had in effect merely taken an angle, tripled it, then found the original angle again.

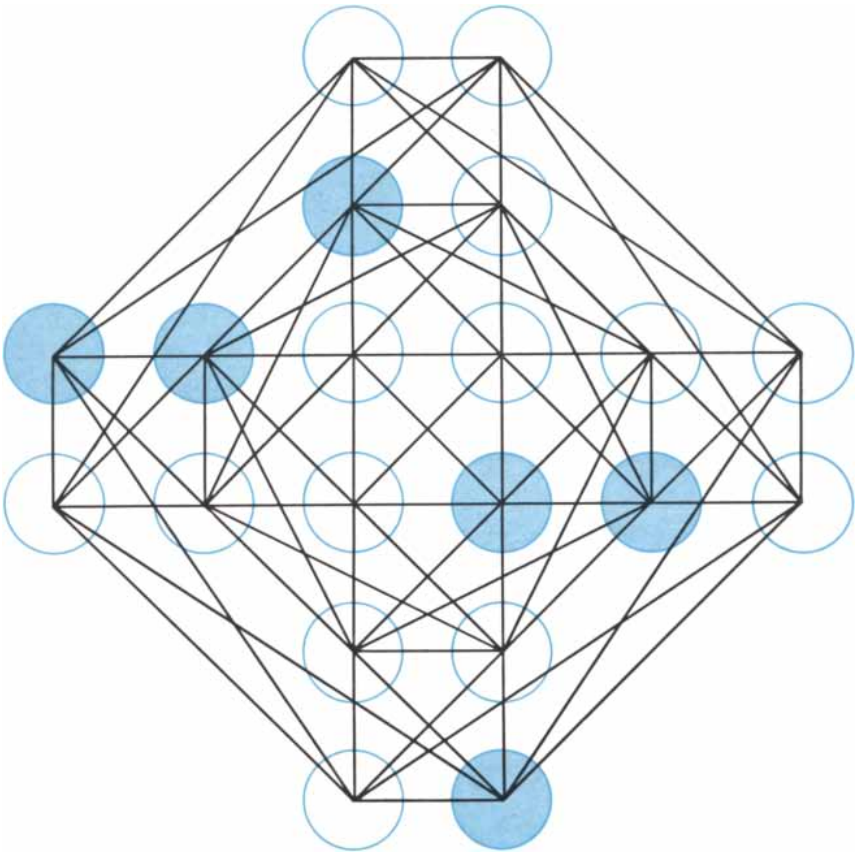
On June 3, 1960, the Honorable Daniel K. Inouye, then a representative from Hawaii, read into the *Congressional Record* (Appendix, pages A4733–A4734) of the 86th Congress a long tribute to Maurice Kidjel, a Honolulu portrait artist who has not only trisected the angle but also squared the circle and duplicated the cube. Kidjel and Kenneth W. K. Young have written a book about it called *The Two Hours that Shook the Mathematical World,* and a booklet, *Challenging and Solving the Three Impossibles.* Through a company called The Kidjel Ratio they sell this literature along with the Kidjel ratio calipers with which one can apply the system. In 1959 the two men lectured on their work in a number of U.S. cities, and a San Francisco television station, KPIX, produced a documentary about them called *The Riddle of the Ages.* According to Congressman Inouye (who is now a senator): "The Kidjel solutions are also now being taught in hundreds



Kempe's linkage for trisecting any angle



The "tomahawk" trisector



Solution to 20-counter problem

of schools and colleges throughout Hawaii, the United States and Canada." One hopes the statement was exaggerated.

Just recently a correspondent in California sent me a clipping from the *Los Angeles Times* for Sunday, March 6, 1966 (Section A, page 16). A man in Hollywood had taken a two-column advertisement to display, in 14 steps, his method of trisecting.

What can the mathematician say today to an angle-trisector? He can remind him that in mathematics it is possible to define tasks that are impossible in a final, absolute sense: impossible at all times, in all conceivable (logically consistent) worlds. It is as impossible to trisect the angle as it is to move a queen in chess the way one moves a knight. In both cases the ultimate reason for the impossibility is the same: the operation violates the rules of a mathematical game. The mathematician can urge the trisector to get a copy of *What Is Mathematics?* and study the section mentioned above, then go back to his proof and try a bit harder to find where he went astray. But angle-trisectors are a persistent breed and not likely to take anyone's advice. Augustus De Morgan, in his *Budget of Paradoxes,* quotes a typical phrase from a 19th-century pamphlet on angle-trisection: "The consequence of years of intense thought." De Morgan's comment is terse: "Very likely, and very sad."

Last month's problems have the following answers:

1. White checkmates with knight to Q6.

2. The illustration above shows one way to remove six of the 20 counters [*color*] so that no four remaining counters mark the corners of any of the 21 squares.

3. Apart from Sam Loyd's solution to the clock puzzle, shown last month, there are 12 other perfect answers [*see illustration on page 122*]. Each clock-face is divided into four parts, the numbers in each part adding up to 20. The last three solutions are the hardest to find.

4. Loyd's eagle completes its flight at sundown after 39½ days as measured in Washington. The eagle will have seen 38½ "days" (measured by the sunrises and sunsets it saw in flight) but, because it circled the earth in a direction opposite to the earth's spin, it has

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Capability has many faces at Boeing

CHINOOK helicopter, built by Boeing's Vertol Division, is operating in Viet Nam with the 1st Cavalry Division (Airmobile). Chinook is U.S. Army's standard medium transport helicopter.

TEST firing of world's most powerful rocket stage, the S-1C booster of NASA's Saturn V which will launch first Americans on moon journey. Boeing holds NASA contract to build, develop, test S-1C stage, generating 7.5 million pounds of thrust.

85-FOOT antenna near Madrid, part of worldwide Deep Space Network, is one of three which will receive transmissions from NASA's Boeing-built Lunar Orbiter as it circles and photographs moon later this year. NASA has also assigned Boeing responsibility for space flight mission operation.

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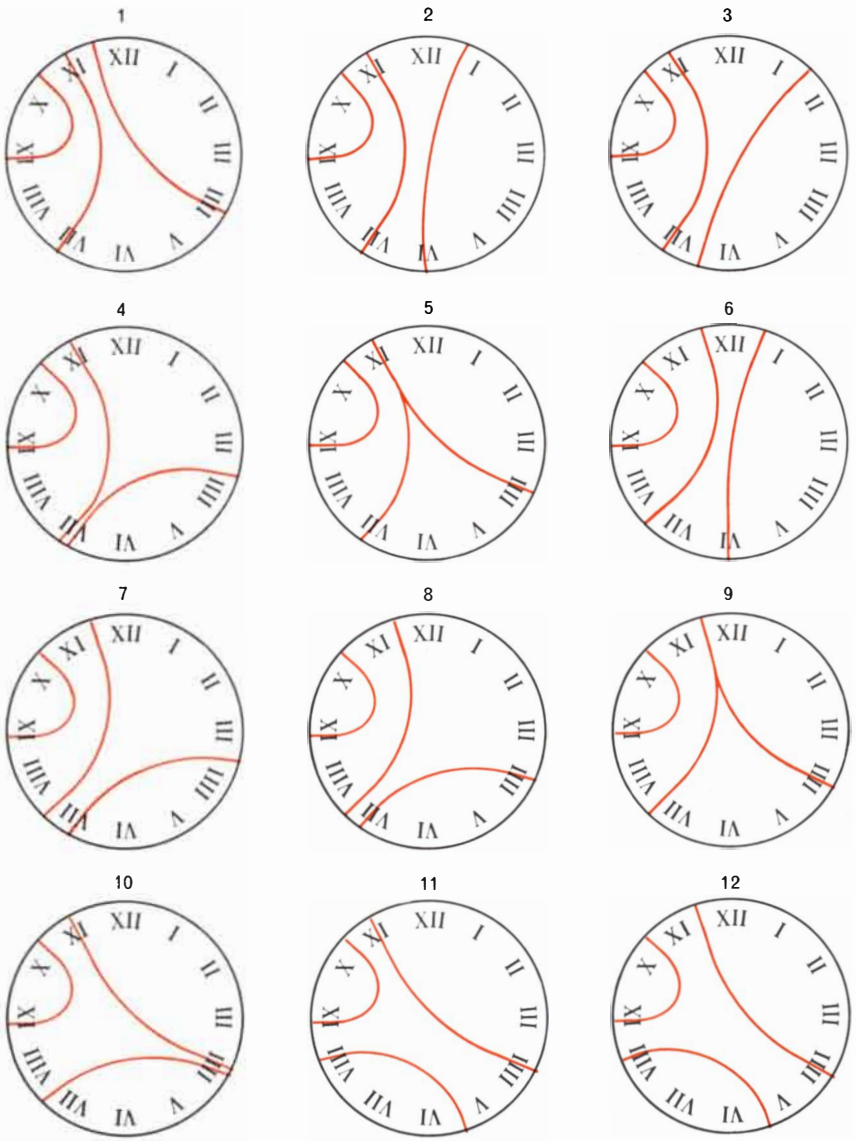
lost a day compared with the elapsed days in Washington.

5. Assume that the explorer and bear are near the South Pole. The bear is 100 yards south of the man, at a spot such that, when it completes its 100-yard walk east, it will be exactly opposite the man on the *other side* of the South Pole. Thus when the explorer aims his gun south and fires, the bullet travels over the South Pole and hits the bear. There is an infinite set of solutions, for the bear can be closer still to the pole so that his walk takes him one and a half times around the pole, or two and a half times, and so on.

The second easily overlooked family of answers hinges on the statement that the man "looking due south... sees a bear 100 yards away." Clearly the man and bear can have initial positions in which they are on opposite sides of the South Pole but 100 yards apart. The man is farther from the pole than the bear is. After the bear has walked 100 yards due east it is halfway around a circle to a spot directly south of the man, on the *same* side of the pole. Of course, the man can be a bit farther from the pole, so that the bear makes a complete circle, or one and a half circles, or two circles, or two and a half circles, and so on, to generate another infinite family of solutions that reaches a limit when the man is 100 yards from the pole. The bear's walk then degenerates into a pirouette on the pole itself. Both families of overlooked solutions are given by Benjamin Schwartz in his article "What Color Was the Bear?" in *Mathematics Magazine*, Vol. 34, September–October, 1960, pages 1–4.



Solutions to last month's clock-dissection problem

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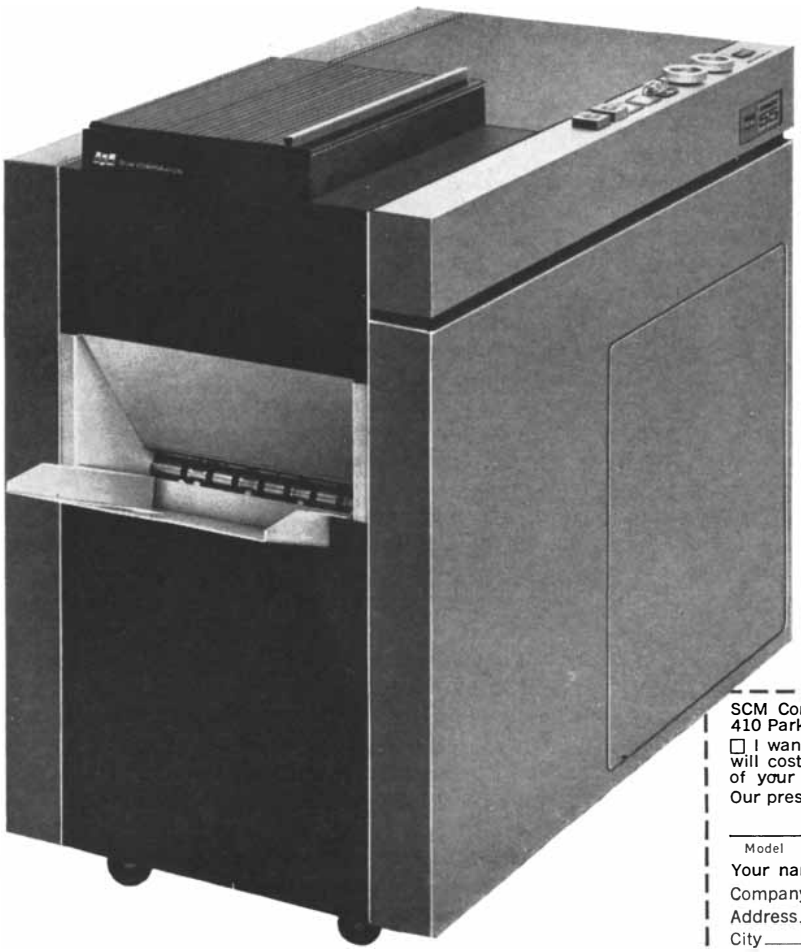

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THE AMATEUR SCIENTIST

How to build a gas chromatograph and use it to separate the components of mixtures

Conducted by C. L. Stong

As recently as 1950 perfumes were graded by the noses of connoisseurs and wines were judged by the palates of wine tasters. Even chemists occasionally relied on taste and smell in some of their procedures. Today these arts have been outmoded by the gas chromatograph. This simple apparatus can quickly detect and measure each of the scores of fractions in a complex mixture, even though some components may amount to only a few trillionths of the total bulk. The gas chromatograph contains no complex parts, and it can be built easily and inexpensively by the amateur.

George V. Downing, Jr., a specialist in gas chromatography, described the operating principle of the device in the October 1964 issue of *The Oregon Science Teacher,* official publication of the Oregon Science Teachers' Association. "The principle of gas chromatography," he wrote, "is illustrated by a stream of inert gas such as nitrogen passing through a tube packed with granules of an inert substance coated with a thin film of liquid such as silicone oil that is essentially nonvolatile at the temperature of the tube. The nitrogen is called the carrier gas and the oily granules are known as the chromatographic column.

"Suppose we now inject at the entrance to the tube one milliliter of a mixture consisting of three gases such as propane, butane and argon. Propane and butane are soluble in the silicone oil, and hence some atoms of each will dissolve in the liquid. Propane is the more volatile of the two and for this reason it has a lesser tendency than the butane to dissolve in the oil. Some atoms of both gases, however, continuously dissolve in the oil and evaporate out of it only to be redissolved and reevaporated again and again during their transit through the oily granules.

"The propane will spend more time during the transit in the moving gas than the butane will. Conversely, the butane will spend more time in the stationary oil than the propane will. Hence the propane will outdistance the butane as the two substances are urged downstream by the carrier gas; the two will separate and the propane will arrive first at the end of the tube. Even so, the propane will have spent some time in the stationary oil. For this reason it will not keep pace with the nitrogen gas that urges it along. Argon is not soluble in silicone oil. This gas would move through the tube at the same velocity as nitrogen and would have arrived at the end before either the propane or the butane."

The chromatographic separation of the fractions and their serial discharge at the outlet of the column depend on the affinity between silicone oil and other substances. In the case of generally inert gases such as nitrogen, helium and argon the affinity is insignificant and chromatographic separation does not occur. Affinity is significant, however, in the case of chemically active gases. Moreover, it varies distinctively from substance to substance.

Materials other than silicone oil can be used for the chromatographic column. Detergents, for example, are particularly effective for separating petroleum products. Materials such as the polyglycols are used for the analysis of plant vapors.

Having made the separation, the gas chromatograph must also detect the fractions as they emerge serially from the outlet of the column. Although many detection schemes are possible, three have gained favor. One is based on the relative effectiveness of gases as conductors of heat. The other two are based on the extent to which gases can be made to conduct electricity.

The detector based on conduction of heat makes use of a heated wire immersed in the stream of gases that flows from the column. Each of the gases cools the wire at a characteristic rate. The electrical resistance of the wire varies with temperature and can be continuously measured by a sensitive Wheatstone bridge. Variations of the galvanometer in the bridge reflect changes in the composition of the gas fractions passing out of the chromatographic column. In advanced versions of the instrument variations in the resistance of the detector operate a pen and are recorded as a graph.

Detectors based on the electrical conductivity of gases take the form of an ionization chamber. This enclosure, through which the exhaust gases of the column flow, is fitted with a device that ionizes the gases and with a pair of electrodes that set up a potential field through the gases. A sensitive ammeter connected to the electrodes measures the amplitude of the resulting current.

In one form of the conductivity detector the gases entering the ionization chamber are exposed to a small piece of radioactive metallic foil. High-energy nuclear particles from the foil bombard and thus ionize the gas. In an alternate scheme the radioactive foil is replaced by a burner that is fed with hydrogen and the exhaust gases from the column. The hydrogen burns in the chamber, resulting in pyrolysis: the electrification of the gases by ionization arising from heat. Each gas becomes more or less electrified, depending on its nature. The electric currents developed in the gases are quite small, amounting to less than a millionth of an ampere. Even so, the most sensitive detectors are of the electrical-conductivity type.

Each of the detection schemes has certain advantages and disadvantages. The heated-wire system, known as the katharometer, is reliable and easy to construct but not suitable for use with all carrier gases. The katharometer works best with gases (such as helium) that are good conductors of heat. It can detect differences in gas fractions amounting to about one part in 10,000.

This is adequate sensitivity for the analysis of mixtures in which each component is present in fairly substantial quantity.

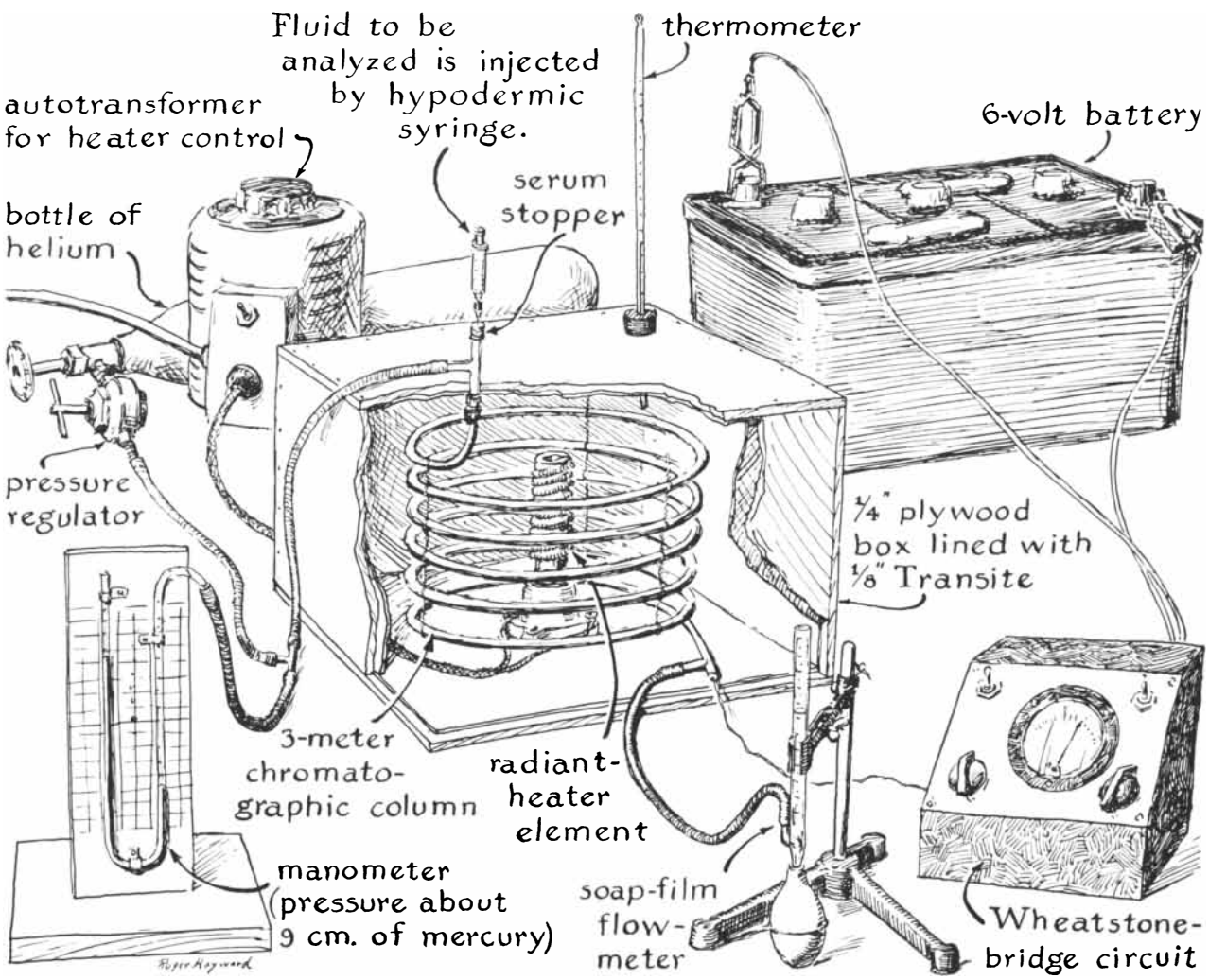
Some investigations, however, require more sensitivity. Examples are the analysis of atmospheric pollutants and the separation of compounds that are unstable at the high temperature necessary to achieve a vapor pressure adequate for detection by the hot-wire method. Many biological materials such as alkaloids and steroids are in this category; the analysis of such substances requires sensitivities on the order of one part in 10 trillion. Sensitivities of this magnitude are achieved by the ionization detectors.

The sensitivity and efficiency of the gas chromatograph vary with the specimen, the composition of the column, the kind of carrier gas and its temperature, the rate at which the carrier gas flows through the column and the detection scheme. Many carrier gases have been tried. Nitrogen was used by A. T. James and A. J. P. Martin, the British chemists who first proposed gas chromatography [see "Gas Chromatography," by Roy A. Keller; SCIENTIFIC AMERICAN, October, 1961]. Helium has the highest thermal conductivity of any inert gas and is a popular carrier in the U.S., particularly for use with a katharometer. Although hydrogen has high thermal conductivity and is inexpensive, it is also reactive and potentially explosive. Air, the least expensive carrier, is usually avoided because it can oxidize the specimen. Argon is used with certain radioactive detectors because it acts as an integral part of the ionizing mechanism.

The rate at which the carrier gas flows through the column is usually controlled by maintaining constant pressure with a regulator of the diaphragm type at the input. The flow can be retarded by placing finely drawn capillary tubes of glass between the regulator and the head of the column. Traces of water vapor and oil are normally removed from the carrier gas by a drying tube, a molecular sieve, sintered glass filters or silica gel.

The rate of flow that yields optimum separation of the fractions must be determined experimentally. If the rate is too high, the components do not have time to separate before they are carried out of the column. If the rate is too low, diffusion can mix the fractions partially and thus prevent sharp separations. In columns with a diameter of six millimeters practical rates of flow vary between 30 and 100 milliliters per minute.

According to Downing, a good column when operated properly will have a useful life of several months. Most columns consist of a copper, a glass or an aluminum tube that has an inside di-



Major components of a homemade chromatographic system

ameter of about six millimeters and is packed with a suitable material. The tube, some three meters long, is coiled or otherwise bent into a package of convenient size.

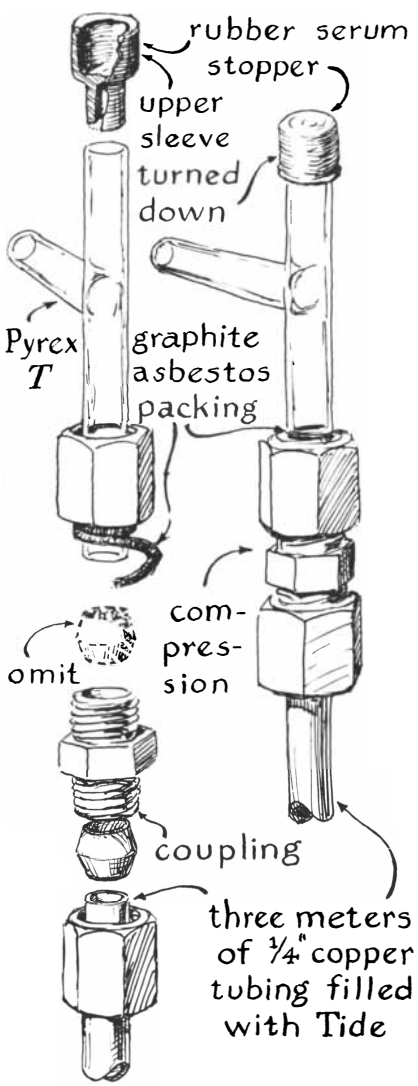
Metal tubing conducts heat better than glass tubing and therefore tends to maintain the column at a more uniform temperature. Metal columns are also more rugged than glass and easier to package for use in ovens. On the other hand, glass assemblies are chemically more inert. They are also transparent and so enable the experimenter to observe the packing procedure in detail and ensure uniformity.

The packing material should provide the maximum possible surface for exchanges between the liquid and the gases. For this reason it usually consists of an inert granular substance coated with a liquid. Widely used granules include diatomaceous earth, pulverized firebrick, glass beads, salt pellets and Teflon pellets. Some commercial detergents act as efficient column substances without a fluid coating.

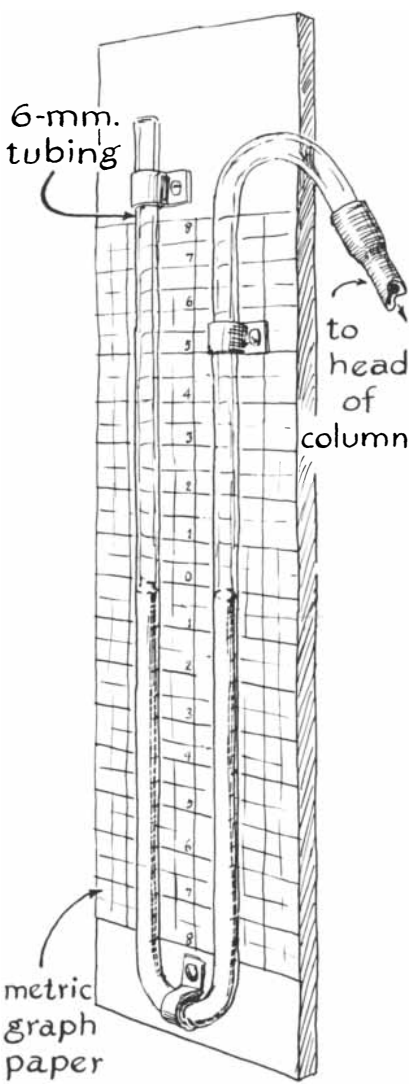
Particles should be screened to remove dust that might otherwise plug the column. Particle sizes of 40 to 50 mesh (a measure of screen fineness per square inch) are frequently used. Column efficiency varies inversely with particle sizes; 80 to 100 mesh or even 100 to 140 mesh have been used. The finer the particles, however, the higher the pressure required to drive the gas through the column.

An introductory experiment in gas chromatography conducted last year by Steve Langhoff and Glen Martin, who were then seniors at the South Salem High School in Salem, Ore., illustrates the procedure. Langhoff and Martin's instrument is properly known as a "vapor phase" chromatograph because the specimen (white gasoline), which exists as a fluid at room temperature, must for analysis be converted to vapor by heating the chromatographic column. The envelope of this column consists of copper tubing eight feet long and a quarter of an inch in outside diameter.

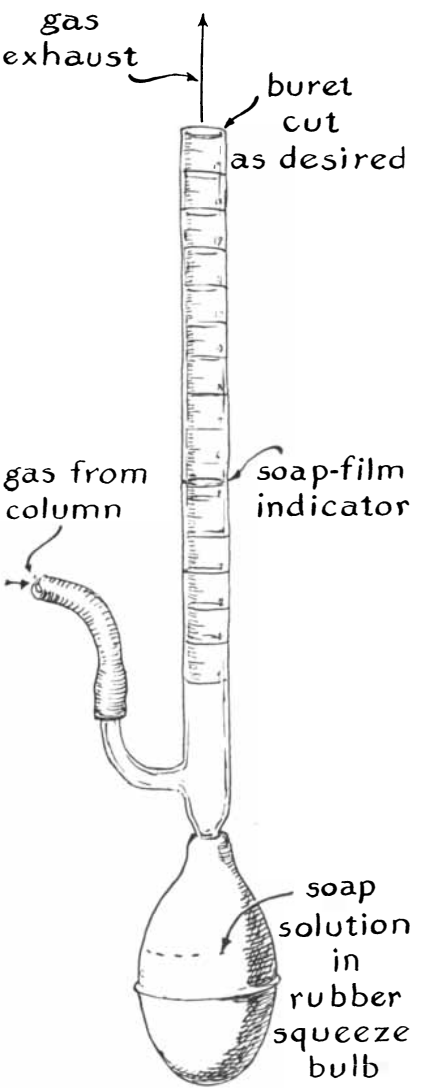
A short *T* connection was first soldered into the discharge end of the tube. The space just beyond the *T* was packed with a plug of rock wool about half an inch long. The tubing was then suspended vertically, with the *T* at the bottom, and completely filled with the commercial detergent Tide. The granules were slowly poured into the tube through a small funnel and packed by holding a vibrator against the metal. When solidly packed, the tube was wrapped around a cylindrical form to make a coil six inches in diameter, a convenient size for use in an oven improvised of plywood, Transite and an electrical heating element of the radiant type [*see illustration on preceding page*].



Entrance to column



A mercury manometer



Details of flowmeter

The carrier gas for the system was helium, which Langhoff and Martin obtained from a local welding shop. A regulator of the diaphragm type maintains the pressure of the carrier gas at nine centimeters of mercury, which is equivalent to 1.6 pounds per square inch. Carrier gas enters the column through the leg of a glass *T*. One end of the crossarm of the *T* is closed by a plastic cap of the kind used for sealing biological preparations such as serum in bottles. The other end of the *T* is attached to the column through a compression coupling as illustrated at the left on the opposite page. The space in the copper tube between the granules of detergent and the compression coupling is plugged with a wad of rock wool. A second *T* fitting that is inserted in the hose connection between the pressure regulator and the column connects to the mercury manometer used for observing the input pressure of the carrier gas.

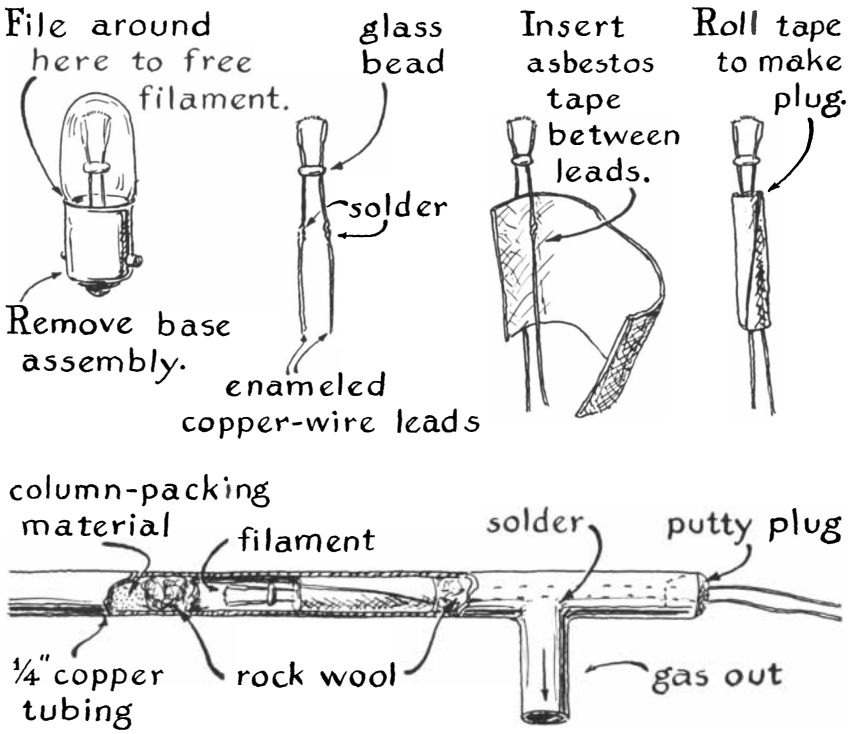
The *T* connection at the exhaust end of the column leads to an ingenious flowmeter suggested to Langhoff and Martin by Don F. Weinhart, professor of chemistry at the University of Oregon. The device consists of a glass tube calibrated in milliliters and fitted at the lower end by a side arm for admitting gas and by a rubber squeeze bulb partly filled with soap solution [*see illustration at right on opposite page*]. Squeezing the bulb deposits a soap film across the calibrated tube. The soap film is then forced up the tube by gas entering the side arm from the chromatographic column. By timing the passage of the soap film along the graduations the rate of flow in milliliters per minute is easily calculated. The flowmeter was made of a broken buret by cutting off the jagged top, sealing in a side arm at the bottom and pulling the soft glass beyond the side arm into a taper that fits the squeeze bulb.

The oven is simply a plywood box of convenient size lined with Transite and insulated with rock wool. The construction is not critical because the column operates at a temperature of only 130 degrees centigrade. (The temperature of the column need be only high enough to vaporize the specimen, in this case white gasoline.) Heat is supplied by a 600-watt unit from a radiant electric heater. The temperature is controlled by energizing the heater through a variable autotransformer.

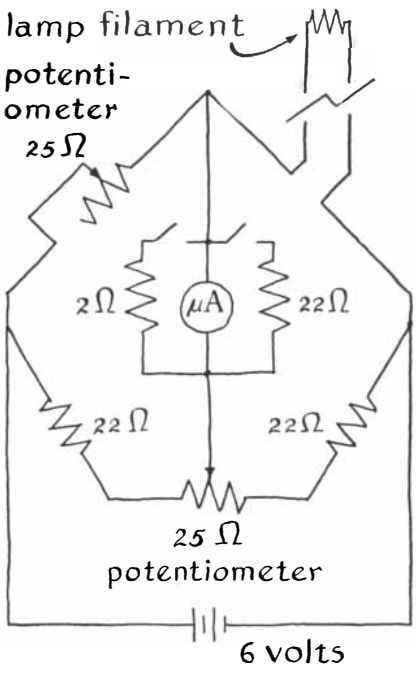
The essential element of the detector is the filament assembly of a 6.3-volt, .25-ampere incandescent lamp of the type used in a four-cell flashlight. Such bulbs are available in most hardware stores. The filament is removed from the lamp by filing a nick completely around the bulb at the point where the glass joins the metal base. Score the glass with a corner of a fine, sharp file. Use light pressure, not more than five ounces. Having extended the nick completely around the envelope, keep filing until the glass cracks. Do not grow impatient and strike the bulb if it fails to break when you think it should. Avoid striking and thus bending the filament assembly when the glass falls away.

Without removing the filament assembly from its base, extend the filament leads by soldering a pair of 24-gauge copper wires about six inches long to the leads just below the glass bead that supports the filament. Use a good liquid soldering flux. Clip off the portion of the filament leads just below the soldered joints and remove the filament from the base. A new base is made by spiraling asbestos tape between the leads and winding it into a cylinder as illustrated above. The assembly is then slipped into the discharge end of the column.

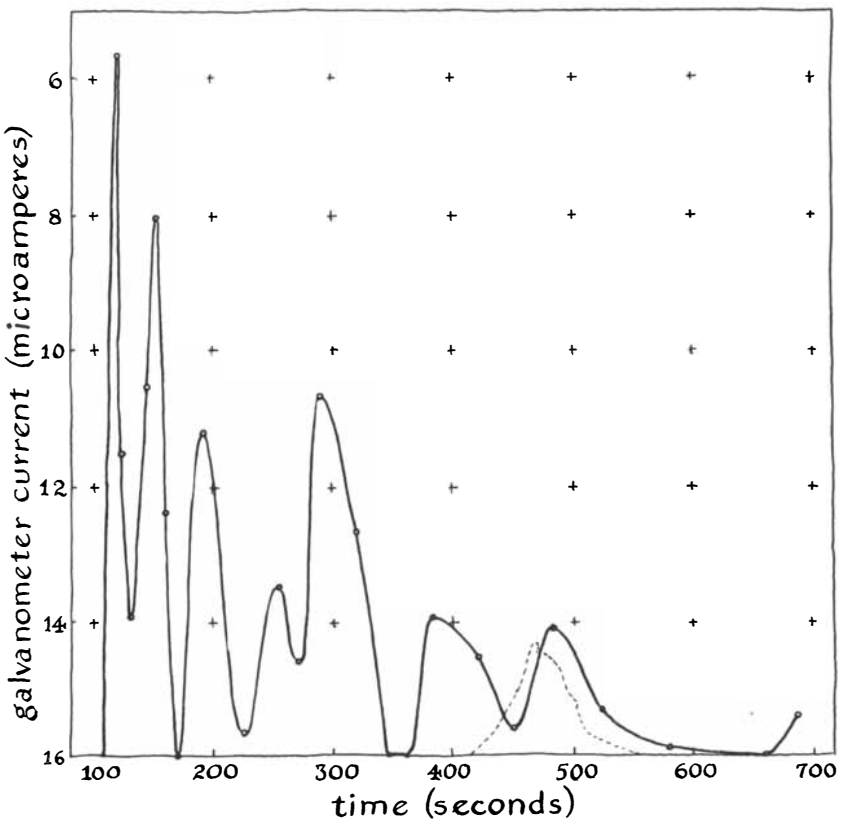
Measure carefully the distance between the end of the tube and the wad of rock wool that retains the packing. Slide the filament assembly into the tubing just far enough so that a space of about a quarter of an inch remains between the filament and the rock wool. Before installing the filament assembly try it for size in a short length of the copper tubing and simultaneously adjust the leads to prevent contact between the filament and the tubing. When all is ready, slide the assembly



Steps in construction of the detector



Circuitry of the Wheatstone bridge



Results of a chromatographic separation

into the column, brace the rear of the asbestos base with a tuft of rock wool and secure the leads in place with a plug of putty.

The Wheatstone bridge can consist of composition resistors of half-watt size. Never apply voltage to the bridge until air in the chromatographic column has been displaced by carrier gas. The filament will burn out if it is heated to incandescence in air. Use a fully charged storage battery for energizing the bridge, because accuracy of analysis requires constant voltage across the filament.

To analyze a specimen of white gasoline turn on the heater and adjust the autotransformer until the temperature of the oven remains constant at 130 degrees C. for 30 minutes. When the temperature has stabilized, turn on the carrier gas and adjust the regulator to a pressure of nine centimeters as indicated by the manometer. After about a minute test the system to see if the carrier gas has displaced air from the column. One makes this test by holding a lighted match or a glowing splint immediately above the discharge end of the flowmeter. If the gas quenches the flame, the probability is that the system has filled with helium.

Close the switches that connect the two-ohm and 22-ohm resistors across the microammeter of the Wheatstone bridge. (Incidentally, the most sensitive microammeter available should be used in the bridge, preferably one that requires not more than 50 microamperes for full-scale deflection.) Now clip the power leads to the battery and adjust the potentiometer in the arm of the bridge opposite the filament until the microammeter indicates minimum current. The resistance of the potentiometer at this setting should approximate that of the heated filament. The setting of this potentiometer should need no additional adjustment.

The fine adjustment is made by altering the setting of the potentiometer that is connected between the 22-ohm arms of the bridge. This is the lower potentiometer in the accompanying illustration at the bottom of the preceding page. The switches that connect the two-ohm and 22-ohm protective resistors across the meter should be closed during the initial adjustments. As balance is approached the two-ohm resistor is cut out of the circuit. This usually increases the excursion of the meter. When the excursion has been minimized by further adjustment of the potentiometer, the 22-ohm resistor is cut out, after which the bridge is balanced as completely as possible.

The temperature of the oven, the pressure of the carrier gas and the rate of carrier-gas flow are then measured and recorded. Incidentally, by dividing the known volume of the column by the rate of flow of the carrier gas the interval required for displacing air with inert gas can be found. This is the interval between the time the carrier gas is turned on and the time voltage can be safely applied to the bridge.

Finally, about a twenty-fifth of a milliliter of clear gasoline is taken up in a small hypodermic syringe. Insert the needle through the serum cap and squirt the specimen on the detergent at the top of the column. According to Langhoff and Martin, the sharpness of separations appears to vary inversely with the size of the specimen. Readings are most conveniently made by two people, one observing the current amplitude and tabulating the results while the other calls the time. Most runs can be completed within 20 minutes. The constituents of mixtures appear as peaks when the results are plotted in the form of a graph.

A typical graph of clear gasoline made by Langhoff and Martin is reproduced on this page. Having made the analysis, the experimenters immediately injected a small specimen of pure octane in the column. Every effort was made to maintain all conditions of the apparatus constant, including the temperature of the column and the pressure of the carrier gas. The results of the analysis of the octane specimen appear as the broken curve below the seventh peak of the graph that represents white gasoline. Langhoff and Martin do not seriously doubt that the seventh peak of the graph was made by the octane fraction in their specimen of white gas, but they cannot explain the slight discrepancy in position between the two peaks. The pure octane appears to have made its way through the column some 20 seconds faster than the octane fraction of the gasoline. Langhoff and Martin plan to make another experiment in which the octane will be added to the gasoline before the run. The combination should result in a single, higher seventh peak. Incidentally, this experiment demonstrates how the gas chromatograph can be calibrated: graphs derived from known fractions are simply compared with the peaks made by unknown mixtures.

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BOOKS

On the Delphic writings of Claude Lévi-Strauss

by Marshall D. Sahlins

STRUCTURAL ANTHROPOLOGY, by Claude Lévi-Strauss. Basic Books, Inc., Publishers ($10).

Claude Lévi-Strauss is a famous French anthropologist. More than that, he is an acclaimed savant, a man of letters and high style, of delicate perception and a penchant for Reason. In other words, Lévi-Strauss may be more French than anthropologist, perhaps even a French national resource—a *philosophe*. Advanced Parisian bookstalls peddle flimsy paper-covered *Conversations with Claude Lévi-Strauss* alongside a book by Claude Lévi-Strauss (*Savage Thought*) that converses with Jean-Paul Sartre. When the Smithsonian Institution last September celebrated with pomp the bicentennial anniversary of James Smithson's birth, Lévi-Strauss was exported from the Collège de France for temporary display in Washington with much the same fanfare as accompanied the procession of the Mona Lisa from the Louvre to the Metropolitan. The Smithsonian celebration was rich in contradictions and oppositions of the kind in which Lévi-Strauss delights: a legitimation of the birth (precise date unknown) of an illegitimate child (Smithson himself) who founded a national monument to empiricism in a country he had never visited, in testimony to which was invited, as sole spokesman of the science of man, a scholar (from still another country) whose writing is devoted to ridding us of "naturalistic misconceptions" in favor of nonapparent "structural realities." But then the Louvre's Mona Lisa was the work of an Italian, and it smiles on us like the masterpieces of Lévi-Strauss, engaging and inscrutable.

Perhaps this dual quality of beauty and mystery explains, at least on a superficial level, the peculiar attraction Lévi-Strauss has for Anglo-American positivist anthropologists. (It is another complementary opposition.) I say "peculiar" because of the kind of attention Lévi-Strauss gets, which as far as I know is unparalleled in the history of anthropology, although the field has had its share of Towering Intellects. But these were mostly plain and straightforward men of a style unchromatic, and if they were occasionally treated with excessive adulation, no one felt compelled to explain to the rest of us just what they were saying. On the texts of Lévi-Strauss, however, our journals are suddenly filled with windy exegesis and learned commentary, given to praise and typically to patient interpretation of the wisdom concealed therein.

The translation of *Structural Anthropology*, a representative collection of 17 Lévi-Strauss essays, will doubtless set off a new round of commentary, with which this review may unfortunately be classed. The collection is wide-ranging, displaying Lévi-Strauss in his characteristic role of composer-conductor of the anthropological symphony, arranging data now one way and now another to bring forth their hidden harmonies. It begins with pieces on structural analysis in linguistics and social anthropology, then goes into specific studies of social organization, magic, myth and art, and concludes with programmatic statements on the method and teaching of anthropology. The American edition of *Structural Anthropology* was preceded by translations of two other major Lévi-Strauss works: *Totemism* and *Tristes Tropiques* (the American edition is entitled *A World on the Wane*). The latter is a spectacular and sensitive travelogue, the Lévi-Strauss book most likely to captivate general readers. In addition English translations of two more main *œuvres* have been announced and will appear shortly: *La Pensée Sauvage* and *Les Structures Élémentaire de la Parenté*.

Thus the qualifications for creative exegesis are being democratized; soon one will no longer need to know French in order to be learned. Although this may take the fun out of it for some, probably many more will accept the opportunity. The earlier commentaries can assume the status of classical literature, and one can engage in commentary on the commentaries. Perhaps then that characteristic quality of exegetical writing will emerge more clearly: the author of the piece, in contrast to his predecessors, uniquely understands the text, has discovered the key. Here Lévi-Strauss has added zest to the game by severely chastising several critics for misinterpreting him. Given these conditions, and a non-Western world rapidly being populated by ex-savages, understanding Lévi-Strauss could replace fieldwork as the means to an anthropological reputation. We may witness the spectacle—in fact, it has already begun to take shape—of assembled wise men, undaunted by Lévi-Strauss's conviction that an understanding based on the appearance of things is a form of blindness, scrambling all over the elephantine erudition of this Parisian savant, making contact with one or another part of it and then pronouncing for the edification of befuddled colleagues on the character of the elephant. "How like a reductionist is a Lévi-Strauss," says one, taking hold of a main-trunk argument to the effect that social order is fundamentally mental order and its explanation reducible to laws governing the operation of the human mind. "How like a Hegelian," comments another, having grasped the hidebound dialectic Lévi-Strauss applies to thought, history and reality. And so on: how like an idealist philosopher, how like a speculative historian, how like a shaman educated in France.

At this point we might take stock of the explications and texts in hand (particularly *Structural Anthropology*), and without presuming to fathom what a Lévi-Strauss truly is—which probably few American-educated prisoners of naturalistic misconceptions can do—at least try to develop some consensus of what a Lévi-Strauss is *like*.

"How like an idealist," we hear. In some broad sense of mind over matter in the ordering of human affairs, Lévi-

Strauss is like an idealist, although he tends to qualify this, and the categorization is in any case not apt if "idealism" is taken in the narrower sense of the primacy of definite ideas or ideals. What is mainly connoted by Lévi-Strauss's idealism is an uncompromising antipositivism. Lévi-Strauss does not believe that the appearance of things constitutes their true nature (their "reality"), nor does he hold any brief for the going naturalistic (empirical, inductive) modes of explanation in anthropology. The nature of cultural materials—myth, social organization, ritual or all of these at once—is comprehended only when we reveal their nonapparent underlying structure. This structure is unconscious, just as the structure of a language is normally unknown to its speakers. Lévi-Strauss would have us operate as linguists do when they uncover the contrasting features in sound that signify differences in meaning, and go on to state the rules for combining significant sound units into meaningful utterances. In a more familiar and in some ways more apposite idiom, one probes like the psychoanalyst for the unconscious construction that in manifest behavior is only repressed and disguised.

The analysis of a particular social organization thus begins from disbelief. The empirically ascertained relations and groups are illusory; they are not the structural "reality" but some transfiguration of it. A certain notion concerning the quality of this manifest social organization is also involved from the beginning; it expresses a native theory and is fundamentally a mental construct. This is bizarre, not to say incomprehensible, to traditional anthropology, which has long since decided that social relations are cultural developments of an order different from thoughts and beliefs. The social system is one thing, the ideological (symbolic) quite another. But for Lévi-Strauss both express mental activity, and the ostensible social relations only hide the real images people harbor of their society (and the world in general).

Lévi-Strauss explains in two different ways why empirical behavior masks social reality. One is that historical vicissitudes, such as the dying out of certain clans, have disarranged the original order, presumably a "true" and harmonious one. This supposition sometimes leads him down the path of speculative historical reconstruction, and also up the creek into some inescapable swamps. For example (this is illustrated in an essay entitled "The Concept of Archaism in Anthropology"), we are forced to conceive, for a group of historically related societies, of an ideal social type that once in fact existed and whose real structure at the moment of creation coincided with its apparent structure. The present derivative societies represent transformations of the pristine—some a development on it and some degenerate but all left by unknown histories with harmony disfigured and covered over. Alternately a disjunction develops between empirical and structural levels because people are compelled to hide, justify or embellish the latter by the former, for reasons I personally do not completely understand. The ostensible organization of society is a mystification, a masquerade of "reality." This supposition is on the high road to Hegelianism.

How is the "real structure" of society discovered? Probably the best answer is "By Lévi-Strauss's incredible ingenuity." Discrepancies may be noticed between a people's behavior ("the actual functioning of society") and its apparent organization. Thus a certain South American tribe was initially described as being divided into two intermarrying groups (moieties), each composed of several clans. This is the obvious organization, and a common one in South America. Further observation revealed, however, that the clans were each divided into three castelike segments—"upper," "middle" and "lower"—and that marriage was permitted only within one's own caste, for example an "upper" could marry only an "upper" of the opposite moiety. Therefore what are in appearance two *intermarrying* groups (moieties) are "in reality" three *intramarrying* groups (castes). Skeptics might deny Lévi-Strauss the privilege of deciding which is the "real" structure; they would decidedly deny the defense that his is the explication without contradiction from fact. For him, however, the so-called dual order is "really" triadic; the moiety division, by cutting across the castes, serves merely to hide and keep together "three societies which, all unknowingly, remain forever distinct and isolated, each imprisoned within its own vainglory, dissimulated even from itself by misleading institutions."

Now, such analyses may be "substantiated" by detecting other social discrepancies, as in kinship terminology, paralleling the hidden "objective" structure. But Lévi-Strauss reserves his most triumphant eureka for the discovery of the same (or a similar) structure in other cultural domains altogether: in the allegations of myth, in symbolic classifications (as of totemic names), in ritual roles, or—in one remarkable instance—designs painted on women's faces. Here, for a society such as the one we have just considered, anything that could be construed as triadic, perhaps interwoven with a dyad, confirms the structural revelation. Indeed, a "real structure" can sometimes be reconstructed solely from symbolic representations, even if it has left no trace in existing social relations.

This radical departure from accepted naturalism hardly needs comment, but one contrast with the prevailing form of anthropological empiricism—"functionalism"—deserves emphasis. Functionalist explanations proceed by referring customs to their empirical context; thus a given belief, say "the meek shall inherit the earth" (in kingdom come), is presumed to sustain the associated system, say a stratified feudal-monarchic order. Note that the relation between belief and social order is in this case organic and complementary and therefore presupposes certain differences in quality between them. In the structuralism of Lévi-Strauss, beliefs, social behavior, art and the like are in relation insofar as they are similar, constituting so many "modalities" of the same structure; this is consistent with treating them as basically the same kind of stuff—as so many expressions of mental activity.

It is not Lévi-Strauss's intention merely to develop the "real" structure—or structures, as there may be several—of particular societies. His vision is also comparative, his objective also to order variant structural models as a group of permutations, permitting the formulation of certain laws of transformation. This requires in the first place that structures be stated in terms sufficiently formal and abstract that they become comparable in spite of differences in content. We are presented in one study with the discovery that certain societies, in substance quite different, in reality have similar underlying structures expressed by Lévi-Strauss in a geometric design: three small circles located on the circumference of a larger circle and linked by a triskelion (a three-armed figure) centered in the larger circle. If it be objected by a refractory empiricist, possibly shocked by the collapse of society to geometry, that the circles or triskelions stand for manifestly different things among Indonesians and South Americans (here marriage rules, there the village layout), Lévi-Strauss contends that "what a given society 'says' in terms of marriage regulations is 'said'

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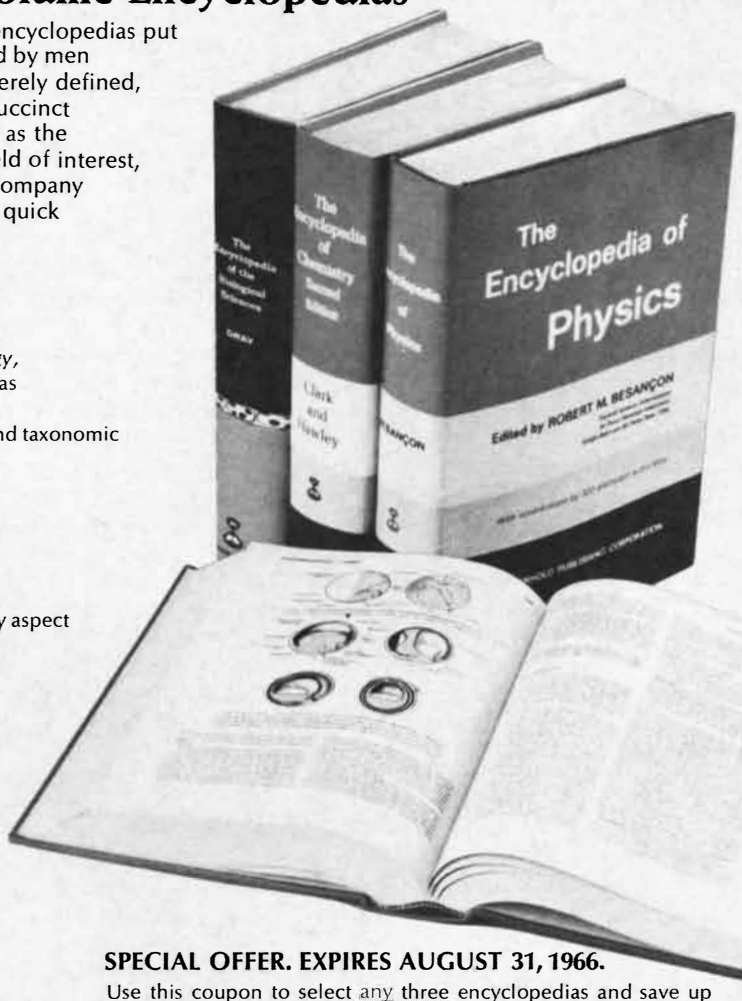

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by another in terms of village lay-out, in terms of religious representations by a third, etc."

Lévi-Strauss's path to comparative understanding is not always easy to trace, but in a general way the following appears to be a favored method. Having established a family of structures, perhaps filled out by the logical construction of permutations not actually known to occur, it remains to consider the significant contrasts within it in the hope of determining rules of variation. The structures of the same class are seen to exhibit complementary practices with regard to specific social possibilities: people marry in their own groups or out, behave familiarly toward certain relatives or avoid them, and so on. Variation in the family of structures is therefore reducible to a number of "binary oppositions," or paired contrasts. Lévi-Strauss likes to symbolize the terms of any given opposition by plus and minus signs. A particular structure can then be stated as a set of plus and minus signs representing its specific combination of the distinctive features involved in the family. The family as a whole can be constituted—perhaps in a chart—as a series of plus-minus sets. The extremes of the series are often logical inversions: what is plus in the structural set at one extreme is minus at the other extreme and vice versa.

From such a series of permutations one derives invariant relations between significant features. To take the simplest example from *Structural Anthropology*—one that happens to reveal the kind of thing that is disconcerting to positivists—Lévi-Strauss develops the following "law" governing differences over a wide range of societies in customary behavior toward certain types of relative: "The relation between maternal uncle and nephew is to the relation between brother and sister as the relation between father and son is to that between husband and wife," that is, maternal uncle/nephew : brother/sister :: father/son : husband/wife. By "relation between" Lévi-Strauss means free and familiar behavior (+) on the one hand and hostility, antagonism or reserve (−) on the other. Now, the interesting thing is that the examples adduced by Lévi-Strauss show immediately that the rule as stated is not to be taken literally, nor is the series of kinds of behavior (pluses and minuses) completely systematic. The series is actually composed of two quite independent invariants: the relation between maternal uncle and nephew is always opposite to that between father and son; similarly, *but not necessarily in parallel fashion,* the relation between brother and sister is always the opposite of that between husband and wife. Therefore the one thing that cannot happen is a literal expression of the rule—that the two signs on one side of the equivalence parallel the two signs on the other (for example + : − :: + : −). Moreover, although Lévi-Strauss considers these four relations the irreducible "atom of kinship" and refers to them as "a system," in actuality if one of the terms is changed, only one other (in the corresponding position on the other side of the equivalence) necessarily changes.

Now, it may be possible to restate the rule correctly, in mathematical terms or by replacing the "as" (::) of the original by some construction indicating "symmetrical inversion" (if that means anything). But it should not conceal the fact that two independent invariants are in play, and the best one can say is that any given structure is an indeterminate combination of two uncorrelated oppositions, yielding four possible structures. This is a substantial improvement over the 16 possibilities of chance variation. On the other hand, as Lévi-Strauss notes, the plus and minus signs oversimplify the variety of kinds of behavior involved; in fact there are many more than four structural resultants.

To a positivist this kind of solution must come as a big disappointment. For one thing, even allowing the compression and reduction of "appearance" to "reality" (plus and minus), and putting aside what may be a romantic attachment to what is going on with people, it is already a matter of common anthropological experience that the options in social life are limited. Over the entire world kinship relations, descent groupings and the like vary only within a finite range, can be characterized by a restricted number of features and embody comparatively few principles of organization. To confirm one's inevitable suppositions does not seem very momentous. In particular to say that one society presents *some* combination of main contrasting characteristics and another society *some* other combination is not very satisfying. It will only bring out that incurable addiction to empirical explanation one sees in certain anthropologists.

Why these differences? Why are certain types of relative avoided among the so-and-so people and the same types treated familiarly in another group? Why here are there clans that marry out, there castes that marry in? If the several contrasts running through a family of structures were interdependent, so that each society embodied a systematic pattern of distinctive features rather than some indeterminate collection, it would substantially reduce the problems of explanation. (Some of Lévi-Strauss's structural analyses do seem to be of this type.) Still, once this simplification has been achieved, the search for conditions that favor one pattern or another is merely facilitated, and the examination of historic and current contexts is merely made more inviting. There is reason to suspect, however, that Lévi-Strauss himself foresees at this point a synthesis of the naturalist thesis and structuralist antithesis.

By now it may begin to be clear why certain other qualities have been ascribed to the elephant by those who have been grappling with it. Consider Hegelianism. Marx stood Hegel on his head. Although Lévi-Strauss claims to have been inspired by Marx, he rather turns Marx on *his* head. This takes us back to Hegel right-side up, which leads Robert Murphy of Columbia University, in a brilliant exposé, to classify the intellectual outcome as "Zen Marxism." Thanks to Murphy, now anyone privy to what must be the vulgar Hegelianism with which Anglo-American realists dispose of that imponderable German can spot the Hegelian reality disguised in Lévi-Strauss's Marxist appearances.

One thing is the very supposition that what is apparent is false and what is hidden from perception and contradicts it is true. Another is an indulgence for historic dialectic, a propensity for conceiving that structures always tend to develop inversions of themselves. The holy Hegelian triad of thesis, antithesis and synthesis emanates everywhere from Lévi-Strauss, be it the structural analysis of myth ("Mythical thought always progresses from awareness of oppositions toward their resolution"), of the medicine man's treatments or of the relation between kinship classification and kinship behavior. Lévi-Strauss has an incurable partiality to "opposition and correlation," to dualistic contrast and resolution, which in his view constitute the way men think, the fundamental methodology of reason and the process by which men everywhere create order out of the hodgepodge of circumstance.

However other men do think, clearly this *is* the way Lévi-Strauss thinks. And since he believes it to be true of all men, it follows that he (or any philosopher, notably a Bergson or a Rousseau, even if he had not the slightest ethnographic

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Deformation and Fracture of Bone

The high sensitivity micro strain measuring technique of the metallurgist has been applied to the study of the mechanical properties of bone. The findings indicate some unexpected characteristics of bone.

Conventional studies of the mechanical properties of bone have been made for many years on stress-strain curves to fracture for a wide range of biochemical variables. These low-sensitivity measurements, however, have not permitted correlation of mechanical behavior with the atomic and defect structure of bone.

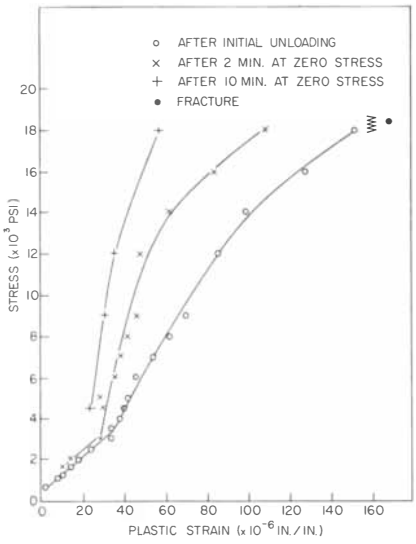

FIGURE 1.

Last year Honeywell's research metallurgists were asked to check inconsistencies in the performance of ivory in a particular application. Using a high sensitivity micro strain technique they had developed for aerospace materials, they determined that plastic deformation can be detected in ivory at the surprisingly low stress level of 180 psi. This and other unexpected findings caused them to broaden their research to include bone and to undertake a two-part investigation of the deformation and fracture of bone.

First, the micro strain technique was used to measure the initiation and extent of plastic yielding in bone. Second, fracture characteristics were determined under impact and tensile loading and as a function of temperature.

Two types of specimens — tensile and impact — were prepared from the outer periphery of compact bone of the femur of a cow.

Using a load unload technique, a series of increasing tensile stresses was applied to the tensile specimens at a strain rate of 3.3×10^{-4} sec. $^{-1}$. The total strain (elastic and plastic) at stress and the residual plastic strain after unloading were measured for each stress level. From these measurements the microscopic yield stress (the stress required to produce the first detectable plastic strain of 2×10^{-6} in./in.) and the subsequent variation of plastic strain with stress were determined.

Fig. 1 shows that the onset of plastic yielding was detected at the low level of approximately 600 psi. As the stress was increased above this level the amount of plastic strain progressively increased. This plastic strain was not all permanent strain since a large anelastic contraction was noted, as the graph shows.

Impact tests were conducted in a modified Charpy impact machine and specimens were struck at their midpoint with a hammer delivering 5.1 in. lb. of energy. The energy absorbed during impact was measured at temperatures from −196° to 900°C.

Fig. 2 plots results obtained for each unnotched longitudinal and transverse specimen with the energy absorbed during fracture shown as a function of test temperature.

Note that transverse specimens showed two marked differences from longitudinal specimens. First, the values of energies absorbed were significantly smaller for the transverse. Secondly, only a small peak in energy absorbed was noted at 0°C.

A series of longitudinal tensile specimens were also strained to fracture at a rate of 3.3×10^{-4} sec. $^{-1}$ at temperatures ranging from −196° to 200°C. Results showed that the tensile fracture stress exhibits a similar temperature dependance to that of the longitudinal impact specimens.

These findings demonstrate that up to a stress near to the fracture point, bone does not deform in an elastic manner as has previously been thought. Instead plastic yielding was detected at the low applied stress of 600 psi.

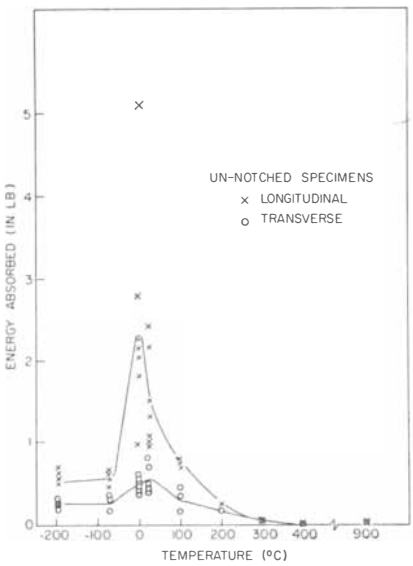

FIGURE 2.

Also significant was the large contraction which occurred with time after unloading. This indicates that the dominant deformation mode of bone must be anelastic and reversible.

The temperature dependance of the fracture characteristics was marked. Further work demonstrated that between −196° and 200°C. these temperature characteristics are related to reversible changes in atomic structure or the deformation mode.

The way bone deforms is obviously much more complicated than previously thought. Having defined deformation and fracture in bone, Honeywell scientists now seek to understand their underlying mechanism. Beyond the medical implications, it is hoped that interdisciplinary work such as this will yield unique results that will aid our understanding of other materials.

If you are engaged in related work and wish to learn more of Honeywell's study of the mechanical properties of bone, you are invited to correspond with Dr. William Bonfield and Dr. C. H. Li, Honeywell Research Center, Hopkins, Minnesota. If you are interested in a career in basic research at Honeywell, please write to Dr. John Dempsey, Vice President, Research, at this same address.

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experience) could by contemplating the navel of his own thought achieve communion with the most exotic customs of this planet. As Lévi-Strauss puts it in *Tristes Tropiques:* "I became convinced that ... people and things could be apprehended in essence without losing that sharpness of outline which serves to distinguish one from the other and gives to each a decipherable structure. Knowledge was not founded upon sacrifice or barter: it consisted in the choice of those aspects of a subject which were *true*—which coincided, that is to say, with the properties of my own thought. Not at all, as the neo-Kantians claim, because my thought inevitably exerted a certain constraint on the object under study: but because my thought was itself such an object. Being 'of this world,' it partook of the same nature as that world."

In other words, Method and Truth are united, because both are Reason. I understand other peoples because their lives are constructed as is my thought. I think, therefore they are!

How, then, like a "reductionist," refusing to concede autonomy to the level of social things but explaining them instead as mental regularities, much as a biologist who would unconditionally surrender the processes of physiology to the laws of chemistry. Of course it is an uncommon kind of anthropological reductionism, which is ordinarily psychoanalytic. Lévi-Strauss emphatically rejects recourse to affectivity or emotion. Emotion is vague where structure is precise, merely sentimental where structure is logical. To invoke emotionalism is to ask mystery to explain clarity—worse, to mistake the effects of living within a given structure for the cause. If his system is a reductionism, it is of a highly intellectualized kind—a French reductionism. Only in this respect do passages of *Structural Anthropology* express a theoretical mortal sin. Kinship systems, Lévi-Strauss writes, are, like linguistic systems, "built by the mind on the level of unconscious thought." And if (as he believes quite possible) homologies can be demonstrated between kinship and linguistic structures, "the road will then be open for a comparative structural analysis of customs, institutions, and accepted patterns of behavior. We shall be in a position to understand basic similarities between forms of social life, such as language, art, law, and religion, that on the surface seem to differ greatly. At the same time, we shall have the hope of overcoming the opposition between the collective nature of culture, and its manifestations in the individual, since the so-called 'collective consciousness' would, in the final analysis, be no more than the expression, on the level of individual thought and behavior, of certain time and space modalities of the universal laws which make up the unconscious activity of the mind."

Yet one can only say that Lévi-Strauss is *like* a reductionist, because in other recent works (particularly *Savage Thought*) he explicitly disavows that he is, or ever was, of the opinion that social practice results from "a conceptual game taking place in the mind," even though he may have sometimes given that impression. Standing Hegel back on his head, he returns to Marx right-side up and anchored firmly in the "infrastructure," the specific material conditions of society. He protests that he has been dealing merely with social superstructures, which always develop under the constraints of the infrastructure. Yet a superstructure can express these constraints only as mediated by the conceptual scheme, "by the operation of which matter and form, neither with any independent existence, are realized as structures." How this all works, however, remains obscure, and it is unlikely that Lévi-Strauss as an ethnologist will ever explain it; that, he conceives, is the task of other disciplines, not ethnology, which is "primarily psychology."

It is plain to see, even for the blind, that this is a complex and subtle Babar with which one gropes. Many of Lévi-Strauss's aspects we have not even touched, for instance his conception of marriage rules and economics (as well as linguistics) as communication structures, or his treatment of art and myth in ways that have never been approached by anthropological positivism. Nor have we documented all the impressions Lévi-Strauss can give, "how like" so many other things he is. On the other hand, there is only thinly concealed in this discussion the reaction of another kind of observer. Committed to the importance of appearances, addicted to empirical verification and repelled by metaphysics, the blind positivist can only respond to the question "What is the elephant?" with another: "What elephant?" At the same time, as every anthropologist knows, some of the best elephant-hunters are pygmies.

Short Reviews

THE COLLECTED PAPERS OF ENRICO FERMI: VOLUME II, edited by Edoardo Amaldi, Herbert L. Anderson, Enrico Persico, Emilio Segrè and Albert Wattenberg. The University of Chicago Press ($22.50). Within a few days after Fermi's arrival in the U.S. in January, 1939, the news reached him of the discovery by Otto Hahn and Fritz Strassmann of the fission of uranium. For the next six years he devoted himself to the development of the physics that flowed from the discovery. This volume, which completes the publication of his collected papers, covers that period.

No one was better equipped—indeed, in this respect it is doubtful that Fermi had an equal—to carry on this delicate work, so portentous in its general consequences for mankind. To a rare degree he combined the skills of a theoretician and an experimentalist. The papers deal with a variety of now familiar topics, some of which belong to the programs that led to the construction of the first chain-reacting pile and the explosion of the first atomic bomb, others to the investigation of the structure of the nucleus and the nature and behavior of subatomic particles. The collection also includes a course on neutron physics that Fermi gave at Los Alamos in 1945, papers on cosmic rays, on mesons, on Monte Carlo calculations, and more popular discussions such as his historical account of the first pile, delivered to the American Philosophical Society, and his amusing lecture "The Genesis of the Nuclear Energy Project," presented as part of the session "Physics at Columbia University" in the year of his death (1954).

Almost all Fermi's writings are gracefully clear. His approach, as some of his students and co-workers have remarked, was intuitive and geometrical rather than analytical, which made his ideas accessible even to those who were not versed in the art of complex mathematical transactions. Fermi never forgot that he was dealing with the physical world, that there is a basic need not to overintellectualize and that it is not enough, if one wishes to understand and control what is happening, merely to satisfy theoretical passions by devising symmetrical, logical and solvable equations. Fermi wanted the books to balance, but he also wanted to keep within the budget of reality. A number of the papers are written with collaborators (among them Herbert L. Anderson, C. N. Yang, Leo Szilard, Bernard T. Feld, W. H. Zinn, John and Leona Marshall, S. Chandrasekhar), but always, when he is a coauthor, one marks the influence of his style, of his way of thinking.

The value of the book and its attrac-

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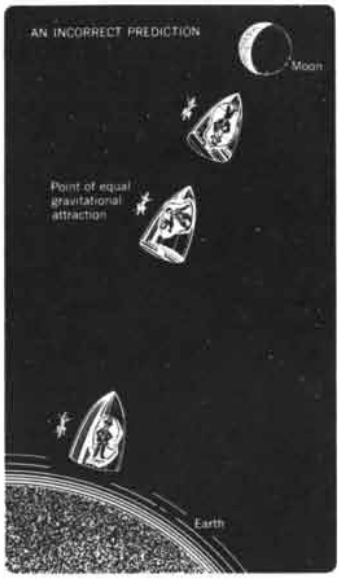

Fig. 3,A. Jules Verne believed that a passenger in a free projectile would stand on the side of the projectile nearest to the earth or moon, whichever had greater gravitational attraction—but that the dog would float along beside the projectile during the entire trip.

Fig. 3,B. Correct prediction is that a passenger would float with respect to the projectile during the entire trip. Verne was correct about the motion of the dog.

Spacetime Physics

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tiveness to the reader is enhanced by the excellent introductions to the papers, most of them written by his coworker Anderson. They are literate, filled with information about not only context and content but also the surrounding circumstances. Many of the anecdotes are well known, having appeared in Laura Fermi's book about her husband, but not a few are less familiar and, in any case, worth hearing again. The paper on neutron production and absorption carries a note stating that this was "the first and also the last experiment in which Szilard and Fermi collaborated." Szilard's way of working on an experiment, says Anderson, "did not appeal to Fermi. Szilard was not willing to do his share of the experimental work, neither in the preparation nor the conduct of the measurements." In another note one learns that Arthur Holly Compton was at the beginning quite cautious in his conversations with Fermi for "security reasons"; he could not bring himself to trust "a recently arrived emigré." Then Fermi stepped to the blackboard at Columbia University and worked out for Compton, according to Compton's own account, "simply and directly, the equation from which could be calculated the critical phase of a chain reaction." Even this did not fully satisfy Compton; a year later, when the Du Pont company inquired as to the trustworthiness of certain emigrés, he "did not say directly that Fermi was all right, but stated that he had gone through Fermi's calculations himself and found the same results." As the atomic-bomb project got under way Fermi found he no longer had the time to participate directly in the experimental work. He had to have the experiments done and then examine the data himself for analysis. This was certainly not to his liking; he commented wryly to Segrè that he was "making physics by the telephone."

Notes by Mrs. Marshall and others provide illuminating comments about Fermi's habits and characteristics, his apparent indifference to politics, economics, philosophy and the visual fine arts, his extraordinary physical insights, his vigor and competitiveness, his gaiety and informality. Altogether this is a most likable work as well as an invaluable one, skillfully and imaginatively edited and worthy of the man it memorializes.

CHEESE, by J. G. Davis. American Elsevier Publishing Company, Inc. ($28). Cheese is defined as "the curd or substance formed by the coagulation of the milk of certain mammals by rennet or similar enzymes in the presence of lactic acid produced by added or adventitious microorganisms, from which part of the moisture has been removed by cutting, warming and/or pressing, which has been shaped in a mould, and then ripened by holding for some time at suitable temperatures and humidities." The milk of the cow, goat and sheep is most commonly used, but one can also use the milk of the buffalo, horse, reindeer and ass. There is archaeological evidence that cows were milked into tall jars more than 6,000 years ago, and it is known that cheese was being eaten in Asia several thousand years before Christ. Cheese is mentioned in almost all the classics of the world's literature, including the Bible (David carried 10 cheeses to the army before he slew Goliath). It was prized by the Egyptians and the Greeks; the Romans so esteemed it that they used the word *caseus* (Latin for "cheese") in referring to the lady of their choice. The earliest efforts at cheese making in the true sense were probably those of the Aryans in central Asia. They were noted herdsmen and appear to have subsisted largely on the products of their herds. In their search for better grasslands they finally migrated to Europe and took their dairy arts with them. At the height of the Roman Empire dairying and cheese making became important industries.

The number of varieties of cheese made throughout the world today is very large. Some hundreds of names are in use, although all can be classified into about 20 types, from hard (Parmesan and Cheddar) to soft (Cambridge), slimy and moldy (Limburger and Camembert) and mold-ripened (Roquefort). Many modern types are thought to be centuries old. Roquefort has a history going back 1,000 years; it is mentioned in the records of the monastery of Conques in 1070. The French were making Gruyère in Doubs in 1288; the Italians, Gorgonzola and Parmesan about 1200; the first cooperative cheese factory was started in Voralberg in the Balkans about 1380. From Roman times to the 17th century there were few improvements in cheese making, but from about 1600 there was a steady increase in the efficiency of the dairy industry, the work invariably being carried out by women. (The word "dairy" is derived from the Middle English "deirie: deie = female servant.") The latter part of the 19th century saw the introduction of the factory system throughout the cheese world, the foundations having been laid, it is believed, in New York by Jesse and George Williams. Major steps in the advance of cheese technology, all of which have occurred during the past 75 years or so, are the commercial preparation of rennet (a complex enzyme that clots the milk), the introduction of pure cultures of lactic streptococci as "starters" (which sour the milk at a quick and steady rate), the pasteurization of cheese milk to destroy harmful microorganisms, and refrigerated ripening (which was introduced in the U.S. and made possible the manufacture of processed cheese). The world produces about 300 million tons of milk annually, of which 10 percent is used to make around three million tons of cheese. The annual per capita consumption in Britain is about eight pounds; it is some two pounds in the world as a whole.

These two volumes are the beginning of a projected four-volume treatise on the scientific, technological and practical aspects of cheese. The first volume, in addition to providing a historical survey, discusses such topics as the scientific basis of cheese making, the classification of cheeses, cheese institutions (because monks have played a significant role in the history of both cheese and wine, the names of monastic orders, monasteries and abbeys have been given to several varieties, for example Trappist and Port Salut), the qualities of milk essential to making good cheese, the nature and behavior of starters, the preparation and properties of rennet, cheese additives, traditional and modern cheese-making equipment, the packaging, ripening and storage of cheese. The second volume consists of a bibliography of more than 6,500 items, with a comprehensive index keyed to it. The third and fourth volumes are to cover manufacturing methods, economic and legal aspects and related scientific topics.

This is a definitive work addressed primarily to cheese makers, but almost everyone will find in it facts of uncommon interest.

MCGRAW-HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY, edited by David I. Eggenberger, Daniel N. Lapedes and others. McGraw-Hill Book Company ($295). The second edition of this excellent compendium has been substantially revised. It contains some 150 new articles on such topics as abscission, military aircraft, cardiovascular disorders, dune vegetation, insect pathology, the laser, space navigation and storm detection, and an equal number

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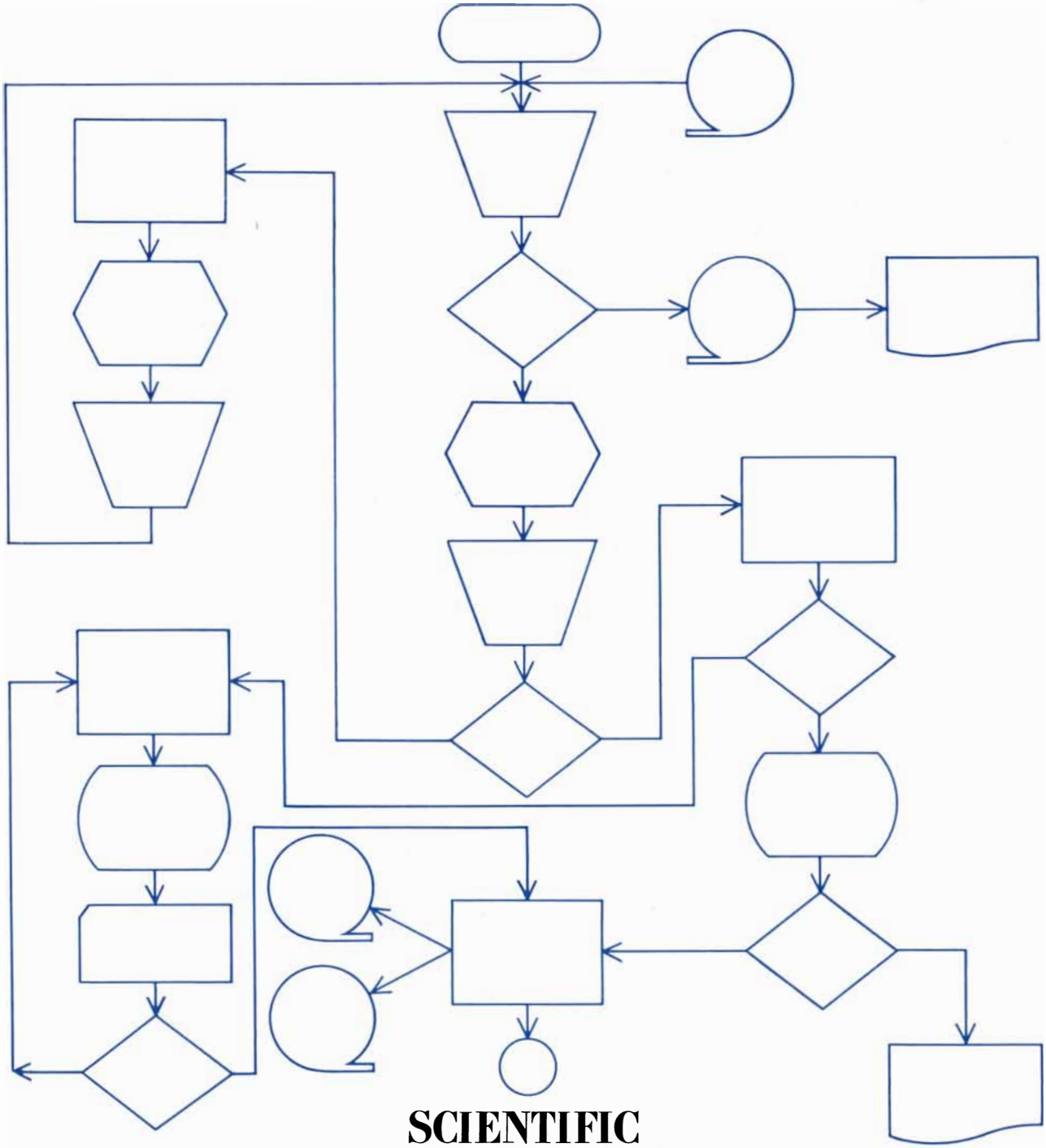
of entirely rewritten articles ranging from atomic constants, terrestrial gravitation, bioluminescence, oncology (the study of tumors) and germ-free vertebrates to the shock absorber, the tomato and automotive suspensions. In addition some 1,500 articles have been amended to provide for later statistics, new bibliographical entries and the like. Of the many illustrations roughly 1,100 have been revised, replaced or added.

The McGraw-Hill, although the star in its field, has limitations. Its comprehensiveness in the physical and natural sciences, for example, is not matched by the treatment of the social sciences. To make up for the lack of biographical coverage a new volume has been issued that gives information on living scientists; there is also a separate volume devoted to bibliographical information. The additions and revisions in the second edition do not, of course, make the first obsolete, particularly since the publisher puts out annuals to keep the encyclopedia up to date, but anyone working in science and technology who can afford the expense will find the new set well worth it.

ANCIENT EUROPE, by Stuart Piggott. Aldine Publishing Company ($7.50). An engrossing survey of the main lines of European prehistory from the beginnings of agriculture to classical antiquity. Piggott modestly describes his survey as "a sketch, an essay in interpretation," but in its clarity, richness of detail and mastery of a large, sprawling, rapidly growing body of knowledge it is the most satisfying book of its kind in a long time. One of its interesting features is elucidation of the interdisciplinary attack on problems of prehistory, involving the help of botanists, zoologists and specialists in the physical sciences. As Piggott points out and as his account demonstrates, this joint approach has enabled archaeologists to make some of their most significant advances in recent years, enriching man's knowledge of his relation to his environment, how he has exploited it and how his culture has been affected by his habitat. The cooperation of botanists has promoted the study of transformations in the natural plant cover by the examination of pollen grains that survive in peat and mud; researches begun in Scandinavia have established a long sequence from glacial and postglacial times showing the changes in forests caused by changes in climate. Zoological cooperation has widened knowledge of hunting practices and of food habits, which also broadens and deepens the



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archaeologist's grasp of the basic economic struggle of some of the oldest societies. This copiously illustrated work is highly recommended.

GENERAL INVESTIGATIONS OF CURVED SURFACES, by Karl Friedrich Gauss, translated from the Latin and German by Adam Hiltebeitel and James Morehead. Raven Press ($3.95). UNTERSUCHUNGEN ÜBER HÖHERE ARITHMETIK (DISQUISITIONES ARITHMETICAE), by Carl Friedrich Gauss. Chelsea Publishing Company ($8.75). DISQUISITIONES ARITHMETICAE, by Karl Friedrich Gauss, translated by Arthur A. Clarke. Yale University Press ($12.50). In 1820 the government of Hanover asked Gauss to make a geodetic survey of the entire kingdom. Performing this task with his usual skill, Gauss brought geodesy to maturity as a science. Something more came of the work: a series of mathematical discoveries that Gauss presented to the Royal Society of Göttingen in 1827 in a paper on the theory of surfaces. The volume translated by Hiltebeitel and Morehead contains the Göttingen paper, an earlier paper of 1825 and related writings. These comprise Gauss's theory of surfaces, described by Richard Courant in his introduction as "a classical masterpiece in content and form." The major contribution of the papers is the definition of surface curvature and the theorem that this Gauss curvature is invariant under certain deformations. Gauss's concepts in this area, later generalized by Bernhard Riemann, are essential to the theory of relativity and can be said to have established modern differential geometry. The other two volumes are a German translation of Gauss's incomparable *Disquisitiones Arithmeticae*, first published in 1801, and the first translation of the work into English. It is astonishing that this magnificent achievement, the source of the ideas from which modern number theory was developed, has so long been unavailable in English. Now we can be grateful for Clarke's faithful service and for its appearance in a handsomely printed book.

WIND WAVES: THEIR GENERATION AND PROPAGATION ON THE OCEAN'S SURFACE, by Blair Kinsman. Prentice-Hall, Inc. ($23.35). This is a sprightly survey of present knowledge about wind-generated ocean surface waves, which considers in some detail both the complex theoretical side of the subject and the practical side: how wave measurements are made, how the data are handled and how the results are inter-

preted. Kinsman, a seasoned yachtsman as well as an oceanographer, devotes a major part of his large monograph to mathematical analysis of the problems, but the text itself is lively, personal and full of agreeable commentary and sidelights. The book has good illustrations and a substantial bibliography.

Notes

NAVEN, by Gregory Bateson. Stanford University Press ($2.95). A softcover reissue of the second edition of Bateson's highly regarded anthropological study of the Iatmul people of New Guinea, Naven being the name of one of their ceremonials that honors members of the tribe on the completion of notable accomplishments, "among which homicide ranks highest."

THE FOUNDATIONS OF MATHEMATICS, by Evert W. Beth. Harper Torchbooks ($4.45). This major study in the philosophy of science first published in 1959 now appears in soft covers. A number of corrections of varying importance have been made for this edition by Beth's widow, together with brief additions to the text and to the bibliographical notes, almost all of them composed by the author himself.

MAGAZINES IN THE 20TH CENTURY, by Theodore Peterson. The University of Illinois Press ($7.50). An enlarged and revised edition (the first edition appeared in 1956) of a readable history of the magazine industry in the 20th century. It is a story full of dramatic ups and downs, telling of the disappearance of a number of long established publications and of the sudden rise to mass popularity and affluence of an even larger number of newcomers.

SURGERY IN AMERICA, edited by A. Scott Earle. W. B. Saunders Company ($8.50). A selection of American surgical writings from colonial times to the 20th century, including a number of classical papers. A major merit of this work is the readability of the material and the vivid portrayal of operations in various periods.

HERMANN VON HELMHOLTZ, by Leo Koenigsberger. Dover Publications, Inc. ($2.25). A republication in soft covers of the English translation of a sound biography of this extraordinary scientist who added richly to fields ranging from theoretical physics to medicine and biology and who was also one of the foremost teachers of the 19th century.

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from "landship" to battle tank

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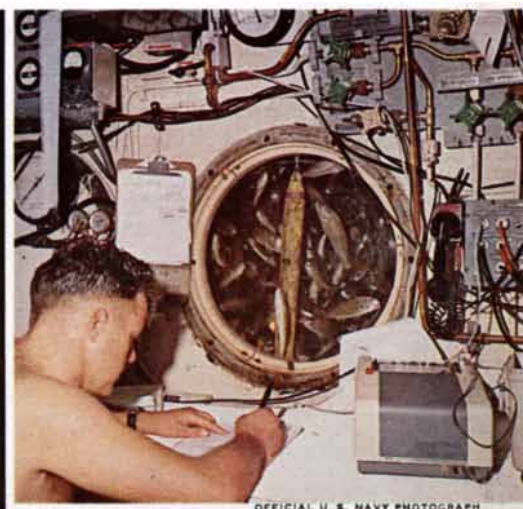

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