SCIENTIFIC AMERICAN

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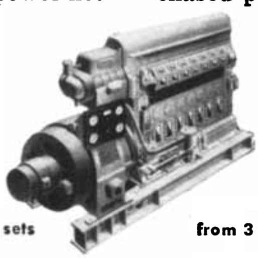

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LETTERS

Sirs:

Your April article by John G. Kemeny about men and machines—Turing, von Neumann and otherwise—sent me back to the late A. M. Turing's own paper on the man-machine question which appeared in the British quarterly *Mind* in 1950. On rereading it I was struck afresh by the boldness of his approach and the wit and charm of his expression. It occurred to me that other readers of your magazine might be interested in making firsthand acquaintance of this original and brilliant thinker.

It is impossible in a letter to follow Turing's argument in detail but perhaps at least something of its unique flavor can be conveyed by some brief quotations from his article.

He outlines his approach to the problem as follows:

"I propose to consider the question, 'Can Machines Think?' This should begin with definitions of the meaning of the terms 'machine' and 'think.' The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words 'machine' and 'think' are to be found by examining how they are commonly used, it is difficult to escape the conclusion that the meaning and the answers to the question, 'Can machines think?', are to be sought in a statistical survey such as a Gallup poll. But this is absurd. Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words.

"The new form of the problem can be described in terms of a game which we call the 'imitation game.' It is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex. The interrogator stays in a room apart from the other two. The object of the game for the interrogator is to determine which of the other two is the man and which is the woman. He knows them by labels X and Y, and at the end of the game he says either 'X is A and Y is B' or 'X is B and Y is A.' The interrogator is allowed to put questions to A and B thus:

"C: 'Will X please tell me the length of his or her hair?' Now suppose X is actually A, then he must answer. It is A's object in the game to try and cause C to make the wrong identification. His answer might therefore be 'My hair is shingled and the longest strands are about nine inches long.' In order that tones of voice might not help the interrogator the answer should be written or, better still, typewritten. The ideal arrangement is to have a teleprinter communicating between the two rooms. Alternatively the questions and answers can be repeated by an intermediary. The object of the game for the third player (B) is to help the interrogator. The best strategy for her is probably to give truthful answers. She can add such things as, 'I am the woman, don't listen to him,' to her answers, but it will avail nothing, as the man can make similar remarks.

"We now ask the question, 'What will happen when a machine takes the part of A in this game?' Will the interrogator decide wrongly as often when the game is played between a man and a woman? This question replaces our original, 'Can machines think?'

"As well as asking, 'What is the answer to this new form of question,' one may ask, 'Is this new question a worthy one to investigate?' This latter question we investigate without further ado, thereby cutting short an infinite regress.

"The new problem has the advantage of drawing a fairly sharp line between the physical and intellectual capacities of a man. No engineer or chemist claims to be able to produce a material which is indistinguishable from human skin. It is possible that at some time this might be done, but even supposing this invention available, we would feel there was little point in trying to make a thinking machine more human by dressing it up with such artificial flesh. The form in

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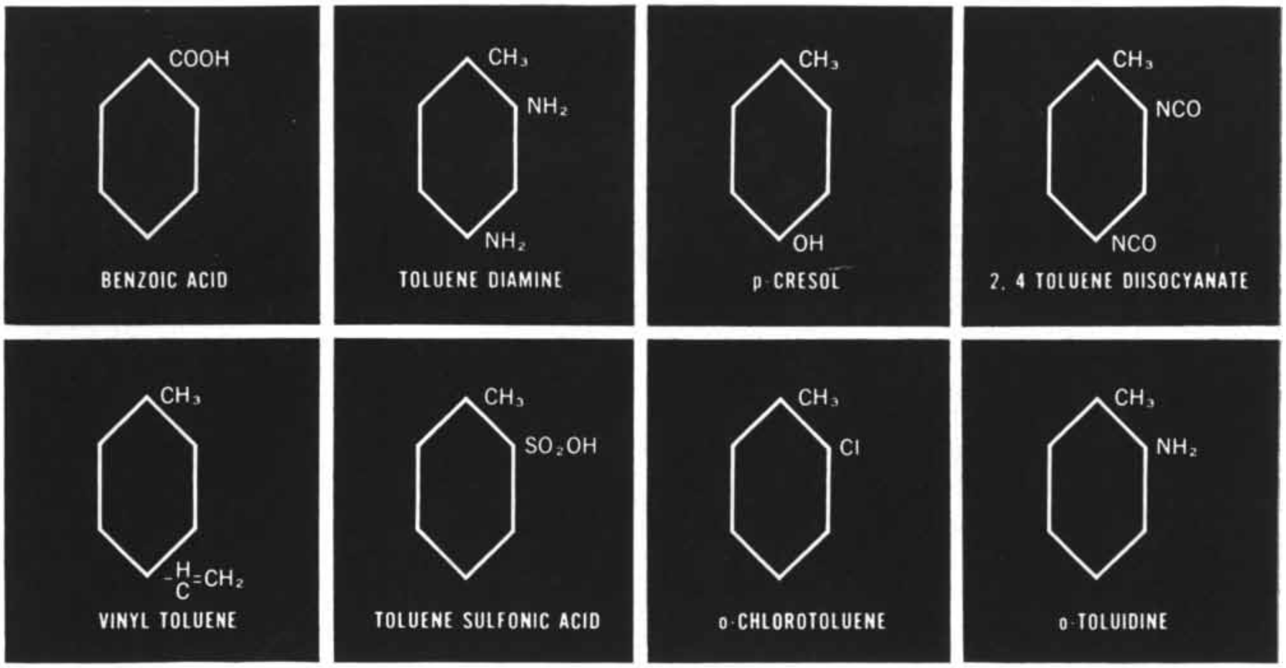

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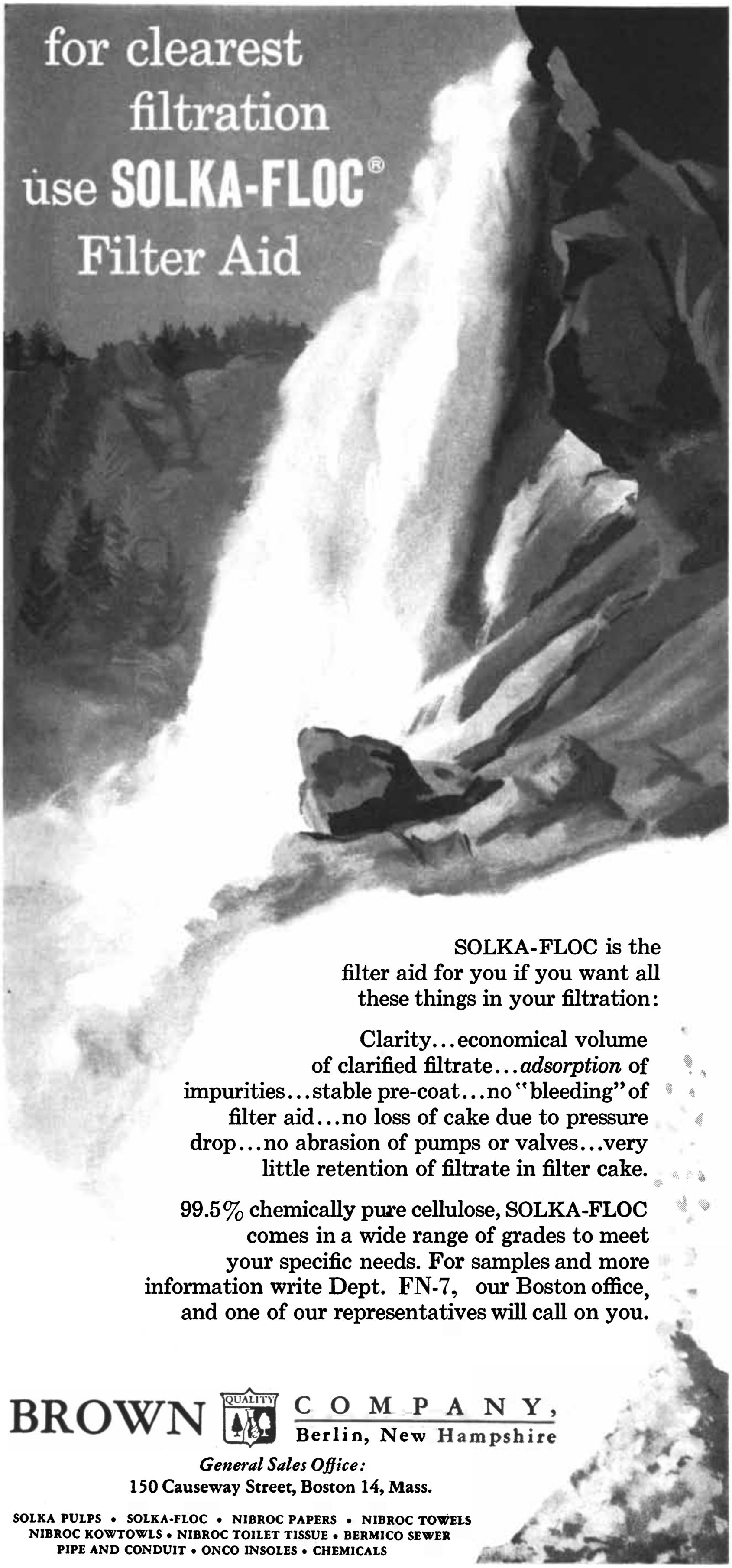


which we have set the problem reflects this fact as does the condition which prevents the interrogator from seeing or touching the other competitors or hearing their voices. Some other advantages of the proposed criterion might be shown up by specimen questions and answers:

"Q: Please write me a sonnet on the subject of the Forth Bridge.

"A: Count me out on this one. I never could write poetry.

"Q: Add 34,957 to 70,764.

"A: (Pause about 30 seconds and then give as answer) 105,721.

"Q: Do you play chess?

"A: Yes.

"Q: I have K at my K1 and no other pieces. You have only K at K6 and R at R1. It is your move. What do you play?

"A: (After a pause of 15 seconds) R-R8 mate."

Turing's answer to his revised question is the following: "I believe that in about 50 years' time it will be possible to program computers, with a storage capacity of about 10^9, to make them play the imitation game so well that an average interrogator will not have more than a 70 per cent chance of making a right identification after about five minutes of questioning. The original question, 'Can machines think?' I believe to be too meaningless to deserve discussion. Nevertheless I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted. I believe further that no useful purpose is served by concealing these beliefs."

He then considers, and rejects, a number of possible objections to this view. Among them is the idea, which had been expressed by the prominent British neurosurgeon, G. Jefferson, that "Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain—that is, not only write it but know that it had written it." Turing answers with the following dialogue:

"Q: In the first line of your sonnet which reads, 'Shall I compare thee to a summer's day,' would not 'a spring day' do as well or better?

"A: It wouldn't scan.

"Q: How about 'a winter's day?' That would scan all right.

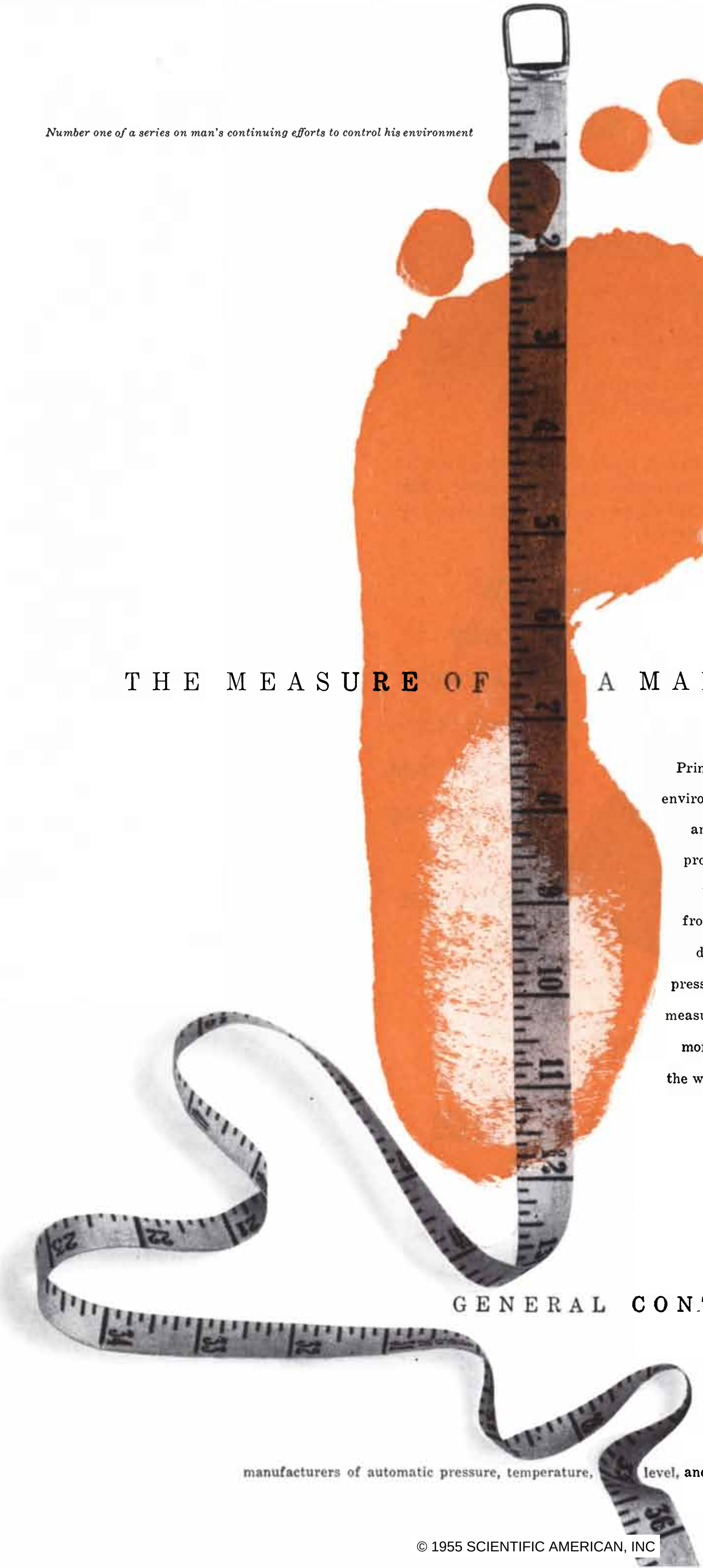
"A: Yes, but nobody wants to be compared to a winter's day.

"Q: Would you say that Mr. Pickwick reminded you of Christmas?

"A: In a way.

"Q: Yet Christmas is a winter's day

Number one of a series on man's continuing efforts to control his environment



THE MEASURE OF A MAN

Primitive Man took the first step to control his physical environment when he used his own footprints to measure a field and plan a shelter from the storm. The human body provided the first units of measurement; the foot, the thumb, the hand spread out, the arms extended. It is a long step from the measured footprints to the automatic controls designed to meet today's need for accurate measurement of pressure, level, temperature and flow. The ability to measure is a measure of Man's progress. The invention of more delicate and complex automatic controls points the way to measureless future possibilities.

GENERAL CONTROLS CO.

manufacturers of automatic pressure, temperature, level, and flow controls for home, industry, and the military and I do not think Mr. Pickwick would mind the comparison.

"A: I don't think you are serious. By a winter's day one means a typical winter's day rather than a special one like Christmas."

"And so on. What would Professor Jefferson say if the machine was able to answer like this? . . . I do not wish to give the impression that I think there is no mystery about consciousness . . . but I do not think these mysteries necessarily need to be solved before we can answer the question with which we are concerned in this paper."

Finally Turing lays out a research program for a serious investigation of the question. He suggests that, given the necessary engineering advances, it should be possible to build a "child machine" which could then be educated to the point where it could play the imitation game successfully.

"An important feature of a learning machine is that its teacher will often be ignorant of quite what is going on inside, although he may still be able to some extent to predict his pupil's behavior. This is in clear contrast with normal procedure in using a machine to do computations: one's object is then to have a clear mental picture of the state of the machine at each moment in the computation. This object can only be achieved with a struggle. The view that 'the machine can only do what we order it to do' appears strange in the face of this. . . . Intelligent behavior presumably consists in a departure from the purely disciplined behavior involved in computation, but a rather slight one."

The conclusion of Turing's article seems worth quoting in full:

"We may hope that machines will eventually compete with man in all purely intellectual fields. But which are the best ones to start with? Even this is a difficult decision. Many people think a very abstract activity, like the playing of chess, would be best. It can also be maintained that it is best to provide the machine with the best sense organs that money can buy, and then teach it to understand and speak English. This process could follow the normal teaching of a child. Things will be pointed out and named, etc. Again I do not know what the right answer is, but I think both approaches should be tried.

"We can see only a short distance ahead, but we can see plenty there that needs to be done."

SAMUEL A. ROSS

New Haven, Conn.

Dr. F. Hubbard Horn, A.B., Oberlin (1937), Ph.D. in Chemistry, Johns Hopkins (1942), came to the General Electric Research Laboratory in 1946. With the equipment shown, he has been able to extend the range of density measurement to a new order of precision. Dr. Horn's work includes pioneering studies of crystals and their imperfections.

Progress toward better transistors

Dr. F. Hubbard Horn seeks more uniform semiconductor crystals at the General Electric Research Laboratory

Recent work by Dr. F. Hubbard Horn has been likened to "measuring and weighing haystacks to find needles in them." The haystacks are crystals of extremely pure silicon. The needles are the impurities and imperfections left in silicon after the crystals have been "zone-melted" and grown in a process developed by Dr. Horn and his associates at the General Electric Research Laboratory.

Dr. Horn has adapted and developed a density-measurement method — involving free suspension of crystals in a liquid column of varying density — which is sensitive to variations of a millionth of a gram per cubic centimeter. These measurements, combined with x-ray techniques, make it possible not only to ascertain the *presence* of impurities, but actually to locate *where they are* in the crystal. This General Electric research will mean greater uniformity in transistors and other silicon semiconductor devices that can operate at high temperatures. It opens the way to wider basic knowledge and important progress in a new field of electronics.

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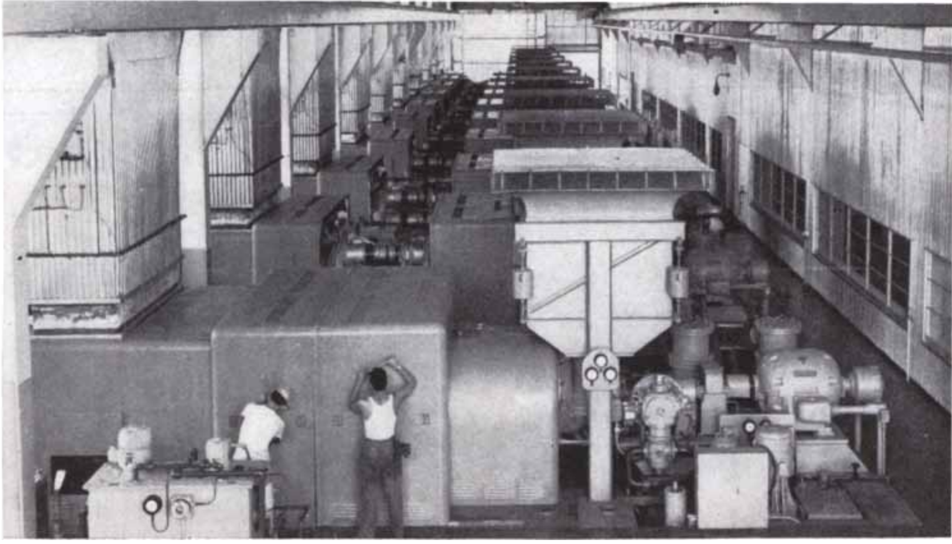
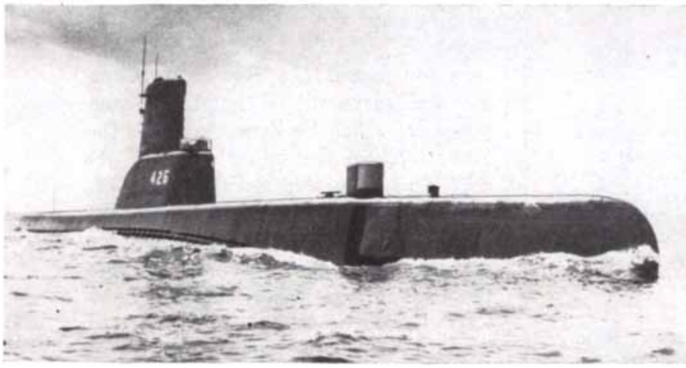
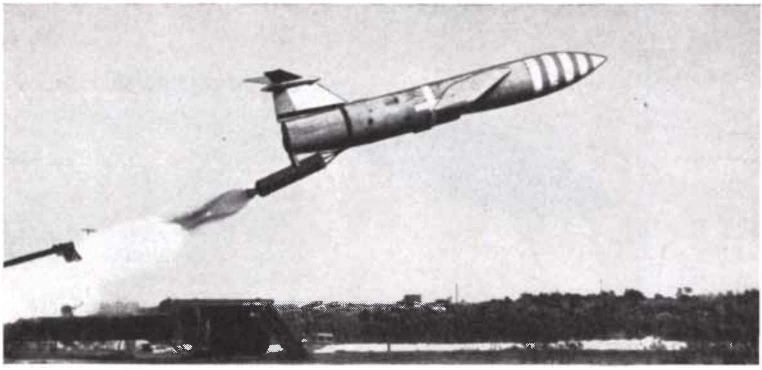


PROCESS CONTROL—Askania controls regulate speed of the ten turbines which develop compression to maintain gas suction pressure in Creole Petroleum Corporation's giant, pile-supported oil drilling operation on Lake Maracaibo, Venezuela.



SUBMARINE OPERATION — Controls developed and produced by Askania Regulator Company are utilized to govern operation of U. S. Navy's modern Guppy type submarines.



MISSILE GUIDANCE —One of the many guided missiles equipped with Kearfott basic gyro reference systems, the B-61 Matador—U. S. Air Force's first successful ground-to-ground tactical weapon.

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themselves, as well as in systems and equipment developed and produced by other manufacturers of advanced technological equipment.

All GPE Producing Companies work in the advanced areas of highly specialized fields and are engaged in the design, development, manufacture and sale of equipment which is closely related from a technical point of view. It is all precision equipment; it derives from similar fields of technical competence; it saves labor, increases productivity or achieves results which cannot be achieved with even limited use of on-the-spot manpower. The chart here shows the specialized fields in which the key GPE Producing Companies work.

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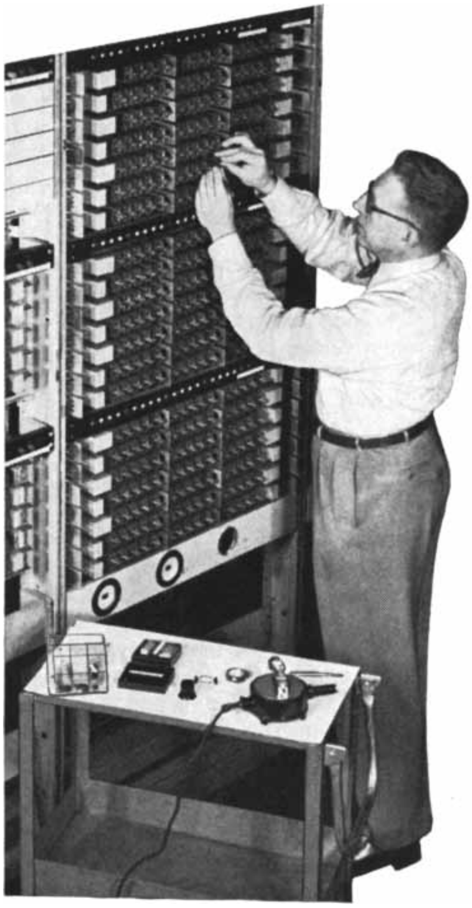
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1905. "The start of the ninth journey of Commander Peary to the Far North is marked by the quiet determination that is characteristic of explorers who attempt the perilous quest of the North Pole. In the course of an interview on board the *Roosevelt*, Commander Peary outlined the plan of campaign by which he hopes to reach the North Pole in the spring of 1906. He will start early this month from New York and sail to Cape Breton, where the present ship's complement will leave her and the crew which will take her into the Arctic regions will be shipped. From Cape Breton he will steam at reduced speed, in order to economize coal, direct for the northern coast of Greenland, the scene of his former explorations. The large amount of ice that has been coming down from the North this year encourages the belief that more than the usual open water will be found."

"When the long distance wire now being laid between Denver, Omaha and Kansas City has been completed, there will be a direct telephone communication between New York and San Francisco, which are nearly 4,000 miles apart."

"During the past hundred years there has been an area of agricultural development on the western border of our developed country, and this has been able to compete at an economical advantage with the older area farther east. The price of land has fallen in the East, while it has risen in the West. From 1870 to 1900 we practically doubled our population and doubled our agricultural area. Aside from the geometrical increase in the population, this development has been due to a fertile, level prairie which was practically treeless. Hitherto the woodsman has hewn his way tree by tree. The development of the area west of the Mississippi River is probably the most remarkable in the history of the world. A second cause for this development is the consolidation of railroads into transcontinental lines; another is the

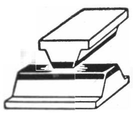


He's "fingerprinting" a relay contact

Bell Laboratories microchemists have perfected an ingenious new technique for "fingerprinting" relay contacts, the tiny switches on which a dial telephone system critically depends.

Using a portable test set, a chemist makes a plastic print of a contact. On-the-spot examination of the print with a microscope and chemical reagents quickly reveals the effects, if any, of arcing, friction, dust or corrosive vapors. While the chemist studies the print, urgently needed contacts continue in service. Findings point the way to improve relay performance.

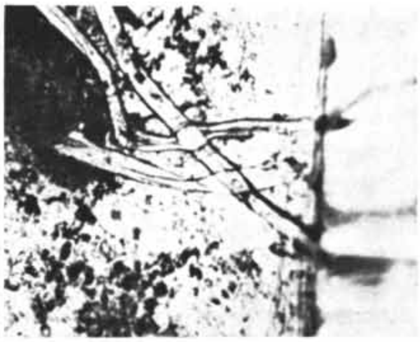
This is another example of how Bell Telephone Laboratories research helps to keep your telephone system the world's best.



Above, Bell Laboratories microchemist applies plastic disc in heated clamp to relay contact. Imprint reveals contours of surface and picks up contaminants, if any. Part of portable test set is shown on table. Contacts, shown in small sketches, are of precious metal fused to base metal.

Preparing disc for microscopic examination. On-the-spot examination may reveal acid, alkali, sulfur, soot or other polluting agents peculiar to an area.

A microscopic look at disc often provides lead to nature of trouble. Unlike actual contact, print can be examined with transmitted light and high magnification.



Here the plastic disc has picked up microscopic lint that insulates contact, stops current. (Picture enlarged 200 times.) Traces of contaminants are identified in microgram quantities. Inert plastic resists test chemicals that would damage contact.

Bell Telephone Laboratories

Improving telephone service for America provides careers for creative men in scientific and technical fields improvement of labor-saving machinery, of which the self-binding harvester is the most conspicuous example."

"For ascertaining the depth of the sea without the use of the sounding lead or other devices, the Norwegian engineer Berggraf has invented a unique method. He sends sound waves perpendicularly into the water, and measures the time they require to return to the surface after having been reflected from the bottom of the sea. The speed of sound in water being known, the length of the space passed through is immediately determined; one half of it is the depth of the water. A period of four seconds, for instance, between the departure and return of the sound corresponds to a depth of 2,400 meters."

"The total eclipse of August 30 will be extensively utilized for special electric and magnetic observations. J. Elster and H. Geitel suggest that an attempt should be made to determine the ionization of the atmosphere during and immediately after the eclipse. The cone of the moon's shadow will intercept the ultra-violet rays, which are mainly effective in producing ionization. Their efficacy does not as a rule perceptibly affect the sea-level atmosphere owing to the opacity of air for ultra-violet rays. But some effect might be perceived, especially if the station is at a high level."

"In a current issue of the *Comptes Rendus* of the Paris Academy of Sciences, P. Langevin shows that Lorentz's hypothesis of a contraction of all matter in the direction of motion completely accounts for the negative results of Trouton and Noble's condenser experiment of 1903. According to Trouton and Noble, a charged condenser suspended by a fiber should turn its plates parallel to the direction of the earth's motion. Now, according to Larmor, the difference between the electric and magnetic energies of a system must be a maximum or minimum in a state of equilibrium. When the system is in motion this equilibrium is disturbed, but not if there is the contraction of Lorentz's hypothesis. There is, therefore, no couple tending to turn the condenser. Hence Trouton and Noble's experiment must give a negative result."

"A general restatement of physical science is now due. The extensive researches in the higher phases and states of matter, beginning with Crookes, and extending to the present, have so enormously expanded all conceptions of

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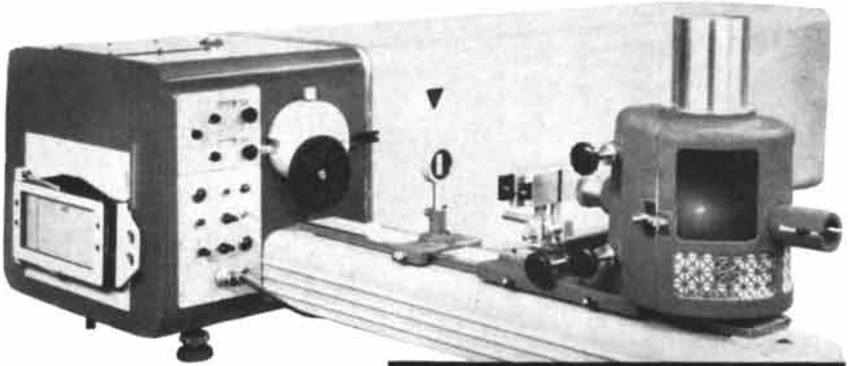
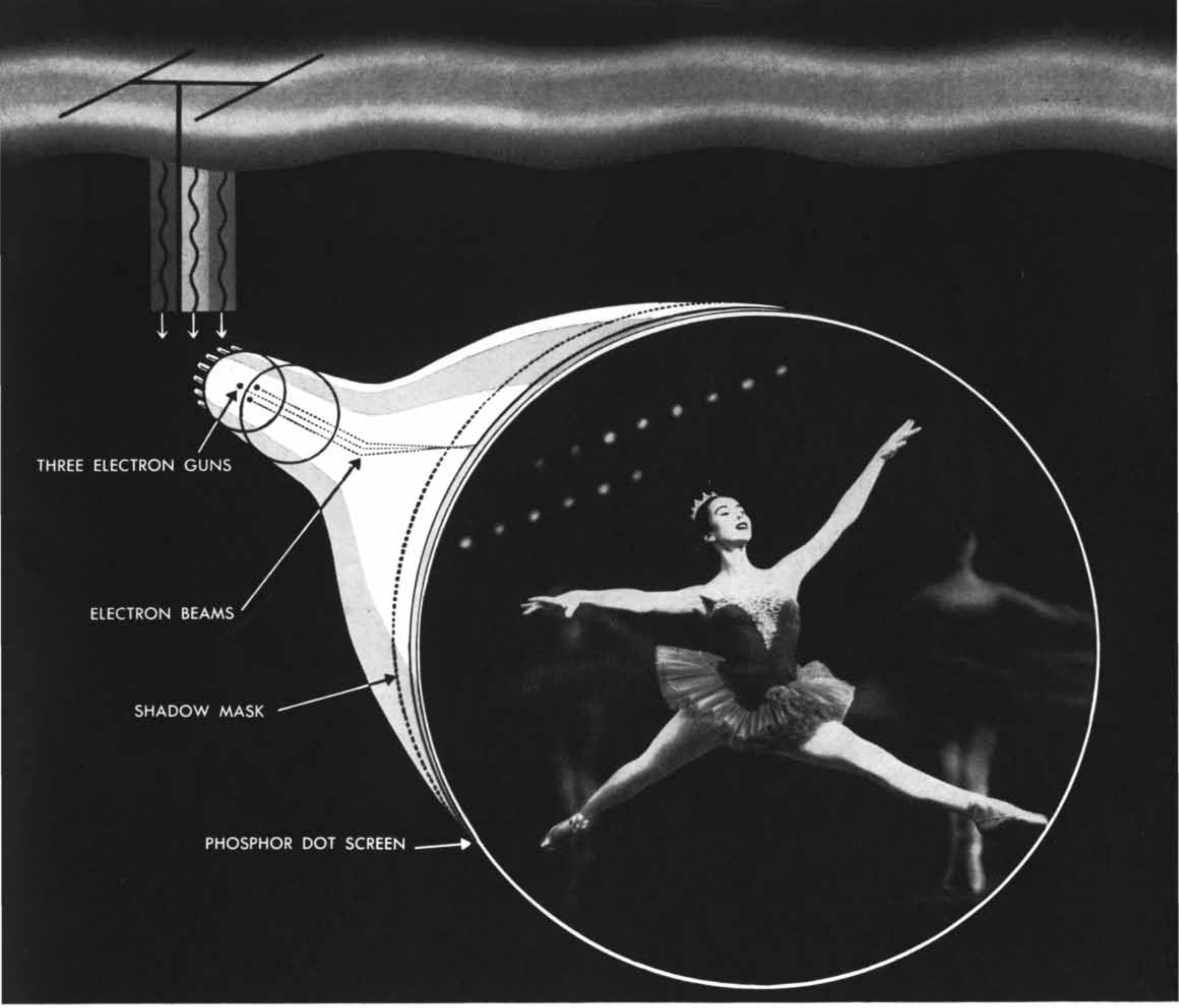


nature, that a vast work like Newton's *Principia* is urgently needed. The new book would be basic, fundamental, and epoch-making. For when gravitation was discovered and its phenomena reduced to rigid law, all men at once saw that it was part of the base of the existing order of things. But Crookes's first vacuum tube made us aware of the existence of phenomena equally important."

SCIENTIFIC AMERICAN

JULY, 1885. "A patent has been granted to Linus Yale, of Newport, Herkimer Co., N. Y., for an improvement in locks for fire proof safes, bank vaults, and other doors. The nature of the invention consists in the employment of a sliding plate and frame, constructed, arranged and operated in connection with pins or rods, and a key of peculiar construction. The advantages of the lock are that it cannot be picked and that there is no opportunity for a burglar to take impressions in wax to form a key."

"It has been publicly announced that the recent failure of the late treasurer of the Eastern Railroad Co., Mass., to meet his liabilities—amounting to $207,000—is in a measure attributable to the money he advanced in order to obtain from Congress, in 1852 and 1853, a large appropriation for Dr. Morton, of Boston, as the discoverer of etherization. We have here some inkling of the large sum that was expended by Dr. Morton's friends in order to operate upon Congress in furtherance of his claims, which ended in a vote to grant $100,000 to C. T. Jackson, M.D., or W. T. G. Morton, or the heirs of H. Wells, upon fair judicial proof of original discovery. Dr. Morton went to Washington and petitioned for remuneration, as being the original discoverer of etherization. He employed counsel, got up testimony in support of his claims, and succeeded in getting committees appointed in both houses on his case. Perhaps he would have been successful in obtaining a large grant, but for the contesting of his claims by Dr. Jackson, and the friends of Dr. Wells, and the prominence given to the subject by the Boston *Medical and Surgical Journal* and SCIENTIFIC AMERICAN. We contended that no grant should be made by Congress but upon such judicial proof as would, in the eye of the law, fairly establish the just claims of the original discoverer."



Photograph courtesy of RCA

PROGRESS THROUGH ANACONDA METALS

The Alloy that helped make color TV possible

THE PROBLEM: *To make colors behave in TV tubes.* Behind the face of a color tube is a shadow mask. This is a paper-thin metal sheet with hundreds of thousands of holes. Each is 1/100th of an inch in diameter.

Each hole guides the tube's three electron beams so that each beam focuses on the right phosphor dot (red, green or blue) on the color screen.

The pioneers of color TV could find no metal that was suitable for etching all the tiny holes on the shadow mask. So they came to Anaconda.

THE SOLUTION: Anaconda Metallurgists developed a brand new alloy – 6% Cupro Nickel. The American Brass Company – an Anaconda subsidiary – now makes sheets of this new metal that are perfect for 21″ color-tube masks. The fantastic problem of etching 400,000 perfect holes in a 21″ TV mask was solved. A brand new form of entertainment came into the American living room to be enjoyed by all. The riotous colors of the rainbow were at last harnessed to enchant millions of fascinated TV viewers.

THE FUTURE: Controlling the aim of electrons is just one way Anaconda helps industry. Research at Anaconda is solving many other metal problems —some of which may affect your industry. Why not talk to the *Man from Anaconda* today? He brings to your problem metallurgical and technological experience that can save you time and money. *Anaconda, 25 Broadway, New York 4, N. Y.* 55221

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One moment airborne . . . *the next moment* WHOMP!

Bendix Landing Gear pillows

THERE are few things so agile and responsive as an airborne airplane or so dead-weighty and ox-like the split second it loses flying speed and whomps onto the runway. Yet you have to treat multimillion dollar bombers and airliners like a basket of priceless eggs. For one thing, they carry precious lives and precision gear that could get out of whack if the landing gear didn't pillow the load. Other parts of the airframe would also suffer undue stress and strain.

Bendix builds complete landing gear systems for many kinds of aircraft. This includes massive shock-absorbing struts, giant wheels and the quickest stopping brakes in the business. From the time we patented the first airplane brakes, stopping heavy planes has gotten tougher and tougher. When these big ships come roaring in for a landing it's like stopping 150 passenger cars going 60 miles per hour. Ordinary brakes and lining can't do it. So we have developed an extra-powerful segmented rotor brake and a special lining called Cerametallic†—and they do the job!

We also make power-steered nose wheels that make taxiing as easy as power-steering a car . . . and hydraulic systems that retract and lower the entire gear, open and close bomb-bay doors and perform other important tasks. We believe the Bendix hydraulic cylinder for retracting the landing gear on the 200-ton B-36 bomber is the largest ever built.

If you direct or influence the purchase of aviation components, the fact that Bendix offers so many complete systems simplifies your job. Landing gear, radio

THE AUTHORS

SEYMOUR MELMAN ("Industrial Productivity") is assistant professor of industrial engineering at Columbia University. He graduated from the College of the City of New York in 1939 and acquired his Ph.D. in economics at Columbia 10 years later. In the meantime he had already begun his studies in the subject of his article. He has pursued his investigation of productivity in England and the U. S. for the last 15 years.

HENRY W. MENARD ("Fractures in the Pacific Floor") is an oceanographer at the U. S. Navy Electronics Laboratory in San Diego, Calif. His interest in oceanography was nurtured by sea duty in the western Pacific during World War II. At that time he already had a B.S. in geology from the California Institute of Technology. After the war he went on to the Woods Hole Oceanographic Institution and to Harvard University, where he took his Ph.D. in 1949. Since his return to the West Coast, he notes that "I have spent about a year at sea on many of the expeditions mentioned in my article and, counting my wartime visits, have managed to glimpse most of the archipelagoes of the Pacific from Tahiti to Kodiak." As a sideline he has taken to mapping underwater geology for oil companies. During the past 18 months he has made more than 300 dives with an aqualung. Of this he says: "Personally I am a track man and have never held much of a brief for swimming, except perhaps in the tropics, but the work occasionally has some element of interest."

SETON LLOYD ("A Forgotten Nation in Turkey") is the director of Ingiliz Arkeoloji Enstitüsü (British Institute of Archaeology) in Ankara, Turkey. He was originally an architect, having followed a six-year course of study at the London Architectural Association. In the middle 1920's he was assistant to Sir Edwin Lutyens in the building of New Delhi. His first excursion into archaeology came in 1928, when he joined the late Henri Frankfort as architectural adviser on an expedition to Egypt. During the 1930's he assisted Frankfort in excavations in Mesopotamia for the Oriental Institute of the University of Chicago and under Frankfort's tuition gradually became a field archaeologist. In the 1940's Lloyd led half a dozen excavating parties to Sumerian and to prehistoric sites for the government of Iraq. He likes

to write about his work, his more popular books growing out of "a conviction that the subject of field archaeology has educational value and a tremendous appeal to the general public, from which the specialist has no right to withhold himself on the grounds of scientific preoccupation."

LAWRENCE P. LESSING ("Coal"), a former member of the editorial board of *Fortune* and later of SCIENTIFIC AMERICAN, is a frequent contributor to this magazine. His most recent article, "Helicopters," appeared in its January issue. Lessing is currently preparing a book on the late pioneer in electronics Edwin H. Armstrong, to whom he devoted an article in SCIENTIFIC AMERICAN for April, 1954.

I. BERNARD COHEN ("An Interview with Einstein") is the editor of *Isis*, the history of science journal, and is associate professor of the history of science and of general education at Harvard University. His most recent appearance in SCIENTIFIC AMERICAN was as author of "Pioneers in the Theory of Heat" in the issue of September, 1954. Aside from the books he has written himself, Cohen has also prepared a modern edition of Newton's *Opticks*, incorporating a rather famous short foreword by Einstein beginning: "Fortunate Newton, happy childhood of science! . . ."

C. A. KNIGHT and DEAN FRASER ("The Mutation of Viruses") are biochemists at the Virus Laboratory of the University of California. Fraser, a graduate of Phillips Exeter Academy and Harvard College, has a Ph.D. in organic chemistry from the University of Illinois. During World War II he worked for the Monsanto Chemical Company on the development of sulfa drugs and DDT, becoming, in his words, "more and more vexed with the facility with which bacteria, milkweeds and other lowly creatures outsmarted the synthetic organic chemists. My increasing fascination with biological chemistry led me to turn toward simpler systems and, finally, to bacterial viruses." At the Virus Laboratory, where he has been since 1948, he is studying viruses with the electron microscope and investigating the structural chemistry of virus strains. Knight is a graduate of Alma College in Michigan, where the influence of Lloyd C. Douglas' *Magnificent Obsession* led him to enroll in a premedical course. Unable to afford a medical education, he turned to biochemistry, taking his doctorate at the Pennsylvania State University with a

BUSINESS IN MOTION

To our Colleagues in American Business . . .

It is a characteristic of American companies that they constantly seek to improve their products; this is in part responsible for the amazing strides made by industry. Revere is glad to aid in this endeavor through its Technical Advisory Service, and its Research Department, particularly for firms whose need for research is not such as to warrant purchasing costly laboratory equipment. A recent problem presented to us came from a maker of fishing reels. He had been cutting gears out of free-cutting brass, in order to achieve the machining economies such material offers.

This brass is widely and successfully used in gears for clocks, meters, and similar instruments. However, experience proved that a fishing reel, which is operated at various speeds and loads, presents a quite different service. Revere was asked to suggest a metal that would be more suitable in this application.

The Technical Advisory Service at once reported that either naval brass or aluminum silicon bronze would last longer. However, in order to determine the relative merits of the two, the Revere Research Department was asked to make tests. Gears of both metals were installed in reels, and a motor-driven machine was rigged to provide an accelerated wear test. Each gear was run at 430 r.p.m. and at 100 r.p.m., at zero tension on the line, and at 1, 2, 3, and 4 pounds tension. After each run the gears were removed, cleaned, examined, measured and photographed. The reels were then reassembled, lubricated, and the next run started.

The results were impressive. After the gears had gone through 186,727 revolutions it was felt unnecessary to proceed further. Both reels were still fully usable. The naval brass was somewhat more worn than the aluminum silicon bronze, however, it certainly was evident that naval brass would be satisfactory. The reel maker was determined to offer the best he knew how to make, and selected the more expensive aluminum silicon bronze. He knows conclusively now that his reels will give long service, enduring satisfaction, and will protect his reputation and help his business grow.

If you have questions as to the best material or materials for your product, no matter what it is, and do not have a modern research laboratory, why not ask your suppliers for help? Some may have an immediate answer; some may wish to test alternatives. You will benefit either way, and make faster and surer progress in your search for improvement.

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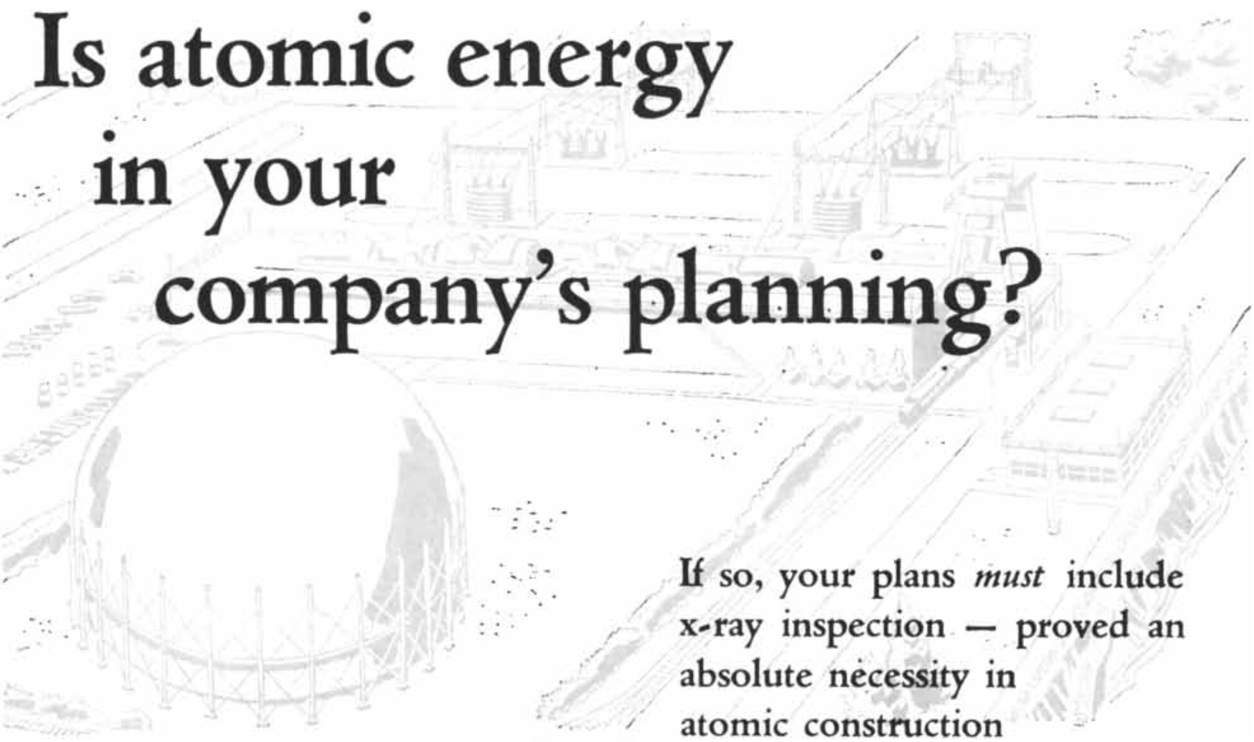
thesis on "Utilization and Excretion of Ascorbic Acid by the Dairy Cow." From 1940 to 1948 he worked with Wendell M. Stanley in the Rockefeller Institute for Medical Research on virus mutation and on the development of an influenza vaccine. He has since continued his work with Stanley in the Virus Laboratory at Berkeley.

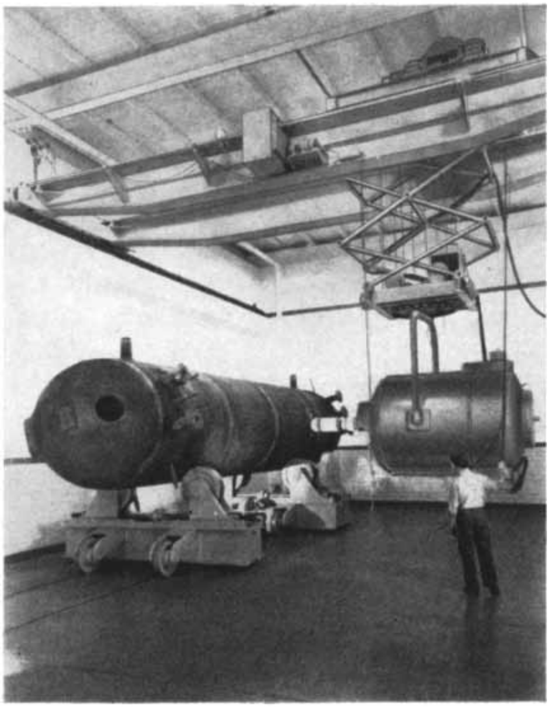
FRANK B. CUFF, JR., and L. McD. SCHETKY ("Dislocations in Metals") are both metallurgists at the Massachusetts Institute of Technology. Dislocations of a geographical sort played an important part in the youth of both men. Cuff, whose father was with the mining division of the Aluminum Company of America, received his early education at various stops in the U. S. and South America. Schetky, the son of a Navy officer, was born in the Philippines and went to school both in the U. S. and Europe. After graduating from the Rensselaer Polytechnic Institute, where he majored in metallurgy, Cuff went to M.I.T., where he is taking his Ph.D. this year. Schetky, also an R.P.I. graduate, took his Ph.D. there in 1953. Cuff is presently studying the creep and deformation of alloys at high temperatures. Schetky is working on powder metallurgy and molybdenum.

TALBOT H. WATERMAN ("Polarized Light and Animal Navigation") is associate professor of zoology at Yale University. He was educated at Harvard University, where he was a Junior Fellow from 1938 to 1940. In 1941 he joined the team of investigators from several disciplines that made up the Psychoacoustic Laboratory, with headquarters in the basement of Harvard's Memorial Hall. He took his Ph.D. in zoology in 1943, then spent two years on the staff of the Radiation Laboratory at the Massachusetts Institute of Technology. He has been at Yale since 1946. His interest in the sensitivity of animals to polarized light dates from a lecture given at Yale by the German naturalist Karl von Frisch, who had recently discovered the ability of the honeybee to orient itself by reference to the blue sky. Waterman writes: "As I had just been demonstrating the electrical activity of the *Limulus* eye to students, I began work in this field by using these horseshoe crab organs as experimental material. Since the initial observations of underwater polarization in Bermuda, I have been collecting further data in deep water near Barbados in the British West Indies, and in shallow water by aqualunging in the Virgin Islands."

Is atomic energy in your company's planning?



If so, your plans *must* include x-ray inspection — proved an absolute necessity in atomic construction



This 2,000,000-volt Resotron 2000 is typical of General Electric x-ray units now serving the atomic industry.

General Electric is presently supplying more x-ray equipment to atomic energy programs than to any other single industry — with good reason. Here, where failure cannot be tolerated, x-ray inspection is the *only* method which provides visible proof of the soundness of components and materials used in nuclear construction.

With the industry's widest experience in high-voltage x-ray — with more than one hundred super-voltage installations — General Electric is a natural choice whenever x-ray equipment is specified in this fast-growing field.

At the very start of your atomic energy planning, consult General Electric for both needed apparatus and necessary application experience. Our representatives are fully prepared to help you work with the atom.

• • •

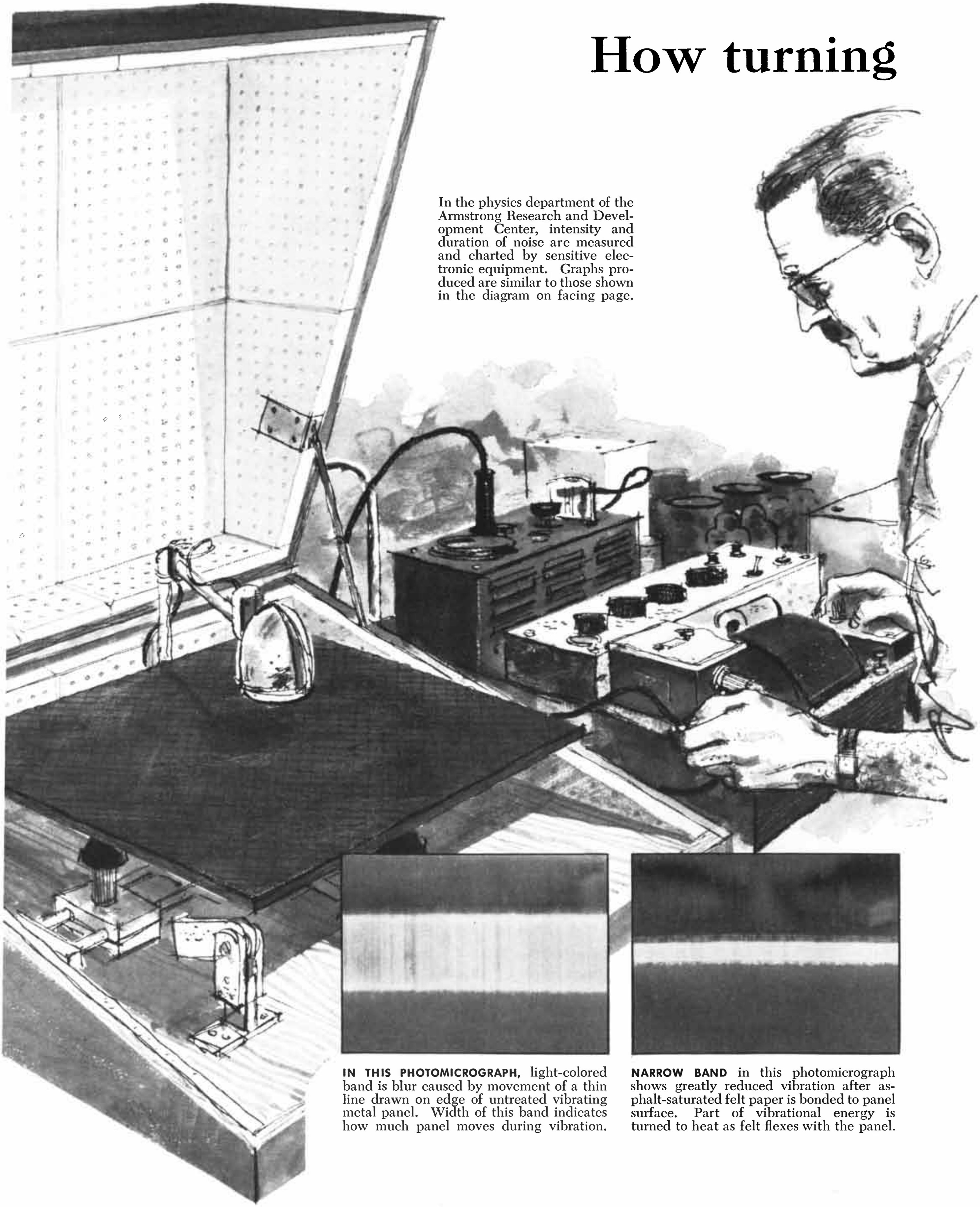
High-voltage x-ray inspection for quality control is just one of the ways G.E. applies x-ray and related radiation to industry. If you have a non-destructive testing or inspection problem, contact your nearest G-E x-ray representative or write X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, for Pub. TT74.

Progress Is Our Most Important Product

GENERAL ELECTRIC

How turning

In the physics department of the Armstrong Research and Development Center, intensity and duration of noise are measured and charted by sensitive electronic equipment. Graphs produced are similar to those shown in the diagram on facing page.



IN THIS PHOTOMICROGRAPH, light-colored band is blur caused by movement of a thin line drawn on edge of untreated vibrating metal panel. Width of this band indicates how much panel moves during vibration.

NARROW BAND in this photomicrograph shows greatly reduced vibration after asphalt-saturated felt paper is bonded to panel surface. Part of vibrational energy is turned to heat as felt flexes with the panel.

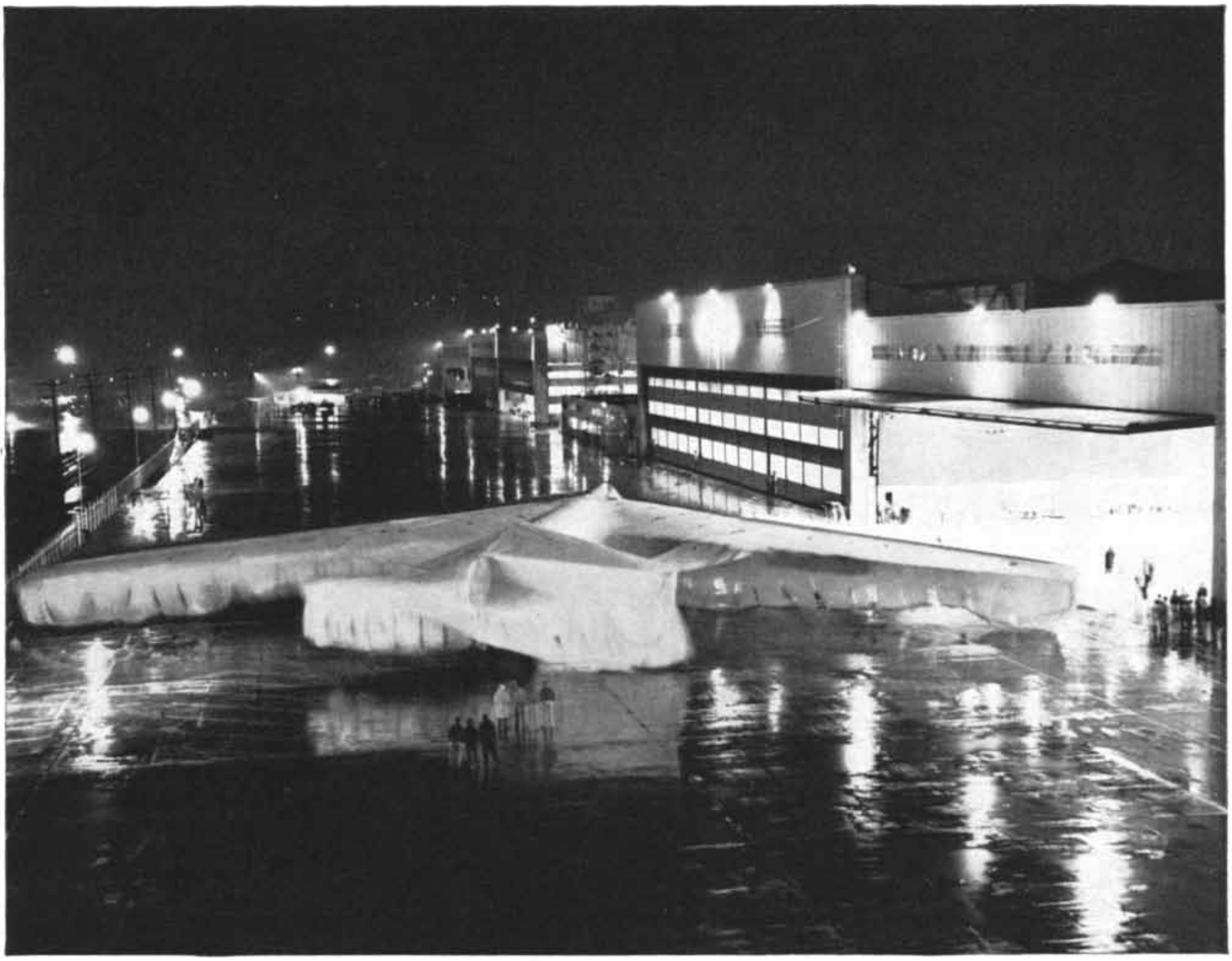
THE COVER

The woodcut on the cover symbolizes a recent trend in the utilization of coal (*see page 58*). The design is patterned after the new coal hydrogenation plant built at Institute, W. Va., by the Carbide & Carbon Chemicals Co. In this plant coal is used primarily not as a fuel but a raw material for chemical products.

THE ILLUSTRATIONS

Cover woodcut by Antonio Frasconi

Page	Source
34-35	Sara Love
36-37	Irving Geis
38	U. S. Navy Electronics Laboratory
39-41	Irving Geis
42-43	British Institute of Archaeology (*left* and *center*), John Langley Howard (*right*)
44-45	John Langley Howard
46	British Institute of Archaeology
58-61	Antonio Frasconi
62-63	Amy Kasai
64	U. S. Bureau of Mines
66	James Egleson
68-72	Paul Weller
74-76	Virus Laboratory, University of California
77	Amy Kasai
78	A. H. Doermann, University of Rochester
80	James Egleson
81	Marsbed Hablanian, Massachusetts Institute of Technology
82-83	James Egleson
84	James Egleson (*top*), Malcolm Fraser, Rensselaer Polytechnic Institute (*bottom*)
85-87	James Egleson
88-90	Bunji Tagawa
92	Talbot Waterman, Yale University
97	Bernarda Bryson
104-106	Roger Hayward
107	John De Haas
108-110	Roger Hayward



Boeing engineers have vital and rewarding jobs

This is the Boeing B-52—mightiest of the world's jet bombers. The "wraps" are off it now. Some of the engineers—electrical, mechanical, civil and aeronautical—who designed it are now at work on the B-52's further development. Many others have gone to work on other "years-ahead" airplanes and guided missiles. But these new Boeing aircraft are classified, and cannot be shown here.

Engineers at Boeing have the satisfaction of vital jobs, where only endless experimentation can keep up with exacting demands. They stand at the top of their profession—thanks in part to highly advanced equipment like electronic computers, superb laboratories and research facilities, and the multi-million-dollar new Flight Test Center.

Boeing engineers can point with pride to recent developments like the B-47 and B-52 jet bombers, the KC-135—America's first jet tanker, and the IM-99 Bomarc pilotless interceptor. These Boeing engineers are now at work on widely diversified projects: rocket, ram jet and nuclear propulsion, supersonic flight, research in new materials, and many more. The result will be planes and missiles that will fly even faster, farther, and higher, and deliver an even greater punch.

These are evidences of Boeing's continuing growth—a growth made possible by uncompromising insistence on engineering excellence. Boeing employs twice as many engineers now than at the peak of World War II. But even more engineers are needed for Boeing's research, design and production teams.

If you want the satisfaction of doing an important job—if you want individual recognition and regular merit reviews—if you want to work with the finest equipment and the pick of the nation's engineers—then it will pay you to investigate career opportunities at Boeing.

JOHN C. SANDERS, Staff Engineer—Personnel
Boeing Airplane Co., Dept. B-41, Seattle 14, Wash.

Please send further information for my analysis. I am interested in the advantages of a career with Boeing.

Name ______

University or college(s) ______ Degree(s) ______ Year(s) ___

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SEATTLE, WASHINGTON   WICHITA, KANSAS

Life on the Chemical Newsfront

WAXES AND POLISHES which contain Cyanamid's CATIONIC SP Antistatic Agent have proved effective in reducing dust and lint pickup. Desired gloss on polished surfaces usually is brought out by rubbing or buffing. Static charges generated by such treatment strongly attract lint and dust. However, CATIONIC SP in amounts of 1% to 5% in wax pastes or emulsions reduces such pickup markedly. **(No. 1)**

NEW LINE OF ACCOSPERSE* PIGMENT DISPERSIONS gives a variety of deep shades and medium to light tints for popular rubber latex interior architectural finishes. ACCOSPERSE pigment dispersions are standardized in color, strength, consistency and bulking value. They contain alkali-resistant pigments in a high degree of dispersion. They eliminate grinding and simplify paint formulation because they provide:

1) high color concentration
2) wide compatibility
3) easy handling and mixing
4) good stability
5) resistance to migration and flushing
6) freedom from efflorescing salts. **(No. 2)**

ROUND-THE-WORLD LUGGAGE comes back good as new. Made of glass fiber and Cyanamid's LAMINAC® Polyester Resin, these cases withstand the rough handling that usually breaks, dents or scars ordinary luggage. They are available in a range of attractive colors which are molded in so the color can't chip or peel. And their handsome finish, with glass fibers contributing an interesting random pattern, will not stain or absorb dirt or moisture. **(No. 3)**

FLEXIBLE VINYL WALL TILE stays supple and durable for years, thanks to phthalate plasticizers made with AERO* Phthalic Anhydride. Available in high purity, and in either flake or molten form, AERO Phthalic Anhydride imparts no unwanted color characteristics to plasticizers for vinyl compounds. Low volatility of these plasticizers assures retention of flexibility. Yet, for all its qualities, AERO Phthalic Anhydride is low in cost. **(No. 4)**

News Briefs

AEROCARB® S AND R CARBURIZING COMPOUNDS offer two cost-reducing factors: high penetration rates for faster case hardening, and wide temperature range in the bath for greater versatility. Simple variation in R to S ratio gives close chemical control. Bath gives light or deep case in minimum time, while finished parts are cleaned easily, are scale free, and unusually bright. **(No. 5)**

AMMONIA SYNTHESIS proceeds at peak efficiency with AERO* Specialty Catalysts. High activity and long-term stability of these catalysts are time-proved properties. Specific AERO Catalysts are available for each commercial process: hydrogen production by methane-steam reaction or water-gas shift reaction, or direct ammonia synthesis from nitrogen and hydrogen. A new bulletin on AERO Specialty Catalysts will be sent on request. **(No. 6)**

MEGASUL® NITROPHENIDE, safest, most effective drug for preventing coccidiosis in chickens, now is offered to feed manufacturers in a free-flowing, non-bridging, dust-free form. This assures even distribution of nitrophenide throughout every bag of feed. In addition to preventing outbreaks of coccidiosis, continuous feeding of MEGASUL to birds results in faster, more uniform growth, more efficient feed utilization, and improved well-being. **(No. 7)**

CYPEL* PAPER RESIN EMULSION, now available, produces excellent grease-resistant coatings with heat-sealing properties on paper and paperboard. CYPEL blends with starch, casein, soya proteins, and synthetic water-dispersible polymers to give toughness and non-blocking qualities to grease-proof paper coatings. **(No. 8)**

*Trade-mark

S.A.

SEND more information on the following items mentioned in the July, 1955 issue of LIFE on the Chemical Newsfront:

No. 1, 2, 3, 4, 5, 6, 7, 8.

Name________________________

Company________________________

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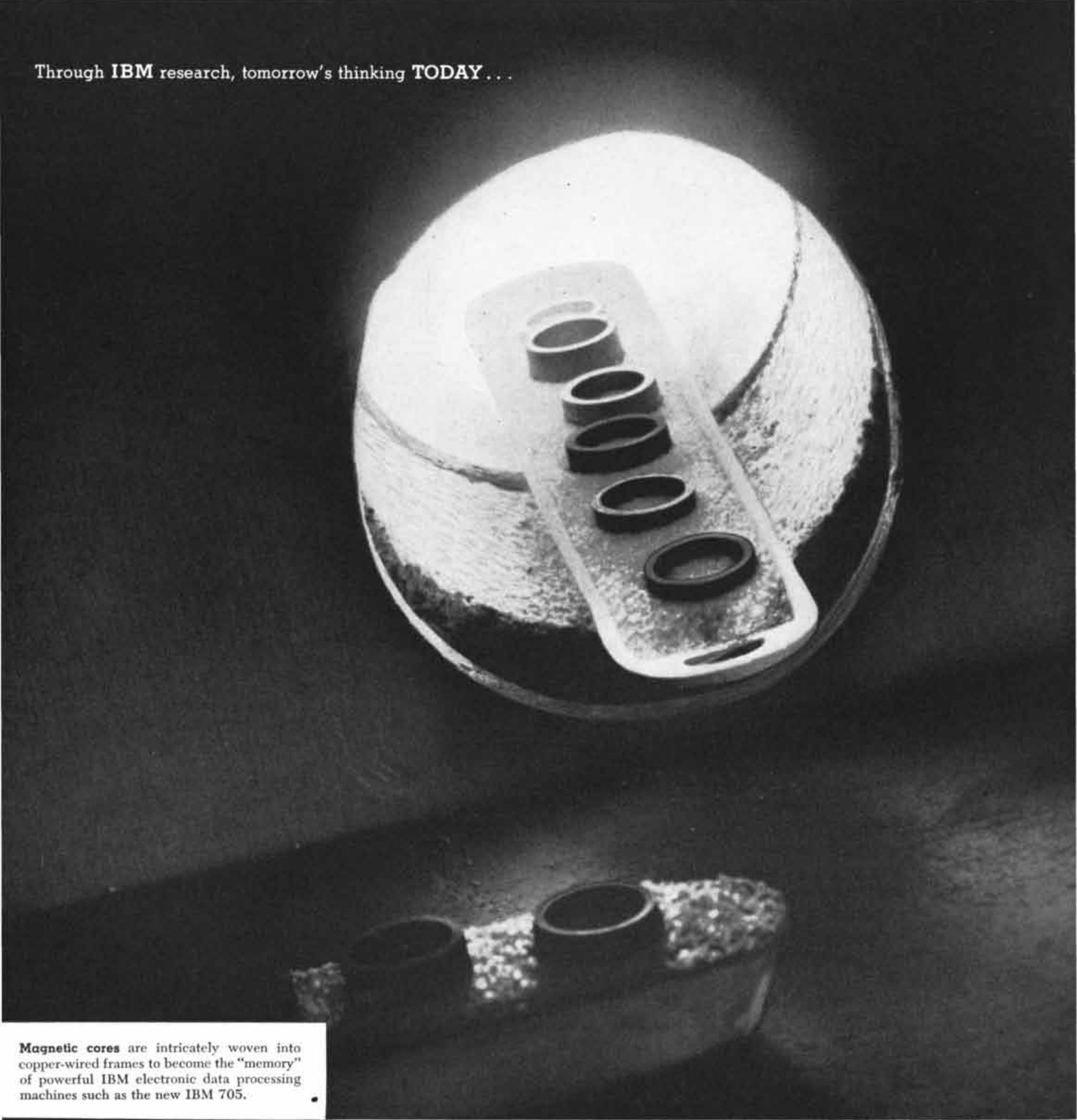
City____________Zone____State________



Magnetic cores are intricately woven into copper-wired frames to become the "memory" of powerful IBM electronic data processing machines such as the new IBM 705.

Memory . . . in the making

Magnetic cores, each one actually little larger than the head of a pin, are shown here dramatically magnified by the microcamera as they are taken from a heat-treating kiln. Their ultimate function: to store or "remember" information fed into IBM electronic data processing machines for business.

They also illustrate IBM's leading role in applying the latest electronics advances to data processing. Out of this continuing leadership by IBM has come today's "quiet revolution" in American business methods.

In almost every field of activity, from fundamental research and engineering calculations to everyday business accounting, IBM data processing is rapidly narrowing the critical gap between problems and decisions.

International Business Machines Corp., N. Y. 22.

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World's largest producer of data processing machines

SCIENTIFIC AMERICAN

Established 1845

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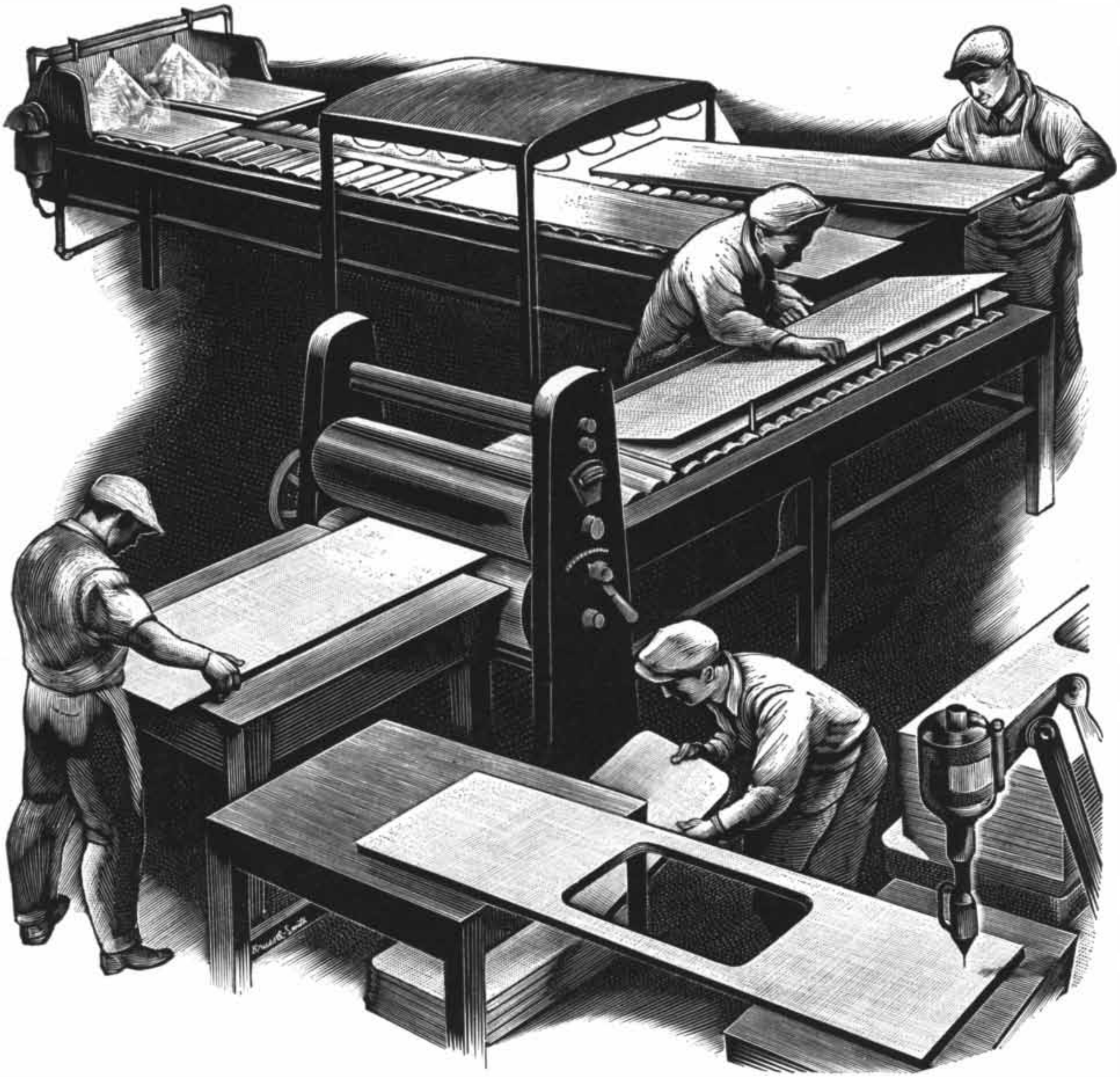
ARTICLES

DEPARTMENTS



Bond plastic laminates with assembly-line speed and economy

For fast, positive assembly-line bonding of high-pressure plastic laminates, use the adhesive that's designed for this tough job—Armstrong D-253.

D-253 has unusually high dead load strength, bonds plastic laminate firmly, permanently—and instantly. The tough, flexible D-253 bond also has high shear strength, excellent resistance to moisture, and good resistance to heat.

Armstrong D-253 is ideally suited to assembly-line use. Applied by spray gun to core and skin sheets, it dries in less than a minute under infra-red heat. After assembly, one run through a pinch roll completes the lamination. D-253's high immediate strength makes it possible to fabricate panels—or ship them—minutes after bonding.

Write today for your copy of our 1955 Adhesives Manual, free to industrial users. Armstrong Cork Company, 8007 Inland Road, Lancaster, Pa. In Canada, Armstrong Cork Canada Ltd., 6911 Decarie Boulevard, Montreal, Quebec.

Armstrong

ADHESIVES • COATINGS • SEALERS

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SCIENTIFIC AMERICAN

JULY, 1955 VOL. 193, NO. 1

Industrial Productivity

What determines how much a worker can produce in different periods and in different countries? The answer is found in the study of a sensitive ratio between the cost of labor and the cost of machinery

by Seymour Melman

U. S. industrial workers now produce about four times as much per man-hour as they did in 1900. Their productivity is far greater than that of workers in other countries. Indeed, output per man-hour in the U. S. is currently two and three times that in the industrialized countries of Europe.

The same knowledge and skills are readily available in both the U. S. and Europe. Some important manufacturing plants in England, for example, are owned by parent firms in the U. S. The productivity of these plants is nonetheless more characteristic of British industry than of their American counterparts. Clearly the availability of technical information does not determine differences in productivity.

How, then, can we account for these differences? What causes changes in productivity? The importance of these two questions lies in the fact that industrial productivity sets an upper limit on the ability of a population to produce goods. Productivity has become a major concern wherever men seek to raise the level of living by means of industrialization.

My investigations in this area began in 1950. At the outset it was established that major variations in industrial productivity have little to do with the physical effort of the worker. They are determined by differences in production technique. It is improved methods of organization and the increased use of machinery that principally account for the increase in productivity.

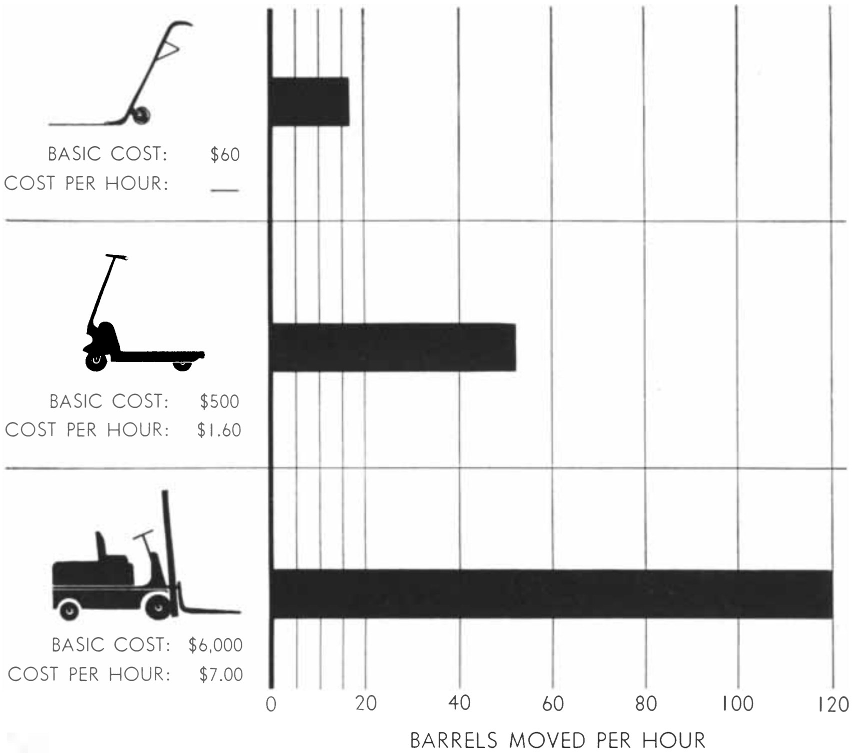
This points to the heart of the problem. How do industrial managements decide upon production methods? Managements do not choose alternative methods on the basis of productivity. Profitability and the growth of the firm are the criteria of success in a business. Therefore it is the cost in money of a production method that determines its selection.

The major elements of cost in a production method are the cost of labor and the cost of machinery. We proceeded on the assumption (later verified) that the ratio of the cost of labor to the cost of machinery would be the most useful expression of the cost factors that regulate the choice of a production method. Moreover, we established that the influence of these cost considerations has far outweighed the effects of other factors that vary among countries. Historical and cultural factors, for example, have not lessened the force of a high or low ratio of labor to machinery cost in causing an appropriate degree of mechanization in industry. But exactly how does this ratio of labor to machinery cost operate in changing productivity?

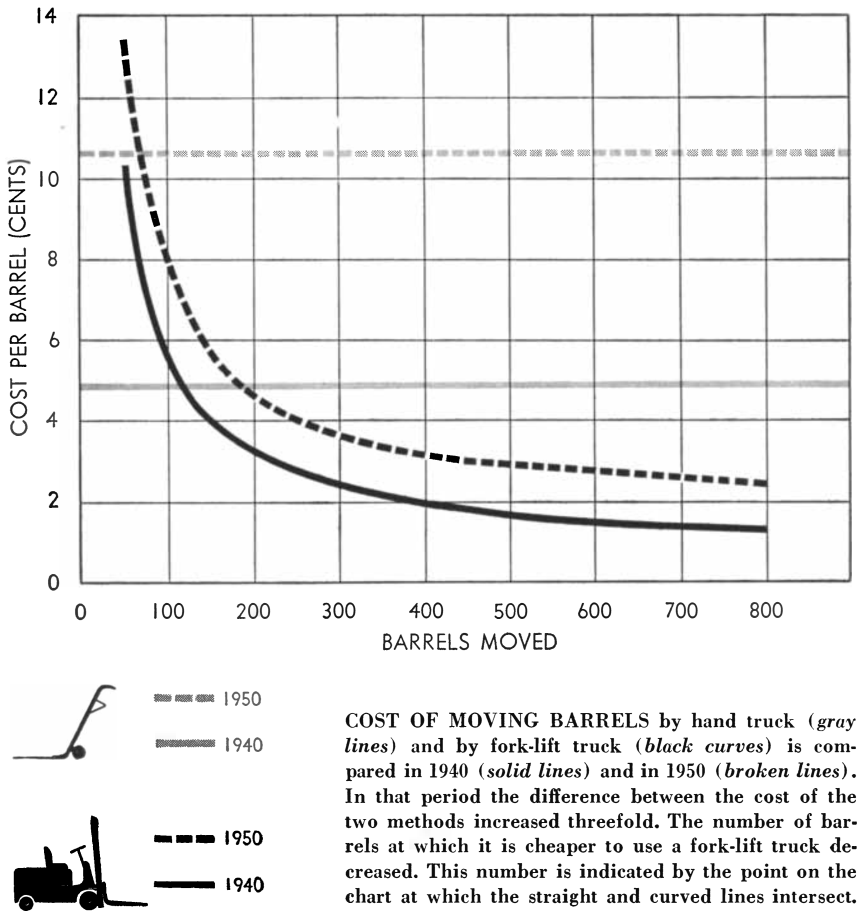
The procedure of the investigation was first to establish the variations in productivity, production methods, machinery cost and labor cost. This was done for different countries and for different times. The variations in productivity were already available in the considerable literature on the measurement of productivity. The information on production methods and costs was gathered by observations in industrial plants, especially in the automobile and allied industries of the U. S. and England.

The variation in production methods may be illustrated by the following example. An industrial management is confronted with the simple problem of moving steel barrels from one place to another. It has a choice of three methods: moving the barrels with a two-wheeled hand truck, moving them with a four-wheeled hand truck incorporating a hydraulic lift, or moving them with a motor-driven fork-lift truck. A man with the hand truck can move 17 barrels an hour; a man with the hydraulic-lift truck, 53 barrels; a man with the fork-lift truck, 120 barrels. The cost of the hand truck per hour is negligible, that of the hydraulic-lift truck is $1.60 and that of the fork-lift truck is $7.

At this point the management can relate these costs to the cost of labor. This can be done by means of a chart such as the one at the bottom of the next page. It may be seen from the chart that the cost of moving barrels by hand truck remains constant with the number of barrels moved. This is because the main component of the cost is the hourly wage, which does not vary with the number of hours worked. In contrast the cost of moving barrels by fork-lift truck rapidly decreases with the number of barrels. This is due to the fact that a large part of the cost of mechanized work is the charge of using the machine per day, which does not vary with the amount of work. Thus as more work is done per day the fixed charges are spread



COST OF MACHINERY is considered in terms of the number of steel barrels that may be moved by three alternative methods: a two-wheeled hand truck (*top*), a hand-drawn truck with four wheels and a hydraulic lift (*middle*) and a motor-driven fork-lift truck (*bottom*).



COST OF MOVING BARRELS by hand truck (*gray lines*) and by fork-lift truck (*black curves*) is compared in 1940 (*solid lines*) and in 1950 (*broken lines*). In that period the difference between the cost of the two methods increased threefold. The number of barrels at which it is cheaper to use a fork-lift truck decreased. This number is indicated by the point on the chart at which the straight and curved lines intersect.

over more units of output and the cost per barrel is decreased.

Now from 1940 to 1950 the average hourly earnings of production workers in American industry increased by 121 per cent (from $.66 to $1.46). In the same time the average cost per hour of using a motor-driven truck in this kind of work increased by only 18 per cent. This differential growth is plotted on the chart. The gap between the costs of these manual and mechanized methods had increased threefold at the midpoint of 400 barrels moved. Moreover, the volume at which machine methods were cheaper than manual had fallen. These cost changes in the U. S. depict the conditions that led industrial managements to mechanize such operations.

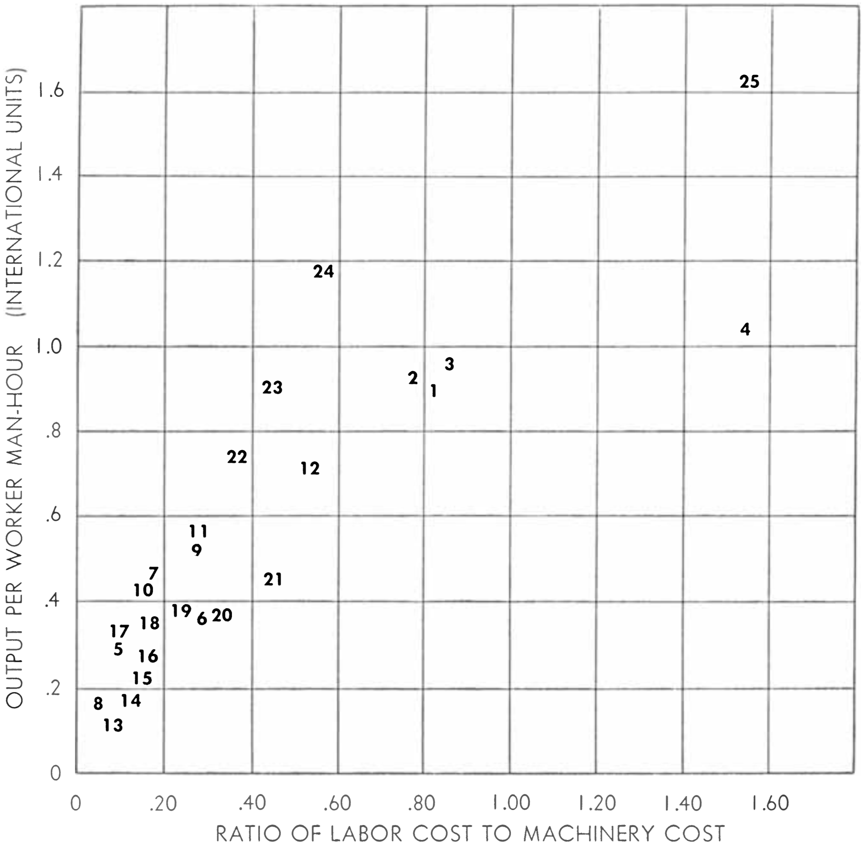
The same kind of cost chart can be drawn for British industry. The differences in the curves are traceable to the differences between U. S. and British labor and machinery costs. Thus in 1950 the cost of manual methods in England exceeded the mechanized cost by 137 per cent (at the 400-barrel mark), and in the U. S. the figure was 239 per cent.

The contrasts between the U. S. and England are most clearly revealed in the ratio of labor to machinery cost. In both countries the relative cost of labor to machinery has increased. The most striking feature of the comparison is the similarity between the labor-machinery ratio (.93) in the U. S. during 1940 and that of England (.99) for 1950. This similarity is made significant by the fact that the kinds of changes in industrial production methods being introduced in England about 1950 were the American innovations of about 1940.

How is it that in all countries the cost of labor rises faster than the cost of machinery? The trend is explained by the fact that the managements of firms which produce industrial machinery are themselves pressed by rising labor costs. In response they have introduced labor-saving work methods, with the result that comparable machines may be produced with fewer high-cost man-hours. Thus the increase in the price of the machines is not so great as the increase in the cost of man-hours. The relationship also holds among countries. In 1950 U. S. industrial workers were paid about four times as much as British workers. At the same time the prices of a sampled group of U. S.-made machines were not more than 60 per cent higher than the prices of comparable British machines.

Exactly how much of the variation in productivity can be explained by the ratio between labor and machinery costs? With statistical techniques developed by the British economist Colin Clark it was possible to estimate the industrial output per man-hour in various industrial countries at various times. The ratio between labor and machinery costs was estimated for the same countries. The figures for productivity and cost ratio were then compared for manufacturing industries in the U. S., England, Canada, Sweden, Norway, the U.S.S.R., Germany, Japan and France. The coefficient of correlation between the two sets of figures is .88. This indicates that about 78 per cent of the variation in productivity is explained by the variation in the cost ratio between labor and machinery.

The countries analyzed account for 75 to 80 per cent of the world's industrial output. They differ widely in whether their industries are controlled by private industry or government. Evidently the seat of top management is less important in the determination of productivity than the rules operating at the plant level.



1	CANADA	1936
2	CANADA	1938
3	CANADA	1939
4	CANADA	1949
5	FRANCE	1931
6	FRANCE	1938
7	GERMANY	1938
8	JAPAN	1938
9	NORWAY	1935
10	SWEDEN	1929
11	SWEDEN	1938
12	SWEDEN	1949
13	U.S.S.R.	1932
14	U.S.S.R.	1935
15	U.S.S.R.	1941
16	U.S.S.R.	1948
17	UNITED KINGDOM	1924
18	UNITED KINGDOM	1930
19	UNITED KINGDOM	1935
20	UNITED KINGDOM	1938
21	UNITED KINGDOM	1950
22	U.S.	1924
23	U.S.	1929
24	U.S.	1937
25	U.S.	1950

PRODUCTIVITY OF NINE COUNTRIES which account for 75 to 80 per cent of the world's industrial production is related for different times to the ratio between the cost of labor and the cost of machinery. The points on the chart tend to fall on the same band.

It should not be overlooked that factors other than the relative cost of labor and machinery affect productivity. Some of these, like the availability of power and raw materials, are expressed in labor and machinery costs. The effect of other factors is reflected by the 22 per cent of the variability in productivity not accounted for by the labor-machinery ratio.

Up to this point we have used the ratio to explain differences in productivity between similar industries in different countries. Plants within a single industry have also been analyzed. Here it was found that, machinery prices being similar for the managements of all the plants, productivity was a direct function of the average hourly earnings of production workers. The managements pressed by the highest wage rates have countered with the most vigorous moves in the use of labor-saving equipment and organization methods.

In the course of productivity studies it has been observed that a group of firms comprising a manufacturing industry requires about five years to alter a production technique extensively. Within this period the firms of an industry are ranged mainly according to the intensity of cost pressure to which the managements must respond. This factor alone, however, does not account for the variation in the speed of managerial response to cost changes. It must be appreciated that major revisions in industrial production methods also entail dramatic changes for the managerial occupations themselves. Like people in other occupations, managers are reluctant to make their occupational skills obsolete. The varying resistance of the managerial occupations to the change in their work affects the relative speed of change in production methods from firm to firm. This is at least as important as the more widely discussed reluctance of industrial workers to being rendered occupationally obsolete.

These studies of industrial productivity disclose that productivity levels are not the conscious goal of either management or labor. Productivity levels are not unilaterally determined by any one group in industry. Management and labor each attempt to deal with their own problems. The impact of their respective pressures compels each to find solutions for the problems that are caused by the other. Industrial workers try to improve their standard of living by pressing for a higher wage. This gives rise to cost problems for management. These cost problems compel management to revise the design of production methods. Thus productivity is primarily the derived effect of the wage pressure of labor and the cost-minimizing countermoves of management.

FRACTURES IN THE PACIFIC FLOOR

The bottom off northern California is broken by a cliff a mile high and more than 1,000 miles long. It is one of four immense fractures apparently due to the same massive deformation of the earth's crust

by Henry W. Menard

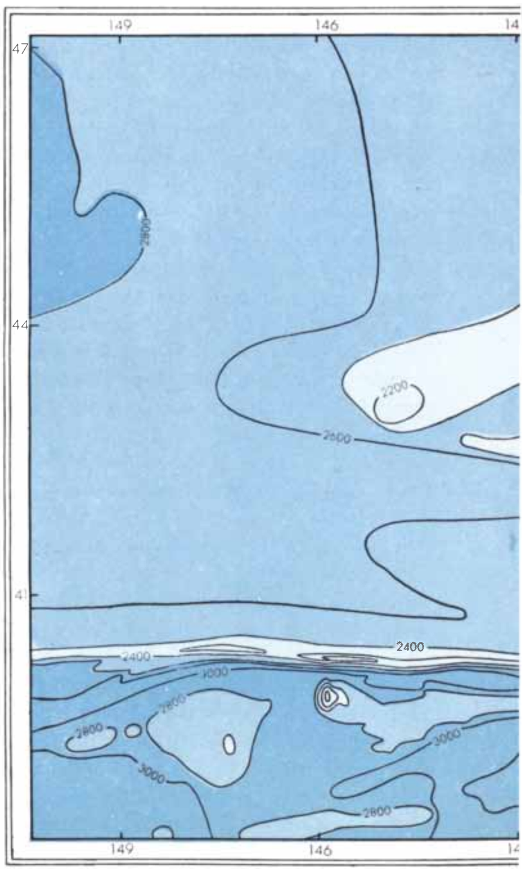
No island, rock, reef, or shoal rises above the abyssal waters between the Hawaiian Islands and the Continental U. S. When we travel over these featureless waters we tend to assume that the bottom is an equally smooth plain. Until relatively few years ago, in fact, geographers and geologists had such a picture. Their only information about this large chunk of the earth's solid surface came from a few soundings made with a heavy weight at the end of a wire. Today oceanographers on a research vessel plumb the depths by bouncing sound waves from the bottom, and it is possible to make millions of observations while the ship proceeds at full speed.

Into this well-traveled but little-known region the Scripps Institution of Oceanography and the U. S. Navy Electronics Laboratory have during the past six years pushed eight major expeditions and many shorter scientific voyages. They have discovered submarine mountains and cliffs which in size and extent are not matched anywhere else on earth. An interesting feature of these discoveries is that almost all of them were predicted before the exploring vessel left the dock.

Under favorable circumstances even geographical exploration can be attacked by the normal scientific method of hypothesis confronted by experiment. The approach was notably successful in the discovery of the Mid-Pacific Mountains during the Mid-Pacific Expedition in 1950. In the northeastern Pacific the scale of the discoveries has been even more impressive. The general nature of the topography at a point in the middle of an unsounded area 1,400 miles across was predicted and subsequently confirmed. This is roughly equivalent to predicting the Atlantic shore line at Norfolk when it has been explored only at Miami and Boston.

Beneath the waters off Cape Mendocino in northern California lies a long cliff a mile high. Called the Gorda Escarpment, it runs due east and west. As early as 1941 this impressive topographical feature had been traced for 70 miles from the shore. F. P. Shepard and K. O. Emery of the Scripps Institution had predicted that a similar escarpment extended at least 400 miles. By 1950 explorations of the U. S. Coast and Geodetic Survey had confirmed the existence of an escarpment for 300 miles. Although this was not known when the Mid-Pacific Expedition put to sea, it seemed that of all the northeastern Pacific the area due west of Cape Mendocino would be the most fruitful for exploration. Thus, on its way from the Marshall Islands to San Diego, the Scripps research vessel *Horizon* detoured far to the north to cross the region in four places. The crossings showed that the escarpment off Cape Mendocino extended due west for at least 1,000 miles. The steeper south side of the escarpment had an average height of about a mile. It was now named the Mendocino Escarpment.

During the Northern Holiday Expedition of 1951 the *Horizon* crossed and recrossed the Mendocino Escarpment 18 times. ("Holiday" is a nautical term referring not to a vacation but to a blank or unexplored area.) This voyage revealed a mountainous ridge at least 1,400 miles long and from 3,300 to 10,500 feet high on its steep south side. Its western end has still not been found. Although features of this scale do not exist on dry land, we can visualize the Mendocino Escarpment in terms of the Sierra Nevada in California. Imagine that the whole Sierra Nevada is lifted bodily, turned so that its steep side is on the south, and submerged two miles. Multiply its length by four and you have the Mendocino Escarpment. South of the Escarpment are parallel ridges and troughs resembling the Panamint Range and Death Valley on the east side of the Sierra Nevada. North of the great submarine ridge the sea floor for hundreds of thousands of square miles is about



MENDOCINO ESCARPMENT is traced for 1,200 miles by this topographic map of the

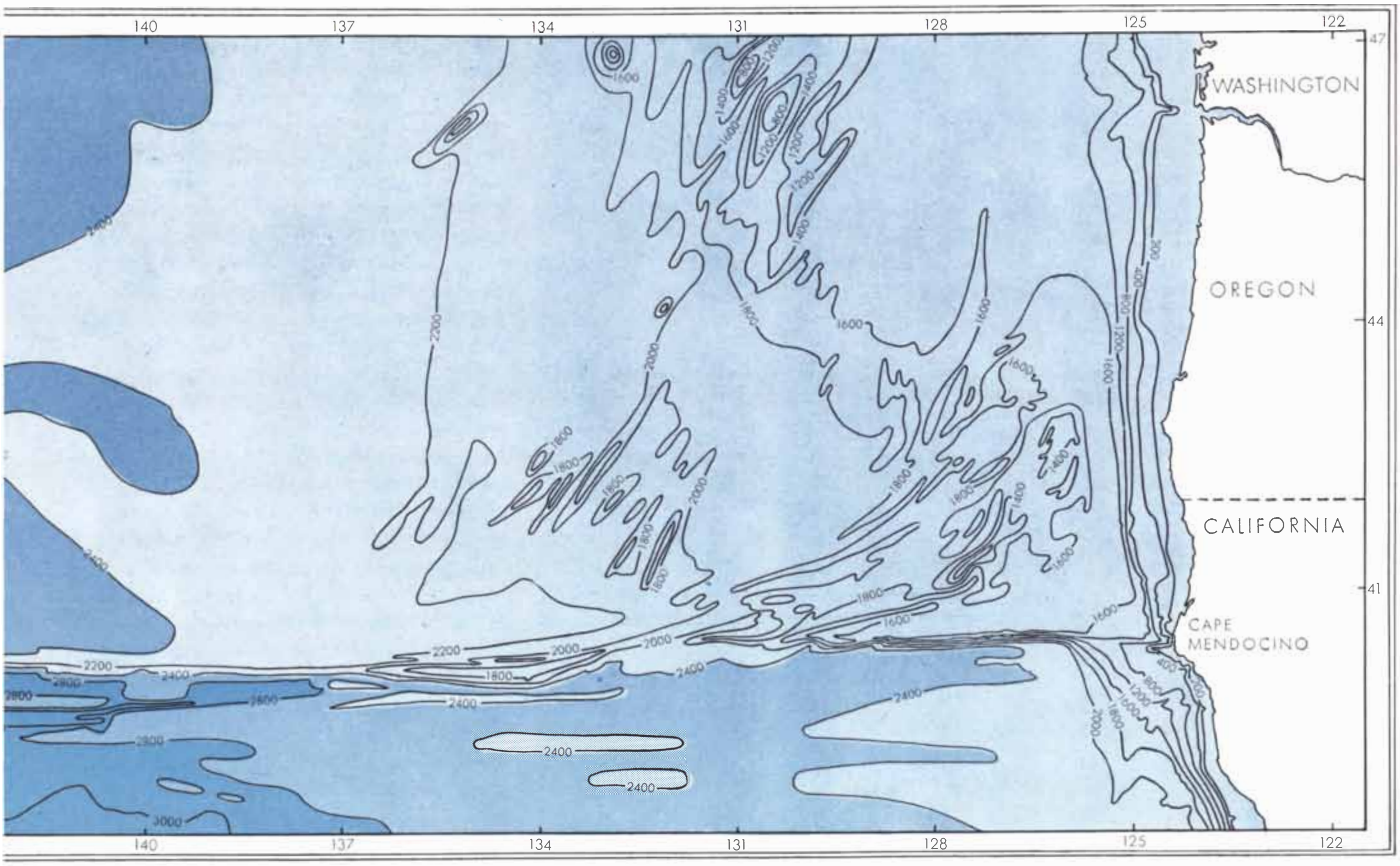
half a mile higher than the floor to the south. There is an analogous difference in the elevation east and west of the Sierra Nevada.

The fact that the Mendocino Escarpment runs east and west was of special interest to geologists who have studied the topography of southern California. Most California mountain ranges run northwest and southeast, but the Transverse Ranges (including the Santa Monica and San Gabriel mountains of the Los Angeles area) are oriented east and west. This exception to the pattern of the California ranges has long puzzled geologists. Now they wondered: Could the Santa Monica and San Gabriel ranges mark the end of submarine mountains running parallel to the Mendocino Escarpment?

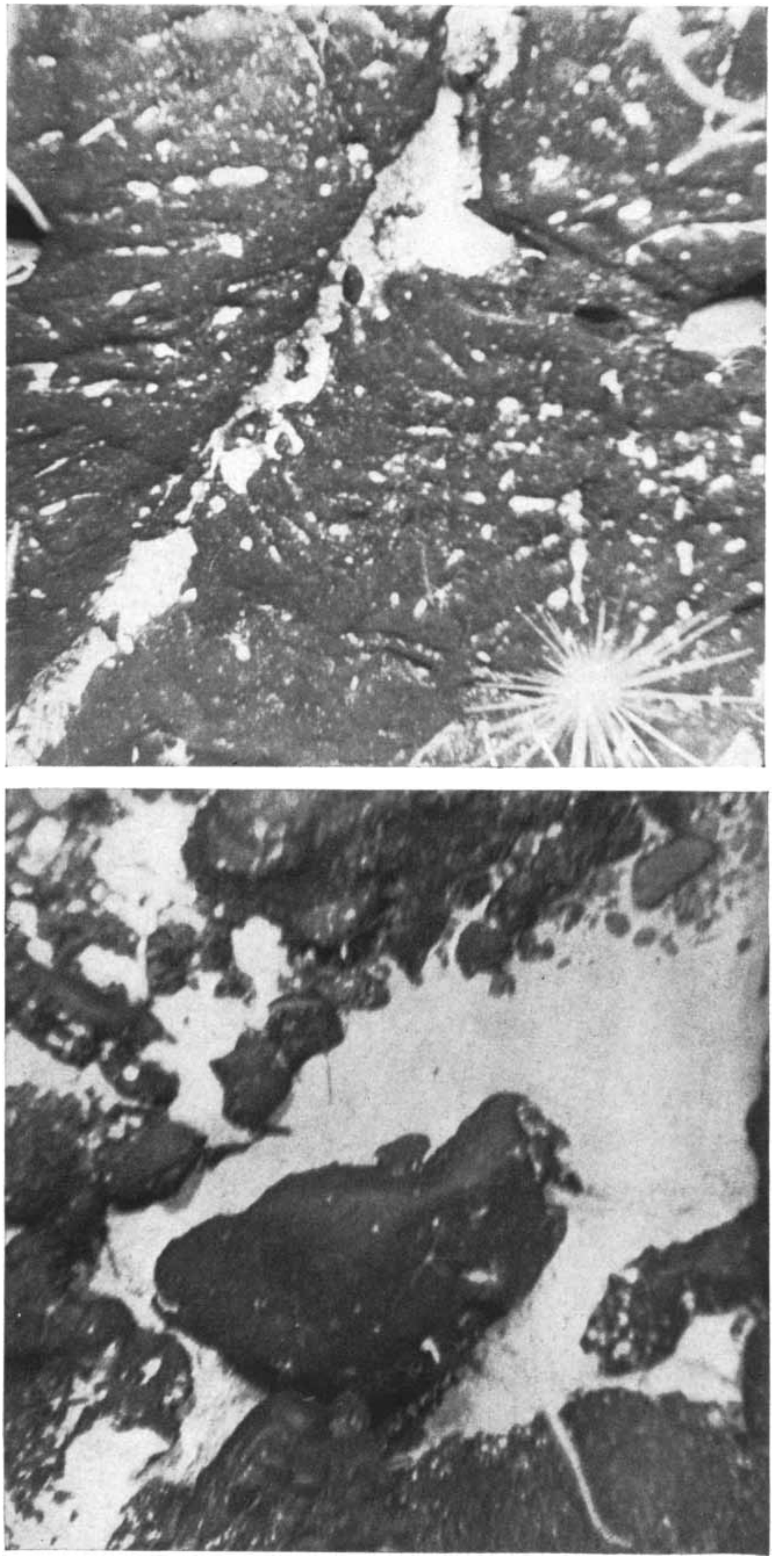
During the concluding stages of the Northern Holiday Expedition the *Horizon* zigzagged 10 times across the waters off southern California. The vessel traced a range of mountains with one main escarpment for 1,200 miles. On a Mercator projection of the earth the Mendocino Escarpment follows a straight line for 1,200 miles; the new range ran in a gentle curve. However, the western 200 miles of the Mendocino Escarpment bends to the south, and here the two features were parallel.

The new range was called the Murray Fracture Zone, because its main escarpment represents a sharp break in the earth's crust. The Mendocino Escarpment may also be regarded as such a fracture. One of the most interesting characteristics of the two fracture zones was discovered quite by accident. In order to meet a critical arrival date during the Capricorn Expedition of 1952-53, the *Horizon* and the *Baird* had to make a quick voyage between San Diego and the Marshall Islands. The shortest course between the two points follows a "great circle," which is a straight line on the spherical surface of the earth. For the convenience of navigators the U. S. Hydrographic Office issues charts on which great circles are plotted as straight lines. In order to use their shortened voyage most effectively, the planners of the expedition plotted prominent underwater features of the northeastern Pacific on such a chart. To their surprise they found that the Murray Fracture Zone itself followed a great circle between San Diego and the Marshall Islands! The apparent curve of the Zone was caused by the distortion of a Mercator map. On the earth's surface the Zone followed a straight line.

Only a few extra hours of sailing time were needed to make 17 new crossings of the main escarpment and the surrounding mountains. The total of 27 crossings now showed that the Murray Fracture Zone follows a great circle for 1,900 nautical miles across the deep-sea floor and into southern California. The Murray Escarpment is as high as 7,000 feet and at least 1,000 miles long. It resembles the Mendocino Escarpment except that its great cliff faces north rather than south. Farther to the west the Murray Fracture Zone forms a vast gash in the earth's crust. Thirty miles wide, the gash separates two great mountain ranges. It is a landscape resembling the famous rift valleys of central Africa, in which long, thin clefts filled with lakes are in many places bordered by ridges. One of these is the Ruwenzori Mountains, the mysterious range which



bottom off Cape Mendocino in northern California. The Escarpment is represented by the narrow band of contours running from left to right near the bottom of the map. The contours are numbered in fathoms below the surface of the sea. One fathom is six feet.

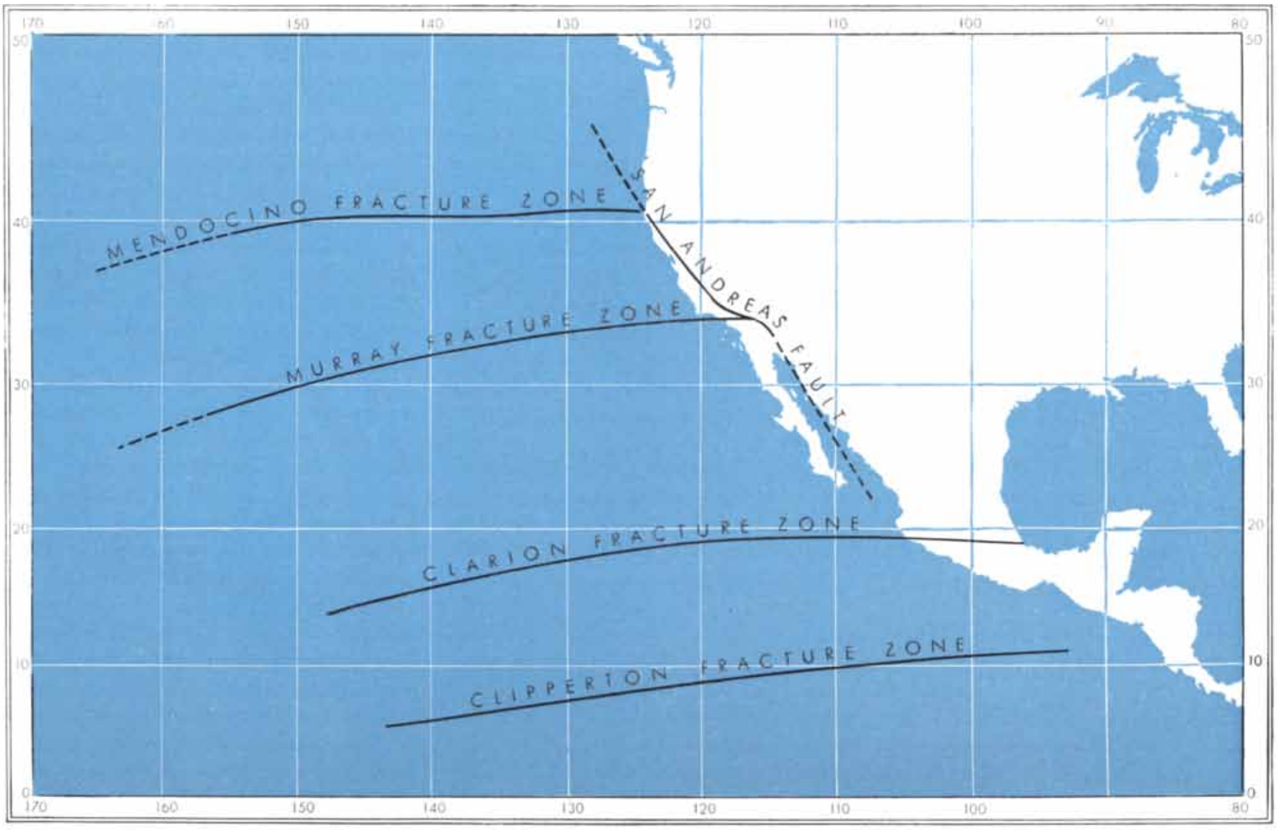


UNDERWATER PHOTOGRAPHS of Fieberling Seamount, a submarine volcano in the Murray Fracture Zone, were made at a depth of 1,650 feet. The top photograph shows the dark rock of the volcano. The bottom photograph shows white sand lying in depressions.

Ptolemy called the "Mountains of the Moon." The Murray Fracture Zone resembles the African rift zone in another way: it contains majestic volcanoes. The volcanic peaks of central Africa are so high that, although they lie on the Equator, they are capped with snow. The volcanoes of the Murray Fracture Zone are drowned by the sea, but they are just as high. Concealed in the black abyssal depths, they might be called the "Moonless Mountains."

One of these submarine volcanoes called Fieberling Seamount has been photographed at a depth of 1,650 feet with a Navy Electronics Laboratory deep-sea camera. The photographs show the scarred lavas of the volcano and some white patches of sand. Some of the patches are covered with ripple marks, proving that water movements capable of disturbing sediment occur deep in the sea. The ripple marks support much other evidence which indicates that the floor of the ocean is not the eternally calm place imagined by 19th-century oceanographers.

At least some of the "Moonless Mountains," which are now 1,000 to 5,000 feet below sea level, were once islands dotting the surface of the northeastern Pacific. Two of the peaks have flat tops rather than the pointed silhouettes of ordinary volcanoes. Most geologists accept the notion that peaks with this form are ancient islands which were planed flat by the surf. Rounded stones dredged from Fieberling Seamount comprise a gravel which appears to have been made on an ancient beach. There is no other direct evidence that any of the "Moonless Mountains" were once islands. But conclusive information is found in another area, the Mid-Pacific Mountains west of Hawaii. There the remains of shallow-water corals and other fauna have been dredged from flat-topped seamounts almost a mile deep. Fossils have also been dredged from Erben Seamount in the Murray Fracture Zone, but they do not indicate the depth at which they lived. They do show that by the middle of the Tertiary Period, perhaps 30 million years ago, Erben Seamount ceased to exist as an island. At present it is not clear whether the island sank or the sea level rose. Samples dredged from seamounts or removed from borings on atolls seem to show that the older islands and seamounts are deeper, which suggests that the sea level rose gradually. On the other hand, flat-topped seamounts of the same age or in the same group are not necessarily at the same



FOUR FRACTURE ZONES are plotted on this Mercator projection of the northeastern Pacific and North America. At the eastern end of the two northern zones is the San Andreas Fault. The Fault is extended to the north and south by evidence from earthquakes.

depth, suggesting they may have sunk. This intriguing problem cannot be solved without more facts.

In 1949 the U.S.S. *Serrano*, on a Pacific cruise for the Navy Electronics Laboratory, sounded a relatively small depression a few miles wide and about 2,000 feet deep. No similar feature was known in the Pacific; indeed, local depressions are uncommon on the sea floor because they become filled with sediment. Two more depressions, one about 5,000 feet deep, were discovered 1,000 miles apart by the Mid-Pacific Expedition of 1950. All three of the depressions lie along a great circle almost parallel to the Murray Fracture Zone. They are about twice as far south of the Murray Zone as the Murray Zone is south of the Mendocino. Were these widely separated depressions part of one long, thin, straight trough? In this case it was possible to confirm the continuity of the trough by plotting old spot soundings on a great-circle chart. Almost all of the apparently inaccurate deep soundings in the area lie on the same line as the three deep depressions.

The trough now appears to be merely the westernmost section of a fracture zone 3,000 miles long. Long, narrow mountain ranges flank the trough, and in most particulars the western part of this fracture zone resembles the western part of the Mendocino and Murray fracture zones. The trough is at least 1,350 miles long and as deep as 5,400 feet below the crests of the adjacent ridges, or 3,300 feet below the average depth of the sea floor in the area. If we project the trough to the east, it is interrupted by submarine volcanoes and possibly by relatively flat portions of the sea floor. If these interrupted troughs are added to the continuous trough to the west, the total length of the trough is 1,700 miles. In that distance the path of the fracture zone deviates from a straight line on the earth's surface by no more than 15 miles—which is about the magnitude of the sounding and mapping error. Just east of the intermittent troughs and submarine volcanoes and along the same straight line lie the Revilla Gigedo Islands, a group of four volcanoes which have risen from the deep-sea floor. The third fracture zone bears the name of Clarion Island in this group. The great volcanoes of central Mexico lie to the east of the Revilla Gigedo Islands along the same straight line. The gradual eastward trend from a continuous trough to a trough interrupted by submarine volcanoes to a line of volcanic islands to a line of continental volcanoes leaves little doubt that all lie on the Clarion Fracture Zone. Like the Transverse Ranges of California, the Revilla Gigedo Islands and the volcanoes of central Mexico run east and west, violating the symmetry of other features in the region. The anomaly is readily explained if we assume that the island and continental volcanoes are a part of a submarine fracture zone and that the other mountains of central Mexico reflect a process of continental geology.

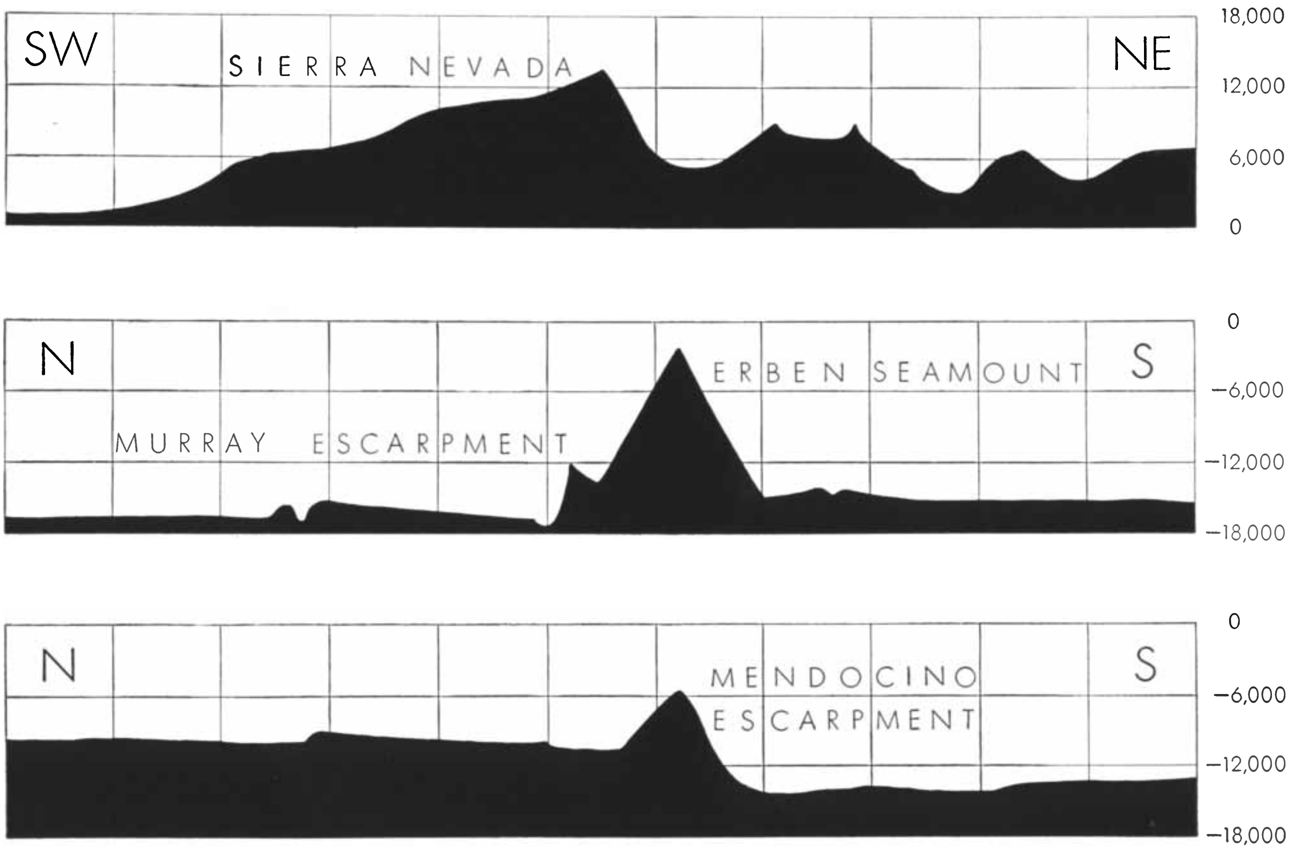
A fourth fracture zone lies along a straight line parallel to the Murray and Clarion fracture zones. It is about as far south of the Clarion Fracture Zone as the distance between the Mendocino and Murray zones. The fourth zone was discovered by the *Horizon* during the Shellback Expedition of 1952. Its existence was confirmed by widely separated soundings during the Shuttle Expedition of 1952 and the Capricorn Expedition of 1952-53. Were it not for its relation to the other fracture zones, the existence of this zone—named Clipperton after Clipperton Island—would be in doubt because the relief of its mountains and troughs is only 1,000 to 2,000 feet. To date the zone has been traced for 3,300 miles along a great circle.

There is little doubt that these four huge fracture zones resulted from some massive deformation of the earth's crust. We find evidence for this presumption both in the crust itself and in the laboratory. When we compress a brittle material in a laboratory machine, we find that the material tends to shear along a network of lines at an angle to the direction of compression. The angle between the axis of compression and the shear plane never exceeds 45 degrees. When the earth's crust is subjected to a local stress, it appears to behave like a brittle material. Where we know that the crust has been compressed in a certain direction, we often find symmetrical fractures (faults) at angles of less than 45 degrees to this direction. On the other hand, recent studies by the Dutch geophysicists P. P. Bijlaard and F. A. Vening Meinesz indicate that if the crust is stressed over a large area and in depth, its deformation is not brittle but plastic. If the material in the laboratory is confined under high pressure and then compressed by a slightly greater pressure on one side, the material will not fracture but will flow like putty. Some materials are initially deformed in a network of lines that mark narrow bands in which plastic yielding is localized rather than spread throughout the whole piece of material. If the stress is continued, shear planes may develop along one or more lines of the network. Shear planes produced in this way are symmetrical, but the angle between shear plane and stress may greatly exceed 45 degrees. Usually it is about 55 degrees.

Neither the whole pattern of the fracture zones in the northeastern Pacific nor the details of their topography indicate whether they were produced by brittle or by plastic deformation. The pattern would give such an indication if complementary shear planes could be found. Then the angle between the fracture zones and the complementary shear planes would provide a clue as to the type of deformation. Because no complementary shear zone has been located in the northeastern Pacific, one was sought on the adjoining land.

The San Andreas Fault is the only feature on the west coast of North America that resembles a fracture zone. This famous fault has been mapped only in California. However, it is associated with frequent earthquakes, and these occur along a line that continues out to sea to the northwest and southeast. If we include these submarine sections, the San Andreas Fault extends for about 2,000 miles from west of Oregon through California to the southern tip of the Gulf of California. It is remarkably straight except for one bend which occurs where it crosses the Murray Fracture Zone. It crosses the Coast Ranges of California with an apparent disregard for the stresses that formed them. The San Andreas Fault appears to be a fracture zone resembling the submarine zones of the northeastern Pacific but with a complementary orientation.

We may now venture the statement that plastic rather than brittle deformation produced the fracture zones. We must assume that the fracture zones and the San Andreas Fault were produced by the same stresses. We know that during earthquakes the crust on the west side of the fault slips northward along the east side. This movement requires a

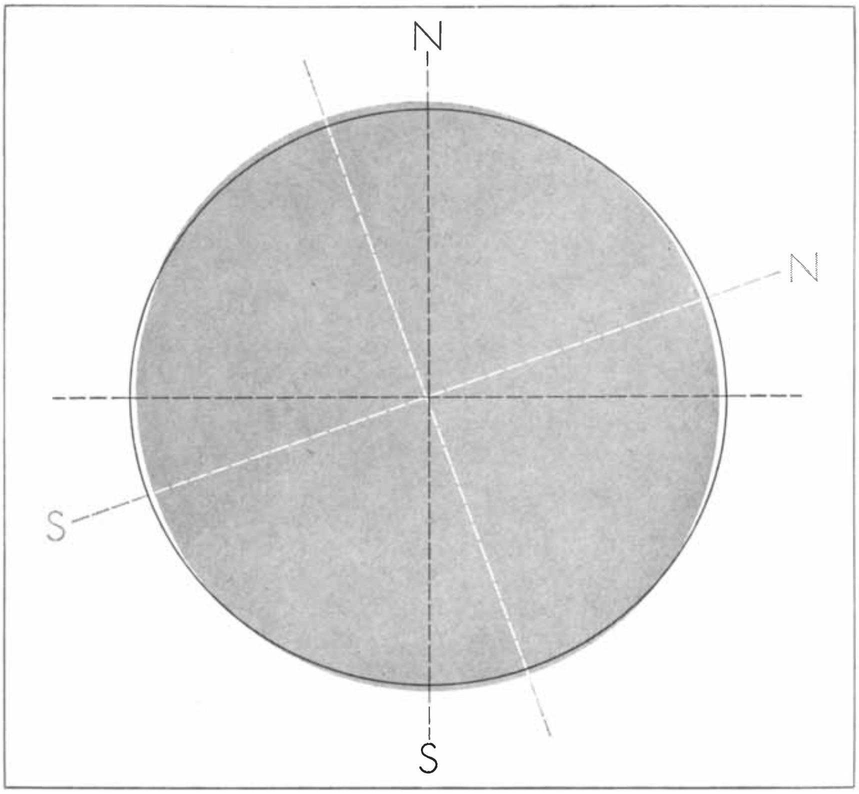


CROSS SECTIONS of the Sierra Nevada, the Murray Escarpment and the Mendocino Escarpment are compared. The vertical scale is in feet. The horizontal intervals are 10 miles. The direction of each section is indicated by the letters at the left and the right.

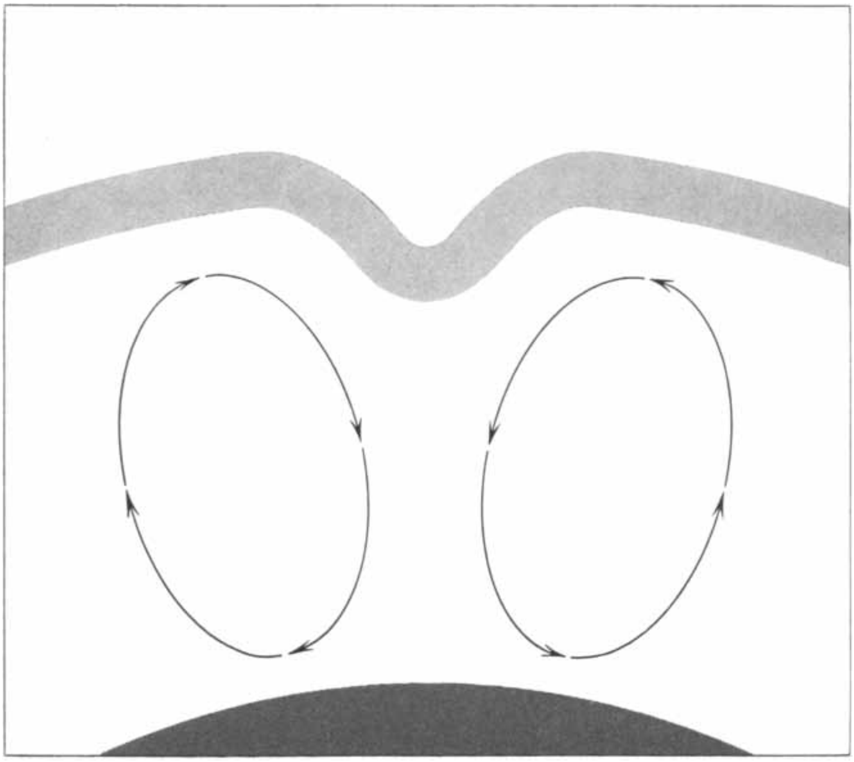
horizontal compression of the crust in a northerly or northeasterly direction. We can now fix the direction of compression more accurately because in northern California it bisects the angle between the San Andreas Fault and the Mendocino Fracture Zone, and in southern California it bisects the angle between the San Andreas Fault and the Murray Fracture Zone. In both areas the orientation of the compression determined in this way is from 25 to 30 degrees east of north. The angle between the line of compression and any one of the fracture zones is approximately 60 degrees. Consequently the deformation cannot have been brittle.

This brings us to the most interesting question raised by the discovery of the fracture zones. What produced the mighty stress which deformed an area of eight million square miles, or about 5 per cent of the earth's surface? At present we have two plausible hypotheses, but there are doubtless many others. Vening Meinesz has proposed that not long after its formation the earth's crust migrated over the underlying mantle. (This has nothing to do with the hypothesis that the continents "drifted" in comparatively recent geological time.) He finds that the great linear features of the crust are statistically correlated with the shear planes that would have been produced by plastic deformation if the North Pole had moved from near Calcutta to its present position. The shear planes plotted by Vening Meinesz closely correspond to the Mendocino and Murray fracture zones and the San Andreas Fault. They do not correspond to the Clarion and Clipperton fracture zones at all. However, only a slight deviation in the path of the polar migration proposed by Vening Meinesz would be needed to account for the last two fracture zones by a second deformation of the crust. We may conclude that the fracture zones may just possibly be due to the migration of the earth's crust over the mantle two to three billion years ago.

A second hypothesis is that the fracture zones may have been formed in more recent geological times by huge convection currents beneath the crust. Such currents might occur if hot material deep in the earth slowly rose, and cooler material nearer the surface sank. There are many reasons to believe that these convection currents exist, but they have never been confirmed in the mantle by direct evidence. If they do exist, they might exert a drag on the underside of the crust that would cause fractures.



ONE HYPOTHESIS on the origin of the stresses that caused the fracture zones is that the North Pole migrated to its present position (*top*) from a point near Calcutta (*right*). This might in turn have caused the crust of the earth to migrate over the underlying mantle.



ANOTHER HYPOTHESIS is that convection currents (*arrows*) in the mantle exerted a drag on the bottom of the crust (*top*). The buckling of the crust is greatly exaggerated.

A Forgotten Nation in Turkey

Three thousand years ago the Hittites pushed south to invade Syria and Mesopotamia. They were unable to subdue their powerful western neighbor Arzawa, the remains of which are only now being excavated

by Seton Lloyd

For 1,000 years the major part of Turkey that lies in Asia has been called Anatolia. This bridge of land that connects Asia to Europe consists of a high central plateau that breaks down on three sides into deep valleys and mild climates. To the east of the plateau the sickle-shaped curve of the River Halys embraces a wide province. Here, half a century ago, a dramatic event took place that marks an epoch in archaeology.

In this province, near the little Turkish village of Boghazköy, lies an impressive ruin of fortress walls and sculptured gateways. It had long been recognized that these were the remains of a very large ancient city, but it was not until 1906 that the German archaeologist Hugo Winckler sought a clue to the identity of its builders. Winckler's excavations met with almost instantaneous success. In a high citadel overlooking a wide panorama of ruins he unearthed long, parallel storerooms packed with cuneiform tablets. These were the royal archives of a dynasty ruling a considerable empire during the two centuries between 1400 and 1200 B.C. It was thus that the Hittite kingdom of eastern Anatolia became a historical reality. The Akkadian script in which the tablets were written was already familiar to philologists, and when, soon afterward, the actual language of the Hittites was deciphered, a wealth of information was obtained from these official records. During the years that followed much more was learned from the excavation of temples, shrines and private houses in

MOUND OF BEYCESULTAN in southwestern Turkey was excavated in the search for the remains of an Arzawan city. In the foreground is the foundation of the large palace described in this article.

ROOM OF PALACE is surveyed. The palace dates back to about 1400 B. C.

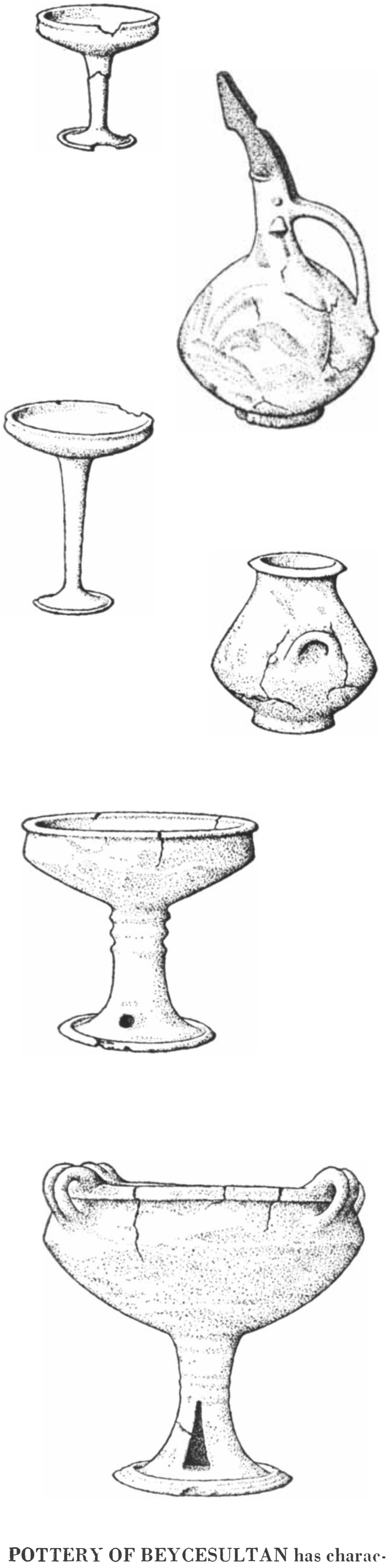
other parts of the city. The sites of other cities within the Hittite dominion were discovered. The Hittite kings had left monuments sculptured on rocks in remote parts of their realm, and these too were studied. The sequence of discoveries initiated by Winckler at Boghazköy has led today to a large body of knowledge about this ancient and remarkable people; about their origins, their everyday life, their laws, their religion, their art and architecture. In the final analysis, however, this great work may have lent the Hittites a significance out of proportion to their actual role in the contemporary history of the Middle East.

In the Hittite kings' own record of their political and military history one fact is abundantly clear: they never succeeded in gaining permanent control of more than the eastern half of Anatolia. From there the Hittite armies thrust southward into Syria, where they found themselves in conflict with Egypt, or marched into Mesopotamia, where they briefly held Babylon. To the West, Hittite efforts at expansion were continually thwarted by neighboring powers. It is these non-Hittite states with which the archaeology of Anatolia is now most deeply concerned. One such state is Assuwa, which occupies the whole of northwestern Anatolia and presumably included Troy of the Homeric legends. Another is Arzawa in southwestern Anatolia, a nation which appears to have been the military equal of the Hittites and may well have exceeded them in cultural attainments.

The freak of archaeological fortune that has thrown such brilliant light on the Hittites has left Assuwa and Arzawa in utter darkness. Nothing is known of them save what can be learned from patronizing and tendentious references in the records of their Hittite enemies. Until recently the only major excavation undertaken in Assuwan territory was on the site of Troy. This enterprise, first taken up by the famous German archaeologist Heinrich Schliemann and later continued by the American Carl W. Blegen, primarily revealed that the remains of the Homeric city had been removed by the Romans to make the foundation of a colossal temple. Our archaeological knowledge of Arzawa was confined to a single village excavated in the 1930s by an English woman scholar, W. Lamb. Now, 20 years later, it is once more an English expedition that has taken up the search. Its objective is an all-out attempt to extract from the soil of western Turkey some tangible evidence giving substance to the phantom of Arzawa.

At the British Institute of Archaeology in Ankara we were fortunately in no doubt as to the best line of attack. Until now all attempts to reconstruct the geography of the Arzawan frontiers had depended upon the sometimes rather confused accounts of military campaigns conducted by the Hittite kings. The results were indecisive or contradictory; it was clearly time that they should be checked against the actual remains of antiquity. At this point we found invaluable some reconnaissances that had already been carried out by our own students. One of them, James Mellaart, had spent many months in a one-man archaeological survey covering almost the whole southwestern quarter of Anatolia. Traveling on foot from village to village, Mellaart had located many of the mounds that in this country mark the remains of ancient settlements, and he had studied the pottery and small objects with which the mounds were littered. Such evidence enables the archaeologist to fix the historical periods during which a settlement has been occupied; one result of the survey was a series of maps showing the distribution of towns

It was destroyed by a fire so intense that some of its foundations were calcined into a white powder.



POTTERY OF BEYCESULTAN has characteristic "champagne-glass" (*first and third from the top*) and "fruit-stand" (*fifth and sixth*) shapes. Second and fourth from the top are other vessels from the excavations.

FIVE NATIONS of Hittite times are roughly outlined on this map. In addition to the Hittite homeland they are Gasgas, Izzuwadna, Assuwa and Arzawa. Arzawa proper lay between Beycesultan and Lake Egridir. On Rhodes and nearby islands were Mycenaean set-

and villages during successive periods in history.

Most interesting to us was the map of the area during the Hittite period. From this map emerged a thickly populated and prosperous province extending from the longitude of Lake Egridir westward to the Aegean Sea. For the moment its most characteristic archaeological features were graceful "champagne-glass" drinking cups and "fruit-stand" vases, and these could only be reconstructed from broken fragments. But the province distinguished by their use closely corresponded to the location assigned to Arzawa by scholars who had studied the written evidence. For us, at least, Arzawa it provisionally became.

The next problem was to decide which of the many mounds in the Arzawan area offered the greatest promise to the excavator. On Mellaart's map the mounds seemed to be concentrated in the Çivril Valley, an upland irrigated by the headwaters of the River Meander. In the center of the valley, where an age-old trade route must have crossed the river by bridge or ford, Mellaart's field notebook described an enormous mound called Beycesultan. Estimating its diameter at more than 1,000 yards, he had noted innumerable fragments of "Arzawan" pottery lying among the grass and spring flowers. He had inferred that the site had not been occupied later than the 13th century B.C. On the summit of the mound he had found a few blocks of masonry; these reminded him of Hittite structures at Boghazköy. A reconnaissance from the Institute in Ankara settled the matter. The mound represented at least a provincial capital of the Arzawan state, and we decided to excavate immediately.

Our decision was made in 1953, but the work could not begin until the winter rains were at an end in the spring of the following year. I arrived at the site alone in the first days of May, and by the time the main expedition joined me a week later I had already done some exploratory digging. The prospect was not reassuring. The mound had two summits, and I had chosen the westernmost for a first trench. We dug to a depth of about four feet without encountering anything more interesting than the remains of buildings dating from the Byzantine period, 2,000 years later than the presumed disappearance of Arzawa from Anatolian history. I could not know then, as we do now, that for a short time in about the 11th century A.D. this part of the hill had been occupied by a miniature Christian city.

Our luck turned within a few hours of my colleagues' arrival. Digging through the Byzantine buildings, we came upon a terrace of little houses dating from the 13th century B.C. They had clearly been destroyed in some great conflagration: buried beneath the fallen roofs were household goods abandoned by the fleeing inhabitants. To our great excitement these goods included many "champagne glasses" and "fruit stands," fragments of which had until now been our most precious clue to the Arzawan culture. Here they were intact and unbroken, testifying to the taste and craftsmanship of the Arzawan people. We had attained our first objective.

The walls of the houses had been built

tlements. Ancient sites are indicated by triangles; modern cities and towns, by dots.

of brick and timber on a stone foundation, and had had small wood-columned porticoes opening onto courtyards. Among the tangle of fallen beams and broken household goods were the charred skeletons of at least two individuals who had been unable to escape from the burning buildings. We now know that the conflagration destroyed the whole settlement in about 1230 B.C.

We were conscious that all we had discovered so far were the modest dwellings of private individuals. Some major public building must next be sought, so during the second week a gang of workmen was detached to investigate the eastern part of the mound. One of our first trenches, cutting into the flank of the hill, struck an enormous mass of calcined limestone and burned brickwork, which for the moment we mistook for the remains of some sort of kiln. It soon became clear that these were the ruins, again destroyed by fire, of a palace. The plan of this very large structure began to take shape as chamber after chamber was cleared of ashes and debris. Their excavation was no easy task, because the roof beams and wooden framework of the walls had burned with tremendous intensity. Some of the limestone foundations had even been calcined by the heat into piles of white powder. We nonetheless uncovered during the next few weeks an area about 100 feet square, and gradually we began to understand the plan of this very interesting building. To our surprise it seemed to share many features in common, not with the architecture of the Hittites, but with the Minoan palaces discovered by Sir Arthur Evans and others on the island of Crete. Evidence later uncovered suggested that it might have been built late in the 15th century B.C., at about the time that the Cretan city of Knossos was destroyed by the Mycenaeans and its inhabitants dispersed. We wondered whether some Cretan architect, eventually reaching the mainland of Anatolia, had been employed to design it.

At one entrance to this building was a sunken "lustral area," where visitors made formal ablutions on arrival; it was surrounded by tall "pithos" jars for water. Then there were rooms with traces of frescoes on the walls; long, parallel storage chambers with cobblestone floors; emplacements for huge circular metal cisterns; and elaborate staircases once leading to upper floors. One of the strangest features of the structure was that the principal chambers had floors raised about a yard above the ground level; beneath the floors were small passages extending all around the rooms. The passages in various rooms were also connected beneath the thresholds of the doors. Since these passages were not high enough for a man to stand up in them, it was hard to understand their purpose. If the building had been put up 1,000 years later, we would immediately have concluded that they were air ducts for heating purposes.

The part of the palace so far excavated was clearly only a single wing of a much larger building; trenches made later revealed that it must cover the whole summit of the hill. But meanwhile we had encountered a characteristic archaeological setback. Our excavation of the burned palace had so far proceeded easily, owing to the fact that there were no remains of later buildings. Now, as we cut into the hillside, we suddenly reached the outer wall of a smaller palace, built over the burned ruins of the older one at a later date. This structure was contemporary with the private houses that had been our first discovery on the western hill. What remained of our excavating season had therefore to be spent in clearing and recording the minor building, and the excavation of its predecessor was reluctantly postponed until 1955.

But now came the equally characteristic compensation. The old palace had quite evidently been burned only after it had been thoroughly looted. During its excavation we had thus discovered very few objects of any interest. With the smaller palace the case proved to be quite otherwise. The architecture of the building, with its well-preserved wooden doorframes and columned porticoes, proved interesting enough in itself; but separated from the palace by a paved street we were pleasantly surprised to find a row of shops.

One of these had a little terrace and was evidently a wineshop, since it contained the remains of a remarkably modern-looking bar. Behind the bar were two sunken terra-cotta winevats and a pile of "champagne-glass" drinking cups. There was also a heap of 77 knucklebones of the sort used immemorially in eastern countries for a game of chance, and a score or so of the crescent-shaped clay tokens for the same game. But the greater part of the space outside the bar was occupied by eight human skeletons. One of them was that of a woman who had been struck on the head, and we could imagine that, during some military violence, the party had taken refuge in the tavern where they had eventually met their death.

Next door was some sort of food shop, surrounded by huge terra-cotta storage vessels still full of various grains. Standing as high as a man's shoulder, they must have been filled and emptied from a wooden gallery above, for we found the little staircase leading up to it. There was also the charred remains of a wooden grain bin, and, hardly displaced from its position on the bin's closed lid, a great basin containing a complete "dinner service": wine jugs and "fruit stands" with a dozen bowls nested inside each other. The room contained more than 60 pottery vessels of every kind, and provided us with at least one example of every domestic utensil used at the time.

All this pottery had a particularly striking and unusual character, owing to the color and quality of its finished surface. Almost all the vessels from the wineshop were a deep orange-red; those from the food shop were black. But when we examined the vessels more closely, we saw that "black" and "red" inadequately described them. The clay "slip" which

WINESHOP was found adjacent to a smaller palace built atop the large one. At the right are wine cups. At the left are the skeletons of people who died when the shop was burned.

FOOD SHOP was also adjacent to the smaller palace. Here a worker shovels carbonized grain from a large vessel. The grain was burned in the same fire that destroyed the wineshop.

gave the vessels their final finish had been mixed with some metallic ingredient that produced a lustrous effect. Thus the red vessels were a very good imitation of bronze, while the black wares, which had been darkened by the destructive fire, still held the gleam of tarnished silver.

In the street between the little palace and the shops we came upon a few fragmentary sherds of Aegean painted pottery of the type known as Mycenaean IIIB. With these this whole period in the history of the Beycesultan city could be dated approximately 1230 B.C. Thus our upper-level buildings—the Little Palace, the shops and the private houses—were destroyed by fire in some military campaign about a generation earlier than the Trojan wars. At this time the sea power of Mycenae, the civilization which preceded that of classical Greece, was at its height in the Aegean. Yet here in Arzawa no imported Mycenaean goods appeared to be in use. The only links with the Aegean which we discovered were a number of rather beautiful Mycenaean weapons, which, since they had clearly been broken or discarded in battle, might have belonged either to the attackers or the attacked. This is perhaps partly explained by Mellaart's map of the settlements of this period. We see that, while the islands off the Aegean coast are packed with Mycenaean towns and villages, the mainland coast (with the exception of a single Mycenaean colony at Miletus) is completely blank. Could this not be an indication of a state of war between Anatolian Arzawa and the seagoing peoples of the Aegean?

Many historical speculations of this sort arise from the results of our first season's excavations at Beycesultan. But at this early stage in our work most of them must remain speculations: they can only be changed into historical certainties by the discovery of actual written documents bearing on political and military events. This is by no means an exaggerated hope. The possibility that the Arzawans were illiterate is already ruled out by the copies that have survived of their correspondence with Hittite kings and even with an Egyptian pharaoh. They spoke Luvian, a tongue slightly earlier in the Indo-European series than Hittite (Nesian). An archive of Luvian documents would now be a most welcome discovery. We have every hope that a royal palace covering several acres is a likely place to find such an archive. We look forward to the resumption of our excavations at Beycesultan this year.

Kodak reports to laboratories on:

wax from gas . . . an heir that can earn his own way

Modern-day myricyl

Here's a razzle-dazzle play in the game of "polyethylene," which is now providing so much fun for the chemical industry.

We've made a wax out of it. Now we're in the wax business.

The familiar polyethylene plastic, after all, is nothing but hydrocarbon chains, a thousand or two carbon atoms long, arrayed into some crystallographic orderliness. Produce shorter chains, oxidize a trifle, and compare with esters like myricyl cerotate ($C_{25}H_{51}\underset{\overset{\|}{O}}{C}OC_{31}H_{63}$, the prominent constituent of carnauba wax), myricyl palmitate ($C_{15}H_{31}\underset{\overset{\|}{O}}{C}OC_{31}H_{63}$, which is what beeswax largely consists of), or the cetyl palmitate ($C_{15}H_{31}\underset{\overset{\|}{O}}{C}OC_{16}H_{33}$) of spermaceti. The resemblance turns out to be more than coincidental. And it *is* more up to date to get your raw materials out of a hole in the ground than from the fronds of some faraway palm tree or the head of a sperm whale.

So it comes to pass that alongside such scriptural-sounding cargos from distant ports as ouricury and candelilla, we plunk down the trademark "Epolene." It sounds less ex-

pensive, and it is. It looks (left) easier to handle and melt down than old-fashioned waxes, and it is. It is compatible with all of them—animal, vegetable, and mineral, except that the all-hydrocarbon, nonemulsifying (no hydrophilic carboxyls) type designated "Epolene-N" is incompatible with certain components of candelilla and ouricury.

It upgrades paraffin in flexibility, dielectric properties, hardness, higher melting point, higher blocking temperatures. The "Epolene-N" gives polishes better gloss, hardness, and scuff resistance than some costlier waxes. It stiffens candles, bodies printing inks, flats lacquers. In rubber compounding, it is an effective calender release agent for the milling operation. The emulsifying type "Epolene-E," can provide, effectively, 100% of the solids for self-polishing waxes.

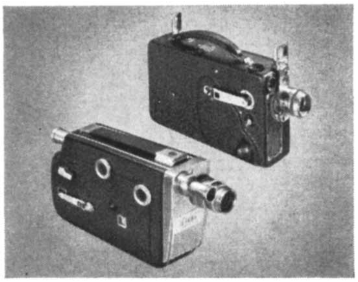
It's the fellow who works out an idea with Epolene Polyethylene Wax *that others hadn't thought of who may wax the wealthiest. For samples, data sheet, prices, or well-mannered salesmanship, write Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).*

K's grandson

Were you around in 1930? Statistically, "no" isn't too improbable an answer, sophisticated as you now are to be reading this periodical. Somewhat more likely, you were a rather young party at the time but old enough to be held in thrall by a certain wonder-world to which 15¢ admitted you on occasional Saturday afternoons. It is just possible that by 1930 you had progressed enough in years and goods to make your own Hollywood with the new Cine-Kodak Model K Camera. Growing economic unease or not, a lot of amateur moviemakers saw fit to invest in that untoylike 16mm movie camera. When you consider how many of those original Model K's are still making happy movies this very summer, it doesn't seem to have been so foolish an investment. How many other personal hard goods of the period are still so treasured?

Before more mist clouds our eye, let us reveal the brand-new model. This heirloom-to-be is designated the *Cine-Kodak K-100 Camera*. Being a product of the fifties instead of the thirties, it looks better suited to flying through the air with the greatest of ease. Functionally as well, 25 years have wrought improvements.

As in the long ago, the *K-100* takes its film from a roll to line it up precisely with the lens axis, but lenses like the *Kodak Cine Ektar II 25mm f/1.9 Lens*, the *Cine Ektar 25mm f/1.4*, and other *Cine Ektar Lenses* from the 15mm wide-angle to the 6× telephoto could not have been made before Kodak rare-element glass was invented. Also, there



has been progress in spring motors: one winding of the *K-100* can pull 40 feet of film. All manner of cinematic changes can be rung—slow motion up to 64 frames per second, one frame at a time for animation, up to two feet of reversed travel by hand crank (as an extra). The finder is a genuine focusing telescope that shows adjacent areas as well as field coverage. Gears are of quiet, long-wearing nylon, driven on ball-bearing mounted shafts. Film gate pressure adjusts automatically to camera speed. The ball-mounted pull-down mechanism can accommodate single-perforated film for sound recording.

There is good economic reason for these and many other such refinements in the *K-100*, aside from the not unworthy one of giving the amateur cinematographer all that his heart could desire. Unlike its 1930 ancestor, the *K-100* has to earn its way at functions more serious than garden parties. The factory time-and-motion-study man must be able to regard it as reliable professional equipment. So must the athletic coach, the TV news cameraman, the audio-visual educator, the industrial or medical photographer, the insurance investigator, the scientist or engineer who uses its electric-motor-drive provision to get a time-lapse study of corrosion or the fleeting tale told by a cathode-ray oscillograph.

*All this for $269 with f/*1.9 Ektar Lens. *Your Kodak dealer awaits your call.*

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This is one of a series of reports on the many products and services with which the Eastman Kodak Company and its divisions are . . . *serving laboratories everywhere*

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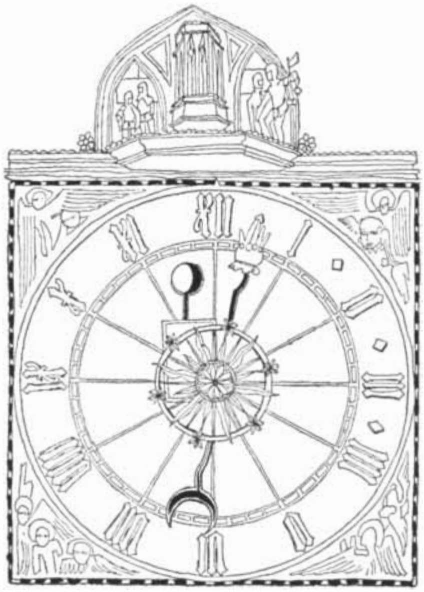
SCIENCE AND



Reactors

The much-heralded atomic age has acquired new substance in recent weeks with the announcement of major plans by government and industry.

The Atomic Energy Commission reported that it is expanding and accelerating its five-year reactor development program begun last year [see "Power Reactors," by Alvin M. Weinberg; SCIENTIFIC AMERICAN, December, 1954]. Work is going forward on the five reactor types originally contemplated (pressurized water, sodium-graphite, boiling water, fast breeder and homogeneous), and now the Commission proposes to test two more. One is the so-called liquid-metal-fueled reactor, in which uranium or other fuel is dissolved in a molten metal. This design, which was developed at the Brookhaven National Laboratory, is said to combine the advantages of homogeneous and liquid-metal-cooled reactors: chemical processing of the fuel is simplified, and the system can achieve high temperatures at low pressure. The Babcock & Wilcox Company is studying the technical feasibility of the design.

The second new concept is a reactor using organic compounds as moderator and coolant. These compounds have high boiling points, do not become very radioactive and cause little corrosion of metal parts. Problems still to be settled are their heat-transfer properties and their tendency to polymerize or decompose under radiation.

Industrial proposals now before the AEC call for some 650,000 kilowatts of nuclear-power capacity. The Consolidated Edison Company intends to build a pressurized-water reactor to supply up to 200,000 kilowatts of electricity. The Nuclear Power Group, Inc., a combination of several electric utilities, has proposed a 180,000-kilowatt boiling-water design. Both projects are to be financed privately. Three other industrial groups have filed plans under the Commission's demonstration program, in which the government is to provide free fuel for seven years and to pay certain of the research and development costs. Atomic Power Development Associates have decided on a 100,000-kilowatt fast breeder; Yankee Atomic Electric Company, on a 100,000-kilowatt pressurized-water reactor; Consumers Public Power District of Columbus, on a 75,000-kilowatt sodium-graphite reactor.

An indication of the present economic prospects of nuclear power is given by the Nuclear Power Group plan. It is estimated that the reactor will cost \$45 million. The Commonwealth Edison Company will pay \$30 million of this and take all the power produced. The other participants will pay \$15 million for the technical information and experience to be gained on the project. Commonwealth Edison estimates that under this arrangement the power will cost it about as much as that from its conventional plants.

In addition to these large power units there are in prospect a number of smaller reactors for research. A recent survey in *Nucleonics* listed 15 reactors, nine of them to be owned privately by universities or industrial laboratories and six by government agencies. The largest are two materials-testing reactors. One has been proposed by the Westinghouse Electric Corporation; the other, to be used largely by the AEC, will also be privately built and owned if the Commission finds a company willing to undertake the project.

With the quickening of reactor development some of the snags which the atomic energy industry will face have begun to appear. One of the biggest, says the AEC, is "the critical shortage of well-trained, experienced scientific and engineering manpower." (According to *Business Week*, a "leading research and development firm" estimates that there are only about 50 men in the U. S. who "know how to build a reactor from start to finish.") The Commission is studying ways to train more people.

A technical area which needs basic exploration is high-temperature chemistry and metallurgy. Willard F. Libby, chemist and member of the AEC, says: "The underlying physical theory . . . is so far ahead of our knowledge of the basic chemistry of processes and materials at high temperatures that it is easier to calculate with some certainty the physics of power reactors than to predict with any certainty whether reactors can be built of actual materials and can be expected to operate satisfactorily." The Commission is now preparing to sponsor a broad program of unclassified high temperature research.

Other problems that may soon be pressing include:

Waste disposal. According to Glenn T. Seaborg, professor of chemistry at the University of California, the ability to dispose of radioactive waste may eventually be the limiting factor in the use of nuclear power.

Insurance. No private underwriters have yet indicated that they will insure a nuclear power plant.

Wide-open Game?

The international conference on the peaceful uses of atomic energy, to be held from August 8 to 20 in Geneva, is generating a good deal of excitement. It may "blow the lid off" secrecy in the field, according to Senator Clinton P. Anderson, chairman of the Joint Congressional Committee on Atomic Energy. This feeling appears to be shared by interested scientists who are talking hopefully about a substantial exchange of information.

Determination to make a good showing is responsible for some very energetic preparations by U. S. officials (and also for considerable coyness about the details of U. S. plans). Senator Anderson remarked: "It could be like a poker game in which neither side is willing to put up any money, but I believe it will be wide open. We certainly are going to try to show the world what can be accomplished. . . . I'm sure the Russians will turn up with something. . . ."

The program will consist largely of

technical papers, the more important ones to be read and the others to be included in the printed proceedings. The meetings are to be divided into five sections dealing with reactors, reactor physics, reactor chemistry and metallurgy, biological and medical aspects, and applications of radioisotopes in industry and research. In the evenings leading scientists will give lectures on various aspects of nuclear energy.

Supplementing the formal program will be a series of exhibits arranged by the participating countries. The highlight of the U. S. exhibit is to be a working research reactor of the "swimming pool" design, which is now being built at Oak Ridge National Laboratory. It will be equipped with dual control and instrument panels so that conference delegates can actually operate it.

All member nations of the United Nations or of its specialized agencies, a total of 84, were invited to the conference. At the end of last month 53, including all the larger countries, had accepted the invitation.

The conference is under the general direction of Dag Hammarskjold, Secretary-General of the UN. He has appointed Homi J. Bhabha, chairman of the Indian Atomic Energy Commission, as president of the conference, and Walter G. Whitman, professor of chemical engineering at the Massachusetts Institute of Technology, as conference secretary-general. There are five vice presidents, including representatives of Brazil, Canada, the U.S.S.R., the United Kingdom and the U. S. Assisting Whitman are 17 scientific secretaries from 10 countries. Robert A. Charpie, assistant director of research at Oak Ridge National Laboratory, and Frederic de Hoffmann, a vice president of the General Dynamics Corporation, are the U. S. members of the group.

Each nation's official delegation is to consist of five members, but there may also be an unlimited number of advisers. One of the U. S. delegates will be I. I. Rabi, who is also a conference vice president. The AEC's preparations for the meeting are in charge of George Weil, formerly assistant director of reactor development for the Commission.

Fission-Fusion-Fission

Recent speculation in the daily press about a new type of nuclear weapon—the so-called uranium bomb—has now been carried further by the British physicist J. Rotblat. In an article in the English *Atomic Scientists Journal* (reprinted by *Bulletin of the Atomic Scientists*) he discussed the evidence for such a device and its probable effects.

From the Atomic Energy Commission's description of fallout after the thermonuclear test of March 1, 1954, Rotblat calculated that the total radioactivity released in the explosion was about 400 billion curies. Japanese measurements showed that almost all the radioactivity came from fission products rather than from materials irradiated by neutrons in a fusion reaction. The most powerful modern atomic bomb should release no more than 10 billion curies. Assuming that such a bomb was used to trigger a fusion reaction, this reaction must in turn have triggered more fission.

The commonest species of uranium (U-238) is not split by slow neutrons, but it is easily disrupted by faster ones with energies of several million electron volts. A fusion reaction liberates neutrons in this energy range. Rotblat suggests that the Bikini device consisted of a plutonium core, a shell of lithium deuteride for the fusion reaction and an outer shell of U-238.

If this is the case, the radioactive contamination from an "H-bomb" explosion must be very much greater than had been supposed. (Fission products emit more radiation, and for a longer period, than the materials in which a fusion reaction incidentally induces radioactivity.) The AEC has stated that all bomb tests to date have exposed each individual to no more radiation than he would receive from a single chest X-ray. Says Rotblat: "Most of this radiation must have come from the very few hydrogen bombs tested less than a year ago. This means that one year of H-bomb tests at the present scale about doubles the natural background. . . . If our guess is correct, the hydrogen-uranium bomb is a kind of cobalt bomb; in fact, in some respects, it is even worse."

101

For a few days early this year there was something new under the sun, but not much of it. Chemists at the University of California had made 17 atoms of element 101. The substance, named mendelevium (abbreviated Mv) after the father of the periodic table, was produced by bombarding element 99 with energetic alpha particles from a cyclotron. The isotope obtained, the atomic weight of which is 256, decays by spontaneous fission with a half-life somewhere between half an hour and several hours. It resembles the rare earth thulium in its chemical properties.

Experimenting with such scarce and

Carboloy Trends and Developments for Design Engineers . . .

- How Hevimet dampens gun-sight vibration
- How carbides cut costs in automated plant
- Advantages of precast magnet assemblies

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In military planes, vibration from engines, armament, and anti-aircraft fire causes severe visual distortion on gun-sight scanning units.

Balanced metal counterweights can effectively dampen vibration of these small, delicate components — but most metals are too bulky for use as aircraft vibration dampeners. Eastman Kodak has found an answer in Carboloy® Hevimet — a tungsten-nickel - copper alloy almost 50% heavier than lead. With it, they licked backlash and gear chatter, greatly reduced vibration.

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Carbides' abrasion resistance boosts pottery production rate

Pottery clay is a most deceptive material. It looks soft and it feels soft — yet one of its principal constituents is hydrated aluminum oxide which, in its anhydrous form, is the abrasive used on many grinding wheels.

On the automated production lines at Scio Pottery Co., the clay's abrasive oxides and silicates gouged out and wore down steel shaping tools as if they were wood. They required regrinding every 8 *hours*. When Scio switched to Carboloy cemented carbide shaping tools, life per grind increased to between 3 and 8 *weeks*. Savings were even more impressive. Steel tools had to be scrapped every 3 months; Carboloy carbide tools are still in use after 4 years.

It's not often that a designer needs to worry about abrasives like aluminum oxide in his machines. But he is usually concerned with wear in one form or another, and carbides' contribution at Scio can be directly equated with time, money, and labor savings on almost any application where wear is a critical factor.

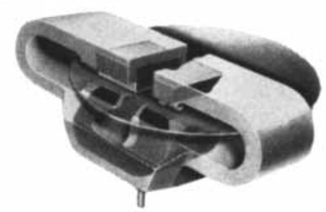
Because carbides are so hard — about 85-93 Rockwell "A," compared to 70 Rockwell "A" for SAE 1095 heat-treated carbon steel—they far outwear conventional materials. They reduce part replacement and maintenance costs, prevent premature machine and part obsolescence. They can virtually eliminate downtime, permitting increased production and production rates — with finer finishes and less scrap.

In addition, Carboloy cemented carbides have other physical properties which make them ideal wear-proofing materials: corrosion, erosion, friction and impact resistance; great compressive and tensile strengths; high moduli of elasticity. For information on physical properties and methods of application to aid you in designing carbide parts, write today, describing the job you have in mind.

New die-casting machine makes alclad assemblies

There is nothing extraordinary about the relay drag magnet assembly shown in the next column.

An aluminum disc revolves in the air gap between the "C"-shaped magnet and the steel return path. The induced eddy currents estab-



lished by the disc moving through the air gap flux, cause a counter torque, or drag, on the disc. It's a principle commonly used on many meters and instruments.

What is unusual, though, is that the entire unit — from magnet to aluminum sheath — was assembled for the manufacturer by Carboloy.

Making magnetic subassemblies is a relatively new Carboloy service . . . but one that promises big dividends to many manufacturers.

Primarily, it means that responsibility for the entire unit is centered on a single source — permitting complete control over all variables affecting air gap flux. The complete magnetic circuit can be supplied premagnetized and pretested. And a time-consuming assembly job is eliminated for the manufacturer, freeing men and equipment for more important work.

Behind this new service is the new 400-ton die-casting machine. It casts aluminum sheaths to almost any configuration . . . yet holds tolerances to thousandths.

Naturally, this method is limited to certain types of jobs, but where it is applicable, the advantages can be spectacular. To get the whole story, write today, outlining your problem.

And for other applications, check into the design advantages of other Carboloy Created-Metals: *chrome carbides* for combating wear; *Thermistors* for the detection, measurement, and control of minute temperature changes; and *vacuum-melted metals.*

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11199 E. 8 Mile Road, Detroit 32, Michigan

CARBOLOY CREATED-METALS FOR INDUSTRIAL PROGRESS ephemeral materials, the California scientists had to work fast. The artificial element 99 is itself obtainable only in tiny quantities and decays quite rapidly (half-life 20 days). About a billion atoms of 99 were electroplated on a thin gold film and exposed to the alpha-particle beam. The atoms that were hit flew off and collected on a second gold plate. This second foil was then quickly dissolved, the gold and other impurities removed and the solution separated into three fractions containing elements 99, 100 and 101, if any.

The researchers had expected to make Mv-255, which according to theoretical predictions should decay, by emitting an alpha particle, with a half-life of about five minutes. They found no evidence for this reaction but instead discovered a much more energetic nuclear explosion that could only represent the fission of an atom of Mv-256. They still expect to make Mv-255 in further experiments.

Collaborating in the discovery were Albert Ghiorso, Bernard G. Harvey, S. G. Thompson and Glenn T. Seaborg.

Mental Health Research Funds

The Ford Foundation announced last month that it has allocated $15 million to be spent on research in mental health over the next five to 10 years. Grants to qualified investigators will be given for work on social and community aspects of the problem, children's disorders, biological and physiological problems in mental illness, personality development and therapy. Some of the funds will also be devoted to training scientists for research in the field. The total current U. S. outlay for mental health research is estimated at less than $10 million per year.

Astronomical Merger

Harvard University and the Smithsonian Institution are coordinating their research in solar physics. The Smithsonian's astrophysical observatory will move from Washington to Cambridge on July 1, and Fred L. Whipple, professor of astronomy at Harvard, will take over as director. Whipple will also remain on the Harvard faculty. Several other joint appointments are contemplated. The Smithsonian's observing stations in Chile and California will be maintained.

New Transistor

A long-familiar electrical property of semiconductors is being applied for the first time to make a new and in some respects superior kind of transistor. It was while investigating this property, called the field effect, that J. Bardeen and W. H. Brattain invented the original point-contact device. Now physicists at the Bell Telephone Laboratories have built field-effect transistors which they expect will perform satisfactorily at higher frequencies than the point contact or junction types.

A field-effect transistor is a slab of *n*-type germanium (in which current is conducted by loose electrons) sandwiched between two smaller *p*-type plates (which conduct by means of positive "holes"). When a negative charge is applied to the outside plates, the current-carrying electrons in the center slab are pushed out of the regions near the *p-n* junctions. Thus the portion of the center slab available to conduct electricity is reduced. If a steady voltage is applied to this slab, the amount of current flowing through it decreases as the negative charge on the outside plates is increased. In other words the outside plates act like the grid of a vacuum tube, controlling the flow of current through the device.

In junction transistors the current carriers move from place to place by diffusion; in the field-effect type they are impelled by electric fields. This means that they move faster in the field-effect transistor, which makes it possible for them to respond to faster fluctuations, *i.e.*, higher frequencies.

Frustration and Rootie Kazootie

Why do some children watch television for hours? Is it because the fantasy they find there distracts them from the pressures of their real lives or provides an outlet for forbidden impulses? If so, the children of strict parents would presumably spend more time at the television set than those whose parents are more permissive.

To find out if this is so Eleanor E. Maccoby, a social psychologist at Harvard University, interviewed 379 mothers of kindergarten children, inquiring about their child-rearing methods and their children's television habits. About half the women were upper middle-class and half were upper lower-class (chiefly the wives of skilled laborers).

In the high-status group the results were as expected: frustrated children—whose sex behavior was repressed, who were punished for aggression against their parents, who were expected to obey orders at once, who were held to stringent standards of behavior, who were spanked often, whose mothers showed

little affection for them—spent significantly more time (up to 50 per cent) at the television set than their less rigorously raised classmates.

In the lower-class families there was no such correlation (except in the cases of sexually repressed and much-spanked children). In fact, in some instances the children of strict parents spent less time watching television.

In *Public Opinion Quarterly* Maccoby suggests that the difference may be explained by the viewing habits of the parents themselves. Upper-class adults spend comparatively little time watching television. Where the relationship with his parents is close, a child tends to imitate them; where it is distant, he escapes to television. Lower-class adults are more likely to be television enthusiasts, so their children are impelled in the same direction by both imitation and escape.

Pattern for Proteins

How does a living organism assemble amino acids into the elaborate and specific sequences typical of its own proteins? Some biochemists have recently suggested that the job is done on a nucleic acid template—*i.e.*, that the nucleic acids in the cells furnish a pattern by which proteins are strung together. Last month the first direct experimental evidence for this theory was announced in *Nature* by Ernest F. Gale and Joan P. Folkes of the University of Cambridge.

The British investigators had previously learned that ruptured *Staphylococcus* cells can synthesize protein out of amino acids as long as the cellular ribonucleic acid (RNA) is present. In their latest experiments the biochemists split staphylococcal RNA into smaller fragments with an enzyme. Then they tried adding each fragment separately, along with a single amino acid, to cells from which whole RNA had been removed. It turned out that different nucleic acid fragments promote the exchange of different amino acids. Gale and Folkes suggest that the various fragments exist in the same form in whole RNA and that their order in the molecule determines how proteins are put together.

Bring 'Em Back Alive

J. Millot, director of the *Institut de Recherche Scientifique de Madagascar*, has probably seen more coelacanths than any other man. Since 1938 Madagascar fishermen have brought him eight of these survivors from the 300-million-year-old past. He still finds each new

catch exciting. The most recent one, says Millot in a report to *Nature*, was the "finest yet." It was the largest (90 pounds, four and a half feet long), it was the first female ever reported and it was alive.

Formerly every fisherman who pulled up a coelacanth promptly clubbed or knifed it to death and hauled it into his boat so that it would not be stolen by sharks or barracuda. As an inducement to stop this "deplorable behavior," Millot offered a double bounty for a live specimen. Last fall Zema ben Saïd Mohamed was fishing off one of the Comoro Islands between Madagascar and the African coast. He had let his line down more than 800 feet when he got a strike. Zema, "an excellent fisherman," suspected he had a coelacanth from the way it took the bait. He hauled it up and confirmed his suspicion. Being only about 1,000 yards offshore, he decided to try for the big prize. By means of a line through its mouth and gill opening the fish was made fast and towed to the harbor of Matsamudu, "though sometimes it was the fish that towed the pirogue."

In accordance with Millot's standing instructions the fish was put into a whaleboat, which was then covered over with a net and sunk in a few feet of water. Throughout the night, which the townspeople spent singing and dancing to celebrate the occasion, local officials watched over the animal. The fish itself passed a quiet night, showing no disposition to escape from its enclosure and "swimming slowly by curious rotating movements of its pectoral fins." After daybreak, however, the light and heat of the sun began to cause the deep-sea dweller acute distress. By early afternoon, just after Millot arrived by air from Madagascar, it turned up its belly and expired. It was immediately covered with a sheet and removed to the town hospital for dissection.

Two principal findings emerged from this short observation of the first living coelacanth: (1) its extreme photophobia—"the light seemed literally to hurt it"; (2) the exceptional mobility of its "pedunculate" fins (attached to a muscular stem). They can move in "almost any direction" and can assume "practically every conceivable position." It is believed that relatives of the coelacanth developed into land animals and that their mobile fins were the precursors of legs.

To preserve future catches, Millot is designing a large submersible cage. The fish will be kept at depths of 500 feet or more and hauled up only for short periods of observation.

COAL

It is by far the largest store of fossil organic substance, but its utilization lags. Scientific and technological advances suggest that it might best be used not as a fuel but as a chemical raw material

by Lawrence P. Lessing

Coal, which powered most of the industrial revolution, is in trouble over most of the world. The U. S. learned in 1953 that for the first time in its history coal had dropped from a leading place as a source of energy to a position behind oil. Coal supplied only 34 per cent of the nation's total B.T.U.'s (British thermal units) as against 39.4 per cent for crude oil, 22.5 per cent for natural gas and 4.1 per cent for water power. This historic fall occurred during a year in which U. S. industrial activity was at an all-time high. This fact, plus coal's continuing depression, leads some to believe that coal will never again regain its pre-eminence. Coal, indeed, is one of the foremost technological problems of our time.

Coal is still a big and vital element in the operations of an industrial society. Some 400 million tons of coal, the amount annually being consumed in this country, is not a trifling quantity. It accounts, through conversion in steam power plants, for over three fourths of all U. S. electrical energy. It is indispensable, in the form of some 100 million tons of metallurgical coke, for the production of iron and steel. In addition, coal tar residues from these coking plants provide the essential raw materials for nearly a third of the whole U. S. organic chemical industry. In a dozen lesser ways coal is woven through all the basic strata of industry.

The major fact about coal, however, is that all the coal so far mined is as nothing to the store remaining underground. Some seven trillion tons runs the estimate; the quantity is so vast that no one really knows. This is by far the biggest reserve of all known organic mineral substances, which are alike in that all are preponderantly the hydrocarbon remains of former terrestrial life. In carbon content alone, mineable coal reserves represent 12×10^{12} tons of carbon against $.04 \times 10^{12}$ tons in the world's estimated reserves of oil. Since carbon is the backbone of all life and commerce—carbon compounds in one form or another making up some 90 per cent by value and 95 per cent by weight of all the products of human labor—this represents a great treasure. Long after the last reserves of oil and natural gas are exhausted, at a date not too far distant by most estimates, there will be coal. Even at the most pessimistic estimates, with proper conservation and development of other sources of energy there should be coal for some centuries to come.

Naturally such a massive deposit must be widely though unevenly distributed in the earth's crust. The tropics are fairly thin in coal. Africa has relatively little. Most major deposits seem to lie in the temperate zones but some are found even in polar regions. The U.S.S.R. is mining coal in the Arctic, and there are known deposits in the Antarctic. Europe's deep and dwindling mines stretch in a wide arc from Great Britain through the Lowlands, France and the Ruhr to the Ukraine. Asia has about a third of the world's coal, most of it in China, where the first coal was mined about 1100 B.C., but where, because of a lag in industrialization, most of it remains to be exploited. The Hopi Indians mined coal in Arizona two centuries before Columbus, and North and South America together have over half of the world's reserves. The U. S. alone has nearly half of all the bituminous and subbituminous, the most valuable of all coals.

Yet the U. S. coal industry today looks like anything but the administrator of so vast a treasure. For over 40 years it has been prosperous only during wars. Though the U. S. economy has expanded enormously, and the coal industry with it, coal in that half-century has had its biggest, most lucrative markets cut from under it by more convenient or more efficient fuels—oil and natural gas for heating, Diesel fuels for ships and railroads. Now it is faced with the emergence of atomic power and of methods for tapping directly the immense free stores of energy in the sun. Both of these developments are moving more rapidly than is generally realized. Both developments, as the century runs out, may well begin to cut into all of coal's remaining markets except steel.

An intricate shifting of the technological base of industry is in progress. For coal the handwriting has been on the wall for many years. Part of the trouble is that the coal industry came out of the 19th century with grimy, backward tenets of mining deep in its system. It was slow to modernize and mechanize, going steadily down in efficiency and up in costs. It persisted in regarding coal primarily as a fuel, in spite of the nudge

The Continuous Miner, made by the Joy

given it by the early development of chemicals from coal tar wastes. While the petroleum industry began early to do heavy research on its basic raw material, the coal industry apparently knew little of its product beyond the fact that it burned. What is known about coal today—and most precise knowledge of it is recent—is almost wholly derived from the inquisitive chemical industry and from independent investigators.

Fossil Origins

If a lump of coal is closely examined, a regular cellular pattern may often be seen, denoting its plant origin. Coal was laid down, according to the geological evidence, by the debris of giant tree ferns and other rank vegetation flourishing in the hot delta bottoms of the late Paleozoic Era, some 300 million years ago. With the slow rhythm of subsidence, sedimentation and uplift, the great swamps were intermittently inundated by the sea, which flattened and covered the vegetation with thick layers of alluvial mud. The weight of these sediments, translated into rock and often folded, exerted those pressures and temperatures basic to all chemical processes, which slowly converted the vegetable matter to coal.

The enormous variety of its vegetable origins and the variables of geological processes make coal one of the world's most complex substances. Not only do coals vary widely in various regions, but also they vary in the same coal seam. Bounded by layers of shale, a coal seam shows an uneven but definite progression from a soft, peaty bottom, suggesting leaf mold, through a bright middle section, with recognizable fragments of decayed plants, bark and spores, to a hard upper layer of massive woody remains.

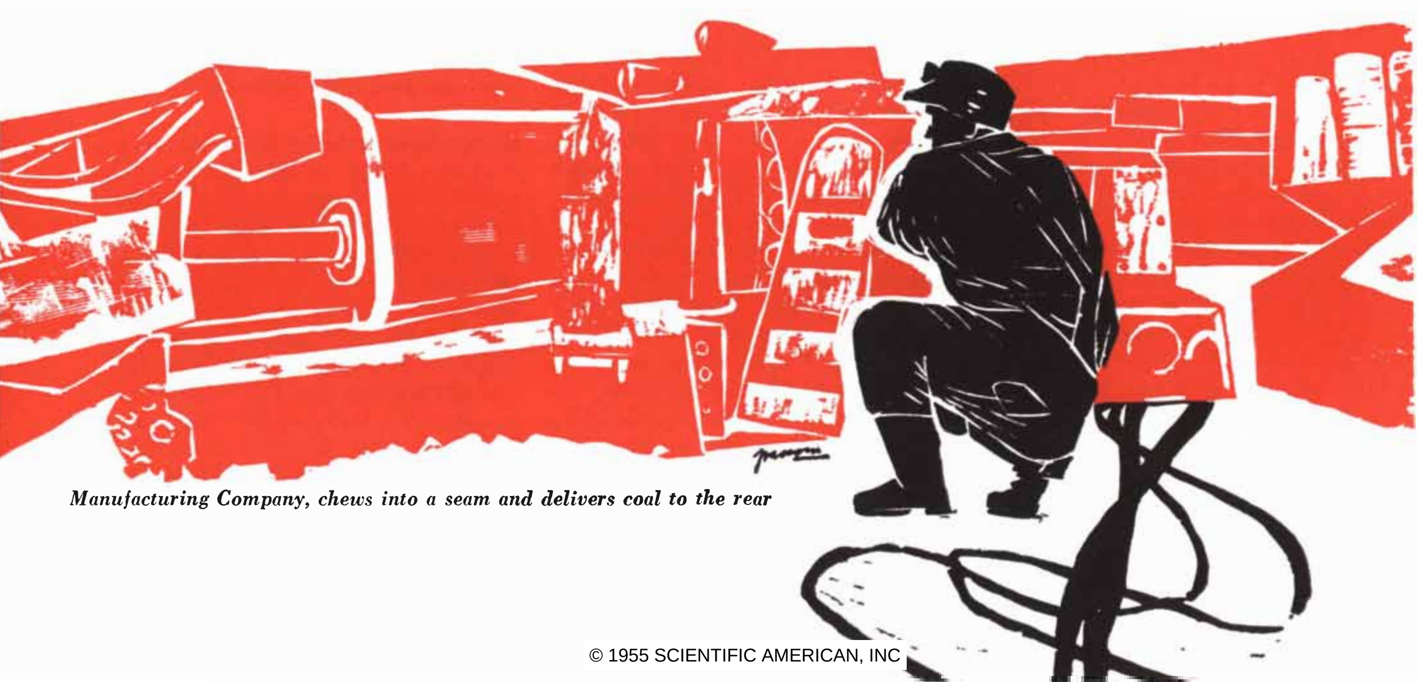
Four broad classes of coal are recognized: peat, a spongy, water-soaked substance of low heat (or carbon) content, generally regarded as the first stage of coal formation; lignite, a less watery form of peat also known as brown coal, which marks the transition to true coal; bituminous, still soft, but with a larger concentration of carbon and a smaller proportion of oxygen; and anthracite or hard coal, in which both oxygen and hydrogen have been nearly squeezed out, leaving almost solid carbon. (Anthracite is so preponderantly carbon that it is relatively inactive chemically and used only as a fuel.) This ranking of coal has no strict chronological order, for different coals were produced by various conditions at widely different times. Between the main classes are many gradations of type, which makes coal classification extremely difficult.

The constituents of coal have been known for a long time. They are mainly carbon, hydrogen, oxygen, nitrogen, sulfur and mineral ash. What long remained a mystery, however, were the processes by which the weight of carbon was progressively concentrated from 60 per cent in peat to 96 per cent in anthracite, while oxygen dropped from 6 to 3 per cent and hydrogen was maintained almost constant (except in anthracite) around a mean value of 5.5 per cent. This is the exact opposite of what happens in the normal decomposition of vegetable material above ground, where most of a dead plant's carbon is lost to the air via carbon dioxide, leaving behind humus.

In peat bogs, however, which may still be studied in many parts of the world, a different transformation takes place. Here plant material drops to the swamp floor and is soon covered by water, muck and other debris, which exclude air. Under these conditions only partial decomposition takes place. Most of the plant carbon is retained, while most of its oxygen is lost as water. If this is coal's first stage, then a number of chemical routes can be mapped by which woody material with a composition by weight of 50 per cent carbon, 6 per cent hydrogen, 42.75 per cent oxygen and 1.25 per cent ash loses 27 per cent of its volume as water and 16.5 per cent as carbon dioxide. This leaves a material containing 80.5 per cent carbon, 5.3 per cent hydrogen, 12 per cent oxygen and 2.2 per cent ash, which roughly corresponds to bituminous coal.

The whole process of coal formation has been partly confirmed by laboratory experiment. The late German fuel chemist Ernst Berl, working at Carnegie Institute of Technology in the late 1930s, succeeded in making synthetic coal. Compressing woody vegetable matter under pressures and temperatures analogous to those exerted by rocks in the Carbonaceous Period, he produced pellets of a material closely akin to brown coal. Since then coals ranging up through bituminous have been artificially made. Of course this process has no immediate practical significance; more energy is required to make the coal than could be regained by burning it. The process may nonetheless be useful as a means of converting vegetable matter directly into needed hydrocarbons.

Though most of coal consists of hydrocarbons, the lesser constituents, mainly in the ash, are astonishing in number. Recently a close analysis of West Virginia bituminous coals showed that the ash, produced in that state alone at the rate of 10 million tons a year, contains 36 different chemical elements. In con-



Manufacturing Company, chews into a seam and delivers coal to the rear centrations over 1 per cent are sodium, potassium, calcium, aluminum, silicon, iron and titanium. In concentrations down to .01 per cent are 26 metals, including lithium, rubidium, chromium, cobalt, copper, gallium, germanium, lanthanum, nickel, tungsten and zirconium. Many of these are in amounts perhaps someday sufficient for economic recovery. Germanium, the new electronic metal, is the most immediately interesting. It is found largely concentrated in the bottom three inches of a coal seam. If this bottom is carefully separated by gravitational means, it yields coal with an ash containing 3 per cent germanium dioxide, worth $57.50 per ton as an ore and $900 per ton as finished product.

Altogether, including other elements only in trace amounts or occasional occurrence, coal is a compendium of no less than 72 items in the periodic table of elements. Thus coal, through the biochemical activity of plants that flourished in a different world eons ago, is not merely a store of carbon energy but a compact bundle of the most varied chemicals.

The Chemical Pattern

The analysis of coal into its elemental constituents, however, tells us almost nothing about it as a chemical substance. For this we must know the chemical structure of coal, the way in which its atoms are linked to form molecules. Until recently the exact chemical structure of coal, due to its great complexity and variability, was almost totally unknown.

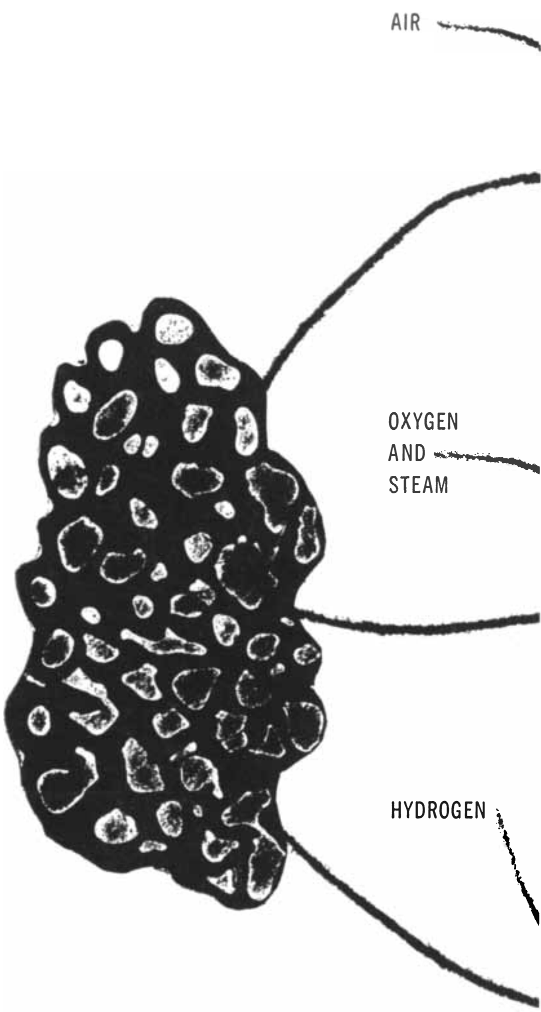
Some clues to structure were contained in the discovery and development of coal tar chemistry just a century ago. In 1856 Sir William Perkin hit upon his historic synthesis of the textile dye mauve from a constituent (aniline) in the tarry messes that accumulated in the flues of gasworks and coke ovens. These tars yielded by fractional distillation a whole series of basic hydrocarbon compounds ranging from benzene, the lightest fraction, to anthracene, the heaviest. From anthracene a few years later two German chemists named Graebe and Liebermann synthesized the red dye alizarin, which theretofore had been obtained only from plant roots. Thus it was apparent that in its vegetable origins coal contained basic organic compounds which could be reconjugated into apparently natural substances by chemical means.

As the derivatives from coal were studied, their molecular structure fell into two wonderfully geometric divisions. From coal tars came a series of compounds, called aromatic because of their pungent odor, whose structure took the form of ring-shaped molecules. The basic unit was benzene (C_6H_6), consisting of a central hexagon of six carbon atoms with six hydrogen atoms attached. On this ring all the rest of the compounds in the series were built by the simple addition of one carbon atom at a time; *e.g.*, C_7H_8 for toluene, the next compound in the series, C_8H_{10} for xylene and so on. As the number of carbon atoms in the molecule reached 10, two benzene rings were fused, sharing two of the carbon atoms between them to form naphthalene. Three fused rings formed anthracene ($C_{14}H_{10}$), which is the largest molecule in the series.

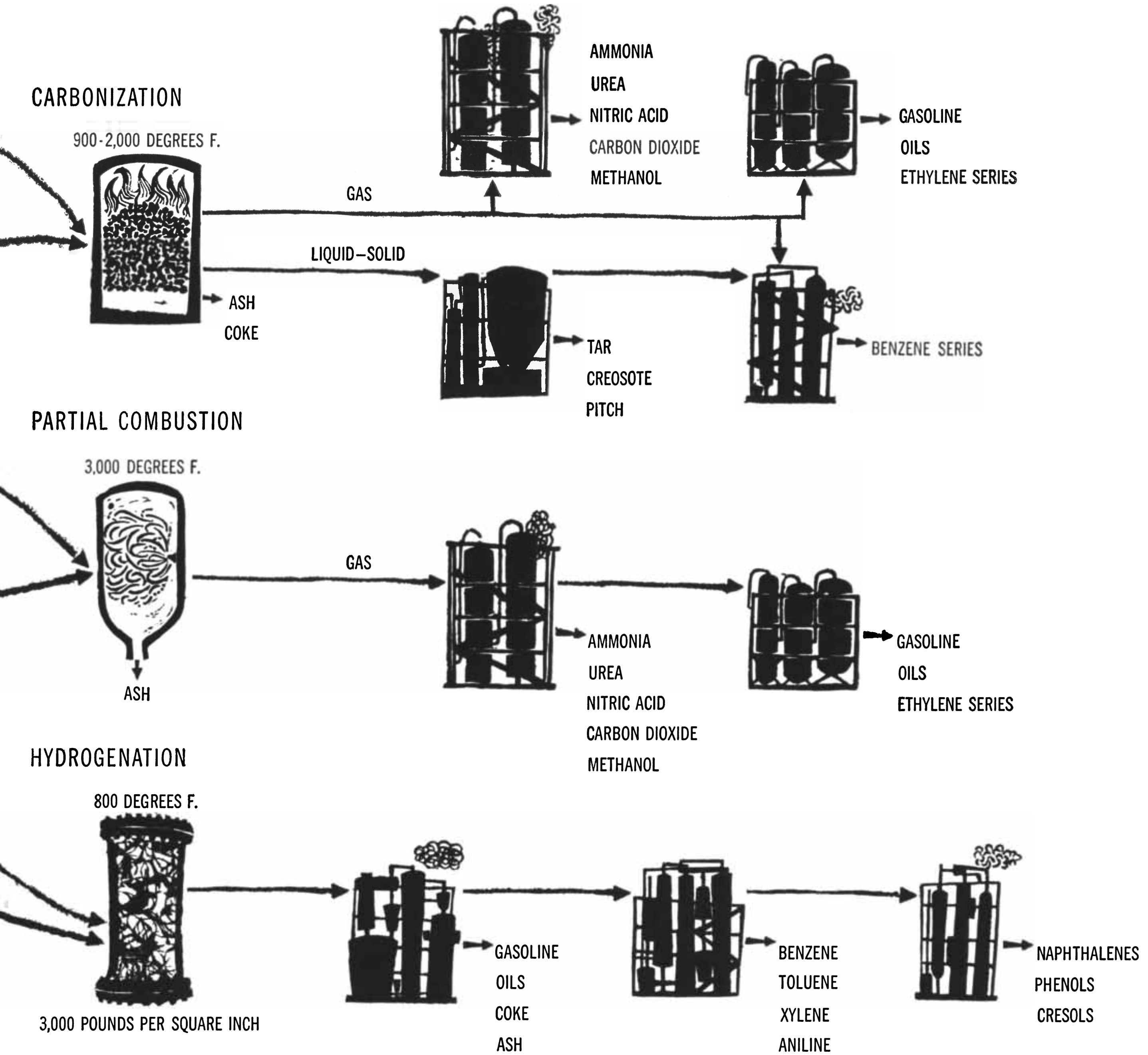
From coal gas and the like came another series of carbon compounds, called aliphatic because of their fatty or oily character, whose distinguishing form was a linear or chainlike molecule. The basic unit in this series is methane, the simplest of hydrocarbons, consisting of a single carbon atom surrounded by four attached hydrogen atoms. From methane the series builds up, again by the increment of one carbon atom per molecule, into progressively longer and longer carbon chains—C_2H_6 (ethane), C_4H_{10} (butane), $C_{10}H_{22}$ (decane) and so on. These chain compounds and others were later found to be more abundant in natural gas and petroleum, fossil hydrocarbons whose origin differs from that of coal. Whereas coal derives entirely from land plants, petroleum is now generally believed to have originated in the decomposing remains of marine organisms.

These two broad structural forms—ring and chain, aromatic and aliphatic—proved to be the cornerstones of synthetic organic chemistry. With the simpler coal derivatives as starting points, molecules could be built up, linked and rearranged by various reactions adding or substituting other elements—such as oxygen, nitrogen, sulphur or chlorine—to form a vast variety of compounds with different properties. Though their number does not begin to approach the enormous variety and complexity of carbon compounds in nature, no fewer than 500,000 compounds have been synthesized. These compounds embrace the whole range of dyes, drugs, perfumes, plastics, fibers, rubbers, explosives, adhesives, detergents, solvents, insecticides and other products that constitute the modern organic chemical industry.

Throughout this development the exact molecular structure of coal remained a mystery. It was thought that the basic benzene and methane series secured from coal tars and coal gas were not representative of the composition of coal itself but were secondary products formed in the partial combustion or destructive distillation of coal by the heat of gas or coke ovens. Exactly how coal was put together was a matter difficult to ascertain. To begin with, coal was a highly variable mixture of complex plant substances—cellulose, lignin, resins, proteins and the like—converted



THREE BASIC PROCESSES for extracting various substances from coal are illustrated in this diagram.



In carbonization coal is heated primarily to produce metallurgical coke. Partial combustion is based on the old "water gas" reaction. In a modern version of the reaction oxygen is fed into the reactor. In hydrogenation coal is heated to 800 degrees F. at high pressure.

by the coal-forming process into other complex substances, all bound together in the solid state. Any attempt to break the complex coal molecules apart by the usual combustion methods so drastically altered them that the resulting fragments could not be confidently identified as bearing any relation to the structure of the starting materials.

Was there a characteristic structure of coal molecules that might be found to hold, with variations, through the various ranks of coal? Was this structure small or large, taking as a scale the macromolecules of plastics and many natural products? Finally, was coal made up of only one, a few, or many different kinds of molecules? These basic questions had to wait upon refined means of disentangling the molecules from coal, and upon research interest.

Coal research has suffered some of the vicissitudes of its industry. In the early epoch of organic chemistry there was no urgent need for precise knowledge of coal structure. Research centered on derivatives. Then came the spectacular development of petroleum chemistry. Oil and natural gas offered a much more easily manipulated range of hydrocarbons than coal, and the industrial emphasis shifted to the aliphatics, which came to account for nearly two thirds of all organic-chemical production. Research emphasis likewise shifted, as illustrated last year by the publication of the definitive treatise *Hydrocarbons from Petroleum*, representing 25 years of investigation and over $500,000 in grants by the U. S. oil industry. No such treatise exists on coal.

The need for basic research on coal is

steadily rising as the organic chemical industry faces the next big step in its development. In the last 10 years a mounting attack on the problems of coal, both here and abroad, has begun to clarify the chemical structure of coal. Techniques for coming to grips with this structure are multiplying. They include X-ray diffraction and infrared spectroscopy; solvent techniques for extracting the molecular constituents of coal; mild oxidation reactions at temperatures from 200 to 500 degrees Fahrenheit to separate the constituents, and thermal decomposition in a vacuum at temperatures not exceeding 975 degrees F. Recently Irving Wender of the U. S. Bureau of Mines, which has an active coal research program, developed a new reduction method employing a metal (lithium) and an amine in a cleavage reaction in order to break out the skeletal molecules of coal.

The sum of the investigations by these techniques is that the basic molecular skeleton of coal is now generally agreed to be a ring-shaped structure whose nucleus is the six-carbon ring of the aromatic compounds. H. C. Howard of Carnegie Institute of Technology's Coal Research Laboratory, one of the pioneer agencies in this field, has shown that all the products of bituminous coal, obtained by whatever techniques and in all the temperature ranges, are predominantly of the benzene-ring type. There was no correlation between the temperatures used and the amounts of such products secured. Thus the evidence is strong that the ring structures are not formed in the heat of the experimental reactions, but are present in the basic molecule of coal itself.

The total molecule is by no means as simple as benzene. Recent investigations have begun to piece together some of its details. The broadest attack on the problem was launched in 1951 by the British Coal Utilization Research Association, which set out to analyze by all available means a series of vitrinites—bright black coal particles—from typical coals. These studies have yielded a working model of the basic molecule of coal.

The skeletal ring of carbon atoms is surrounded by hydrogen atoms and a variety of atomic groups which may replace them. These are hydroxyl units (OH), short aliphatic side chains, ether linkages and other appendages. The carbon ring may also be fused with other rings into discrete nuclear groups or clusters. These cluster units, divisible only by chemical means, probably form the basic molecules of coal. They range in size from about four fused rings in the low-ranking coals to five to 10 in bituminous and up to 30 in anthracite. The clusters are homogeneous for a given coal; *i.e.*, all belong to the same skeletal species, though varying in size, shape and properties according to the different peripheral groups attached to them. The clusters form rather flat molecules which, infrared studies indicate, are stacked so tightly that there may be some chemical bonds between the layers.

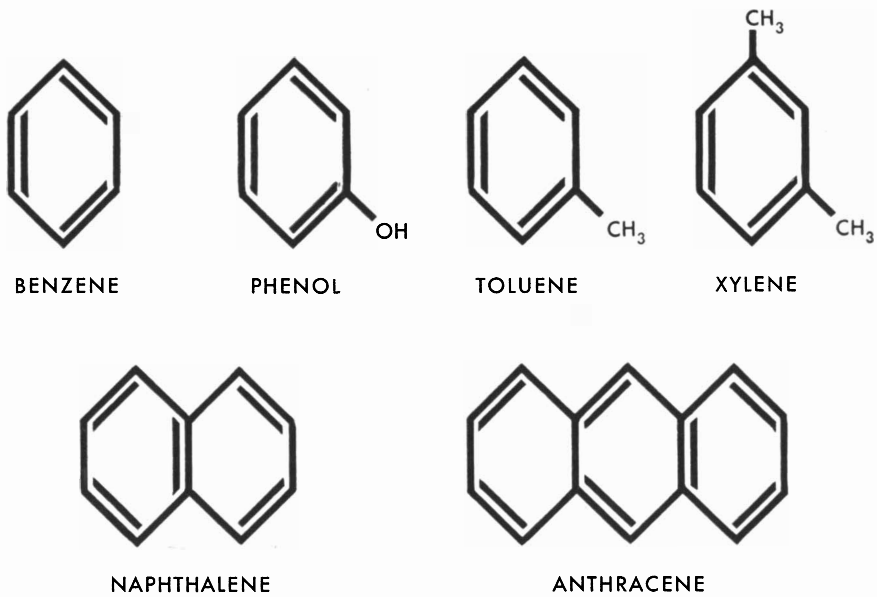
It is estimated that about 75 per cent of the carbon in coal is in the form of such condensed-ring clusters. The clusters are extended in a fairly orderly pattern, which has been visualized as a kind of chicken-wire structure formed by the hexagonal rings of the cluster nuclei. The pattern is broken, however, by smaller components such as phenol and quinone groups. In addition there are stray atoms of nitrogen, sulfur and metallic compounds within the rings or between clusters. Thus coal remains a complex mixture, behaving in a manner unlike that of any other class of chemical materials, with its molecular structure still not fully understood.

The effort to understand the structure of coal is worthwhile because the more that is known about how coal is put together, the more precisely can it be taken apart to yield desirable chemical substances. These studies will lead to the improvement of established chemical processes manipulating coal, as well as to the possible development of new ones. Already one improved process has made from coal over 200 basic chemicals, some entirely new or in quantities never before achieved. It is this fact that leads chemists and conservationists to conclude that the most wasteful thing to do with coal is merely to burn it.

Five Chemical Routes

There are five basic processes for extracting the hidden wealth of materials from coal. Most of them were originally devised in Germany, where, because petroleum was lacking, research centered on this alternative source of basic hydrocarbons. The processes range from methods for reducing the chemical parts of coal to the simplest gaseous molecules, then rebuilding them into desired products, to methods for extracting chemicals directly from coal in mixed groups, then separating them. In these coal processes, as well as in the more advanced ones of the oil industry, the old distinction between aromatic and aliphatic sources is largely lost. Oil products may now be made nearly as readily from coal as from petroleum; petroleum is already supplying by special processes such aromatics as benzene and toluene. Organic chemistry thus moves toward blending the two fields into one continuous spectrum of hydrocarbons.

This is the range of coal processes, in



AROMATIC COMPOUNDS derived from coal tar are characterized by the ring-shaped molecule of benzene (C_6H_6). This structure is commonly represented by the hexagon at the upper left. At each corner of the hexagon is a carbon atom from which projects a hydrogen atom. The double lines in each of the hexagons indicate double chemical bonds.

increasing order of complexity or specialization:

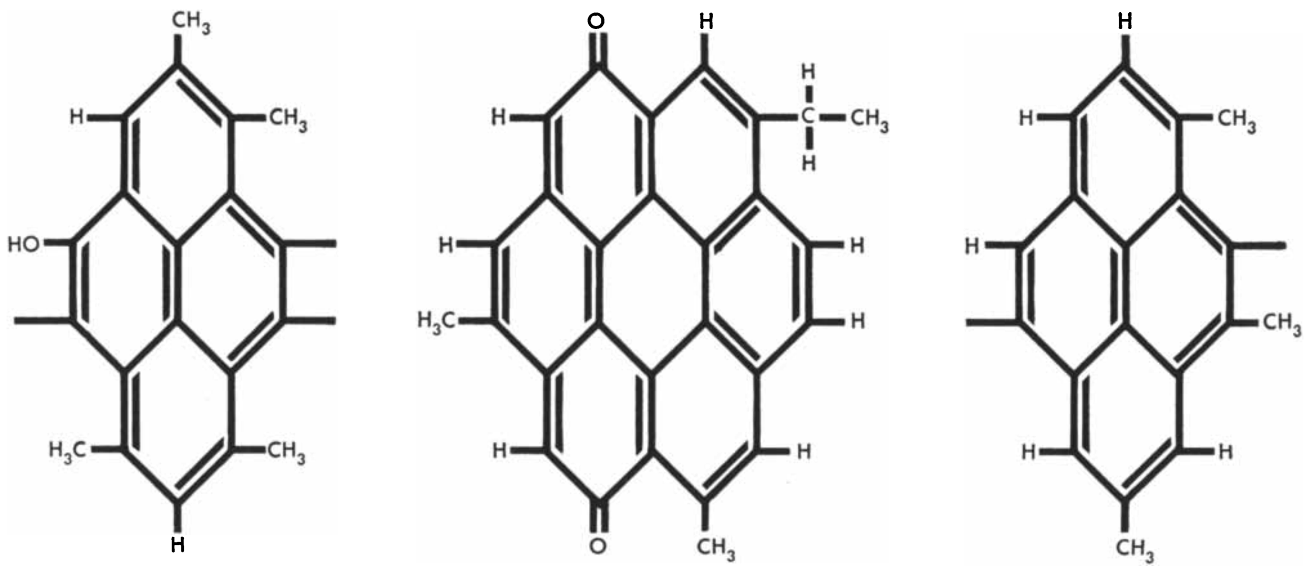
Carbonization. This is the oldest process, embodied in the by-product coke oven, where charges of bituminous are roasted in a controlled atmosphere at 2,000 degrees F. to burn out part of the carbon, drive off volatile substances and give three main product groups: metallurgical coke, coal tar and gases. The principal gas is carbon monoxide (with some methane and nitrogen), used as fuel gas and to make ammonia, methanol and other chemicals. This carbonization process, whose leading chemical exponents in this country are the Allied Chemical & Dye Corp. and the Koppers Co., Inc., is still capable of further development. Only about a third of the tar finds its way into useful chemicals, and nearly half of the coal tar chemicals remain commercially undeveloped. Low- or medium-temperature carbonization processes, with closer control of conditions and catalytic assistance, could now yield more of the desired or unexplored chemicals without lowering the quality of the coke.

Partial combustion. This also is based on an old process, the "water gas" reaction invented in the U. S. in 1873 but hardly changed until recently. A jet of steam is blown over an incandescent bed of coal or coke in a closed chamber to produce large quantities of mixed carbon monoxide and hydrogen, the base of domestic fuel gas. Since the steam cools the coals, which then have to be brought back to 3,000 degrees F. by a blast of air, the process is inefficiently intermittent and has lost ground steadily to higher-B.T.U. natural gas. However, this simple, important process is the first cheap method for adding reactive hydrogen (from water) to coal to get a synthesis gas that can be manipulated into many chemicals. Germany made two advances in the process. In one it is made continuous by substituting pure oxygen for air and feeding the oxygen and steam steadily to the reaction. In the other the pressure is raised to 300 pounds per square inch to cause part of the carbon to combine with the hydrogen to form methane, thus enriching the gas. The efficiency of these developments is now being increased to produce synthesis gas of great chemical promise.

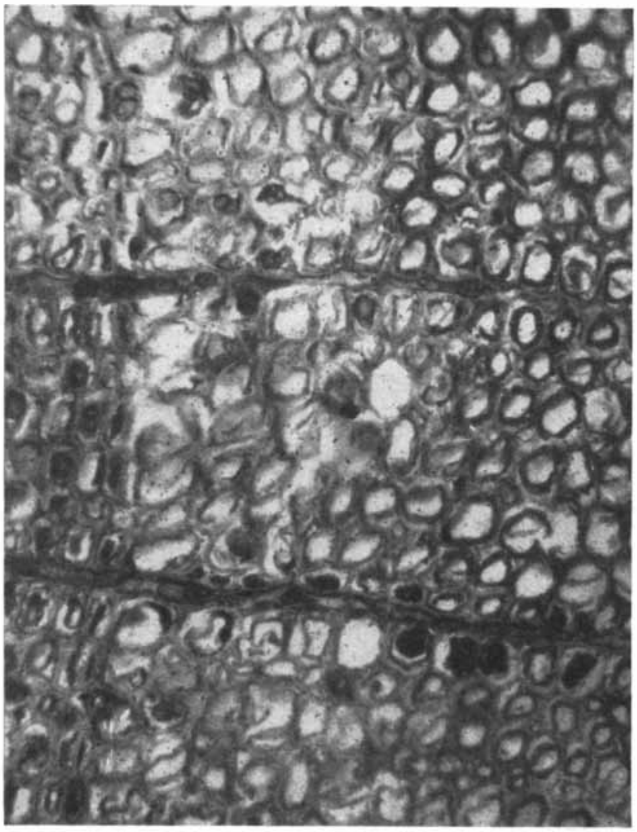
Fischer-Tropsch. If synthesis gas or the residual gas from coal carbonization are now fed across a cobalt or iron catalyst at low heat and pressure, a magical stream of products results: petroleum-like products ranging from gasoline to lubricating oil, plus a range of alcohols beginning with methanol and ethanol, the synthetic forms respectively of wood and grain alcohol. Heat, pressure and catalyst force the small gas molecules to link up into the short-chain molecules of the aliphatic series. By varying the controls, the preponderance of oil or chemical products may be altered. This process is the creation, dated 1933, of the German chemists Franz Fischer and the late Hans Tropsch. U. S. investigators, using fluid-bed catalysts and other techniques, are speeding up and refining the process.

Hydrogenation. This process, another product of German ingenuity developed by Friedrich Bergius in 1910, is the first chemical process to work directly from coal. A blast of pure hydrogen (separated from synthesis gas) is shot into a paste of pulverized coal and catalyst at medium temperature (850 degrees F.) and high pressure (3,000 pounds per square inch) literally to explode the coal molecules and attach hydrogen to their dismembered chains and rings. This, with its massive additions of hydrogen, produces the widest range of coal chemicals: gasoline, Diesel and heavy oils, benzene, phenols and the range of coal tar chemicals, aniline and a swath of nitrogen compounds, plus a small amount of hydrocarbon gas and high-grade coke. Depending on the catalyst and controls, oil products or other chemicals may be the major yield. Germany used this process for the bulk of its wartime gasoline, with Fischer-Tropsch supplying the rest. It is a process capable of many variations and refinements.

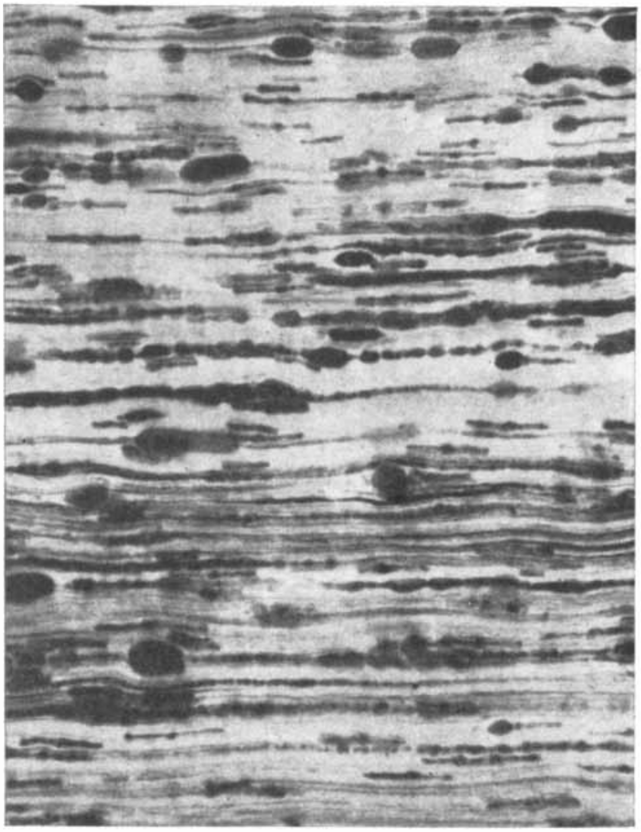
Solvent extraction. A great range of solvents has now been explored for selectively dissolving specific chemicals out of coal paste. None has yet reached commercial status. Solvents are expensive to handle, being merely temporary vehicles in the process. But with the in-



BASIC MOLECULAR STRUCTURE of coal is also characterized by the benzene ring. In coal, however, the rings are assembled in larger structures called cluster units. Depicted here are three typical cluster units. The long bonds that do not end in atoms or atomic groups are presumed to be connected to carbon or oxygen atoms in other cluster units. The flat cluster units are tightly stacked in layers that may be joined by chemical bonds. This gives coal a basic structure rather like contiguous layers of chicken wire.



PEAT is revealed in the first of this series of micrographs made by the U. S. Bureau of Mines. It has the cellular structure of wood.



LIGNITE from North Dakota is streaked with dark bands of resinous material. All sections on this page are enlarged 200 diameters.

BITUMINOUS COAL from Kentucky has bands of coarse material (*bottom*) and fine (*top*). The coarse band has a woody structure.

CANNEL COAL is typical of unbanded coals. It has the pattern of finely divided plant remains such as resins, humus and spores.

creasing efficiency of solvent recovery, chemical extraction by this means may prove attractive. It is low in heat cost and is the least destructive method of obtaining certain compounds.

Toward Carbochemicals

Economic factors have retarded the application of most of these processes in the U. S. So long as oil and chemical products can be secured easily and directly from petroleum and natural gas, there is no strong incentive to take the more difficult, roundabout routes from coal. Nearly all involve net deficits in energy. Moreover, coal as a solid presents inescapable problems of physical handling and ash disposal, even in chemical processes. The multiplicity of chemicals from coal, which have unequal value, present other problems. One large hydrogenation plant, it has been estimated, could pour out enough phenol to supply nearly the whole U. S. requirement at present. But with increasing limitations in the price and availability of natural gas, and with the time approaching when petroleum will not be so freely plentiful, the chemical industry is making a start toward carbochemicals. Two experimental plants are under way. Both are located in the dark, narrow valley of the Kanawha River, flowing between West Virginia's bituminous mountains.

The first and broadest of these experiments is a great, black coal hydrogenation plant at Institute, W. Va., built at a cost of $11 million by the Carbide & Carbon Chemicals Co., a division of Union Carbide & Carbon Corp. This plant, as distinct from the German practice, is designed primarily to produce chemicals. It embodies a number of engineering advances, chiefly in the direction of economy. It cuts the reaction time from about 45 minutes to three minutes. A 300-ton-a-day stream of coal paste is almost continuously piped to two big steel reactors, heavy as naval guns, from which debouch a stream of sludgy mixed products. Through several separation stages, heavy oils, coke and ash are drawn off to one side and hydrocarbon gases to the other. This frees the main stream of liquid chemicals: volatile aromatics beginning with naphthalene in one group, phenolics in another, nitrogen compounds in a third. Early last year the Institute plant shipped its first tank car of high-boiling phenols. Since then it has supplied six other bulk chemicals and a dozen more in experimental amounts.

Altogether Carbide spent over 15 years, interrupted by the war, studying coal in all its chemical aspects. Natural gas, around which it had built its big chemical plant at Charleston, W. Va., had a foreseeable end in that area. Coal hydrogenation, as worked out by its chemists, had three attractions. It supplied certain chemicals such as benzene, the demand for which was outrunning the supply of the coke ovens. It provided still other chemicals which were either wholly destroyed or reduced to barely recoverable amounts in the heat of the coke ovens. Thus it gave promise of developing a base for new products and markets which would permit a gradual shift from natural gas to coal. Some of the products already evolving are new types of phenolic plastics, new pharmaceuticals based on quinoline (nicotinic acid) and on picoline (tuberculosis drugs), and new rocket fuels.

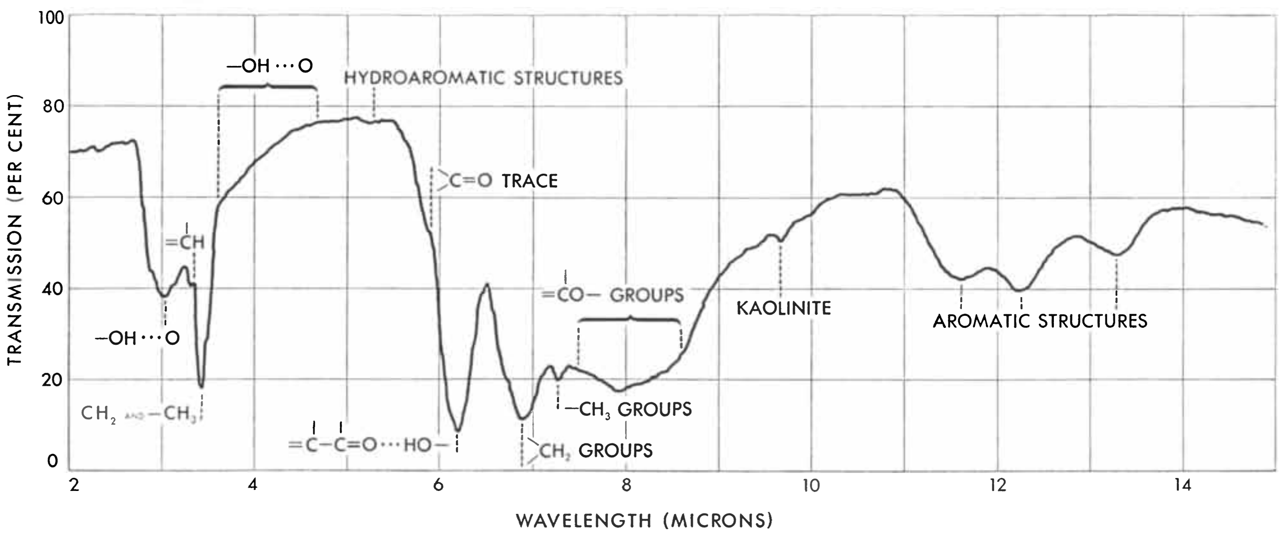
Carbide continues its basic coal studies. It has investigated the underground gasification or burning of coal *in situ* in the earth, concluding that the process is still too uncontrolled and variable in the production of synthesis gas to allow a continuous chemical operation. It is studying other gasification schemes and variations on the Fischer-Tropsch. As natural gas dwindles, some such process will have to supply the large volumes of gas and intermediates needed for synthesis. It is not neglecting the more mundane aspects of coal mining and transportation, which account for over 80 per cent of coal's high costs. Its engineers have developed an experimental robot miner, controlled entirely from above ground, which chews its way 1,000 feet into a coal seam, throwing out a stream of fine coal by means of a flexible conveyor carried behind. It mines up to two tons a minute, with only three outside operators. Carbide's engineers are also looking into the long-distance transportation of pulverized coal by pipeline.

In the next round of expansion, as Carbide scales up to a full-sized 1,000- to 5,000-ton-a-day hydrogenation plant, its engineers envision a continuous-flow operation characteristic of the chemical industry. A never-ending stream of coal from the mines will be processed and sent by pipeline to the chemical plant, which 24 hours a day will split the black mass into nearly 100 sparkling streams of chemicals.

The second big experiment in carbochemicals is taking place a few miles up river at Belle, W. Va. Here for a quarter of a century E. I. du Pont de Nemours & Co. has had one of its basic plants. It has operated on the old water gas reaction, synthesizing from the gas such chemicals as ammonia, urea and other nitrogen products (for fertilizers, plastics, explosives), methanol and other carbon compounds (for solvents, antifreeze, intermediates). The first raw materials for nylon (adipic acid and hexamethylene diamine) were derived here. But any process unchanged for 25 years is suspect to chemists, and the water gas process is not only discontinuous but dirty, throwing out clouds of partially burned coke particles as the steam and air alternately play over the glowing coke. Thus nine years ago du Pont's Polychemicals Department began working on a cleaner, more efficient means of coal gasification. Later the help of the Babcock & Wilcox Company was enlisted in the design of a plant.

The new plant at Belle, which went into operation early this year, is an advanced model of the partial combustion of coal. A jet of oxygen and superheated steam meets a stream of pulverized coal being shot through a burner nozzle into a great tubular furnace. Synthesis gas is tapped off continuously at the top of the furnace, ash and molten slag is continuously washed out at the bottom. From this gas du Pont will make the same products as before except methanol, which is now more cheaply derived from petrochemical sources. The new unit will supply about a third of Belle's gas requirements. If it works out well—and operation thus far indicates that it has marked economic and control advantages over water gas—the process will supplant all of du Pont's remaining water gas units.

Du Pont long weighed the alternative of switching completely away from coal to natural gas, which is now the most economic source of both methanol and synthetic ammonia. But all its newer plants are based on petrochemistry, and du Pont decided that it had better experiment on coal as insurance against the future. Coal partial combustion may some day be called upon to supply the synthesis gas which, with the addition of Fischer-Tropsch-type processes, can be turned into both organic chemicals and liquid fuels. The search for a cheap source of synthesis gas is in flux in many laboratories. The oil industry has done much work on coal gasification as insurance against a decline in petroleum supplies. One of the latest schemes is a process for the underground gasification of Western lignites and other subbituminous coals.



INFRARED SPECTRUM made by R. A. Friedel of the U. S. Bureau of Mines indicates molecules, atomic groups and chemical linkages in a bituminous coal from Pittsburgh, Pa. Kaolinite is an inorganic constituent. The aromatic structures are single and multiple.

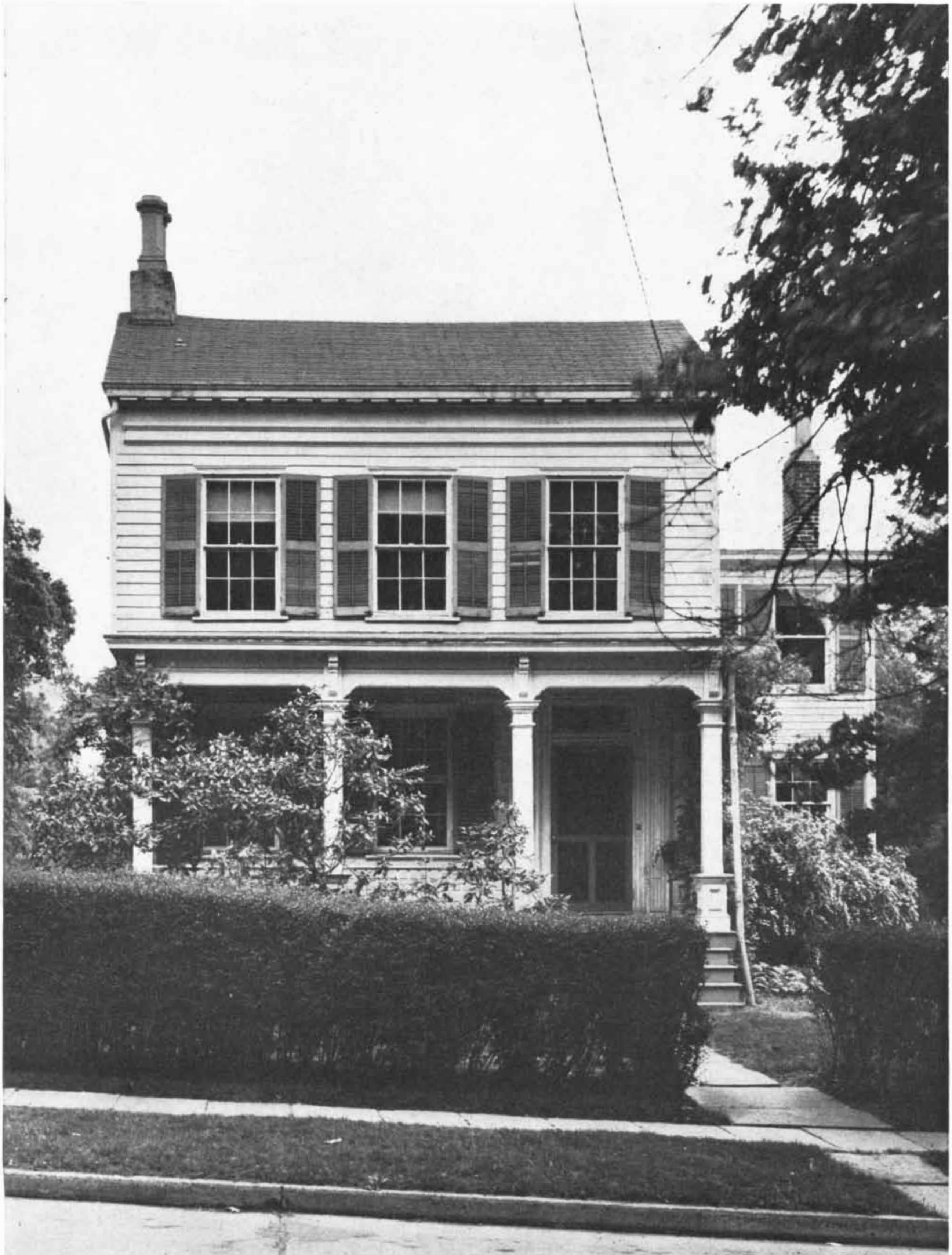
For a time during one of the recurrent oil-shortage scares it was thought that the oil industry would lead the way toward making chemicals from coal. But shifting reserve estimates, regional resource patterns and the even more shifty economics of hydrocarbon sources make prediction dangerous. The development of carbochemicals will probably follow the pattern of the so-called petrochemicals. The chemical industry will explore and establish markets. The oil industry will come in later, as it is pressed to make synthetic fuels, to supply by-product raw materials in huge quantity for the future carbochemical industry.

The Future of Coal

The absence of the coal industry proper in all these endeavors is most noticeable. There has been a certain amount of awakening recently. A few coal companies, such as the Pittsburgh Consolidation Coal Co., have undertaken research programs looking toward coal as a basic carbonaceous chemical material. A few producers have come to support the cooperative Bituminous Coal Research, Inc., which last year raised near Columbus, Ohio, the first general laboratory in the industry in an attempt to catch up on the research so signally lacking in coal for a century. But research funds are meager compared with those in the oil and chemical industries.

What funds are available might better be turned to the fundamental study of coal chemistry, for it is within the molecule of coal that the future of the industry lies. Such fundamental studies would promote the balanced development of coal both as a source of new chemicals and of new energy, for these aspects of coal cannot be separated if this great natural resource is to be most efficiently utilized.

No one can exactly predict the pattern of the new coal age. Eugene Ayres, an authority on energy sources, thinks that low-temperature carbonization will come to the fore on the basis of its low cost and high thermal yields to supply char for electric steam generating stations at the same time that it supplies gas and tar for chemicals and synthetic liquid fuels. Others foresee great coal gasification plants close to the mines simultaneously turning out gases for chemical and liquid-fuel synthesis and by-product gas for heating. Still others see a range of coal-hydrogenation plants to supply a large group of organic chemicals, plus some oil products, some synthesis gas and vital amounts of metallurgical coke for the steel industry.



Einstein's home at 112 Mercer Street in Princeton, N. J.

An Interview with Einstein

Two weeks before Einstein died he was visited by a historian of science. They sat in Einstein's study and discussed some of his illustrious predecessors in the evolution of physics

by I. Bernard Cohen

On a Sunday morning in April, two weeks before the death of Albert Einstein, I sat and talked with him about the history of scientific thought and great men in the physics of the past.

I had arrived at the Einstein home, a small frame house with green shutters, at 10 o'clock in the morning and was greeted by Helen Dukas, Einstein's secretary and housekeeper. She conducted me to a cheerful room on the second floor at the back of the house. This was Einstein's study. It was lined on two walls with books from floor to ceiling and contained a large low table laden with pads of paper, pencils, trinkets, books and a collection of well-worn pipes. There was a phonograph and records. Dominating the room was a large window with a pleasant green view. On the remaining wall were portraits of the two founders of the electromagnetic theory—Michael Faraday and James Clerk Maxwell.

After a few moments Einstein entered the room and Miss Dukas introduced us. He greeted me with a warm smile, went into the adjacent bedroom and returned with his pipe filled with tobacco. He wore an open shirt, a blue sweat shirt, gray flannel trousers and leather slippers. There was a touch of chill in the air, and he tucked a blanket around his feet. His face was contemplatively tragic and deeply lined, and yet his sparkling eyes made him seem ageless. His eyes watered almost continually; even in moments of laughter he would wipe away a tear with the back of his hand. He spoke softly and clearly; his command of English was remarkable, though marked by a German accent. The contrast between his soft speech and his ringing laughter was enormous. He enjoyed making jokes; every time he made a point that he liked, or heard something that appealed to him, he would burst into booming laughter that echoed from the walls.

We sat side by side at the table, facing the window and the view. He appreciated that it was difficult for me to begin a conversation with him; after a few moments he turned to me as if answering my unasked questions, and said: "There are so many unsolved problems in physics. There is so much that we do not know; our theories are far from adequate." Our talk veered at once to the problem of how often in the history of science great questions seem to be resolved, only to reappear in new form. Einstein expressed the view that perhaps this was a characteristic of physics, and suggested that some of the fundamental problems might always be with us.

Einstein remarked that when he was a young man the philosophy of science was considered a luxury, and most scientists paid no attention to it. He assumed that the situation was much the same with respect to the history of science. The two subjects must be similar, he said, because both deal with scientific thought. He wanted to know about my training in science and in history, and how I had become interested in Newton. I told him that one of the aspects of my research was the origin of scientific concepts and the relation between experiment and the creation of theory; what had always impressed me about Newton was his dual genius—in pure mathematics and mathematical physics and in experimental science. Einstein said that he had always admired Newton. As he explained this, I remembered those striking words in his autobiographical statement following a critique of Newtonian concepts—"Newton, forgive me."

Einstein was particularly interested in the various aspects of Newton's personality and we discussed Newton's controversy with Hooke in the matter of priority in the inverse-square law of gravitation. Hooke wanted only "some mention" in the preface to Newton's *Principia*, a little acknowledgment of his efforts, but Newton refused to make the gesture. Newton wrote to Halley, who was supervising the publication of the great *Principia*, that he would not give Hooke any credit; he would rather suppress the crowning glory of the treatise, the third and final "book" dealing with the system of the world. Einstein said: "That, alas, is vanity. You find it in so many scientists. You know, it has always hurt me to think that Galilei did not acknowledge the work of Kepler."

We then spoke of Newton's controversy with Leibniz over the invention of the calculus, and how Newton had attempted to prove that his German contemporary was a plagiarist. There was set up a supposed international committee of inquiry, composed of Englishmen and two foreigners; today we know that Newton anonymously directed the committee's activities. Einstein said that he was shocked by such conduct. He did not appear too much impressed when I asserted that it was the nature of the age to have violent controversies, that the standards of scientific behavior had changed greatly since Newton's day. Einstein felt that whatever the temper of the time there is a quality of human dignity that should enable a man to rise above the passions of his age.

Then we talked about Franklin, whose conduct as a scientist I had always admired, especially because he had not entered into such controversy. Franklin was proud that he had never written a

The Institute for Advanced Study, at which Einstein was professor of mathematics

polemic in defense of his experiments or his ideas. He believed that experiments can be tested only in the laboratory, and that concepts and theories must make their own way by proving their validity. Einstein only partly agreed. It was well to avoid personal fights, he said, but it was also important for a man to stand up for his own ideas. He should not simply let them go by default, as if he did not really believe in them.

Einstein, who knew of my interest in Franklin, wanted to know more about him: Had he done more in science than invent the lightning rod? Had he really done anything of importance? I replied that in my opinion the greatest thing to come out of Franklin's research was the principle of the conservation of charge. Yes, said Einstein, that was a great contribution. Then he thought to himself for a moment or two and, with a smile, asked me how Franklin could have proved it. Of course, I conceded, Franklin was only able to adduce some experimental examples of equal positive and negative electrification, and to show the applicability of the principle in explaining a variety of phenomena. Einstein shook his head once or twice, and admitted that until then he had not appreciated that Franklin deserved a place of honor in the history of physics.

The subject of controversies over scientific work led Einstein to take up the subject of unorthodox ideas. He mentioned a fairly recent and controversial book, of which he had found the non-scientific part—dealing with comparative mythology and folklore—interesting. "You know," he said to me, "it is not a bad book. No, it really isn't a bad book. The only trouble with it is, it is crazy." This was followed by a loud burst of laughter. He then went on to explain what he meant by this distinction. The author had thought he was basing some of his ideas upon modern science, but found the scientists did not agree with him at all. In order to defend his idea of what he conceived modern science to be, so as to maintain his theories, he had to turn around and attack the scientists. I replied that the historian often encountered this problem: Can a scientist's contemporaries tell whether he is a crank or a genius when the only evident fact is his unorthodoxy? A radical like Kepler, for example, challenged accepted ideas; it must have been difficult for his contemporaries to tell whether he was a genius or a crank. "There is no objective test," replied Einstein.

Einstein was sorry that scientists in the U. S. had protested to publishers about the publication of such a book. He thought that bringing pressure to bear on a publisher to suppress a book was an evil thing to do. Such a book really could not do any harm, and was therefore not really bad. Left to itself, it would have its moment, public interest would die away and that would be the end of it. The author of such a book might be "crazy" but not "bad," just as the book was not "bad." Einstein expressed himself on this point with great passion.

Much of the time we spent together was devoted to the history of science, a subject that had long been of interest to Einstein. He had written many articles about Newton, prefaces to historical works and also biographical sketches of his contemporaries and the great men of science of the past. Thinking aloud about the nature of the historian's job, he compared history to science. Certainly, he said, history is less objective than science. For example, he explained, if two men were to study the same subject in history, each would stress the particular part of the subject which interested him or appealed to him the most. As Einstein saw it, there is an inner or intuitional history and an external or documentary history. The latter is more objective, but the former is more interesting. The use of intuition is dangerous but necessary in all kinds of historical work, especially when the attempt is made to reconstruct the thought processes of someone who is no longer alive. This kind of history, Einstein felt, is very illuminating despite its riskiness.

It is important to know, he went on, what Newton thought and why he did certain things. We agreed that the challenge of such a problem should be the major motivation of a good scientific historian. For instance, how and why had Newton developed his concept of the aether? Despite the success of Newton's gravitation theory, he was not satisfied by the concept of the gravitational force. Einstein believed that what Newton most strongly objected to was the idea of a force being able to transmit itself through empty space. Newton hoped by means of an aether to reduce action at a distance to a force of contact. Here is a statement of great interest about Newton's process of thought, Einstein declared, but the question arises as to whether—or perhaps to what extent—one can document such intuition. Einstein said most emphatically that he thought the worst person to document any ideas about how discoveries are made is the discoverer. Many people, he went on, had asked him how he had come to think of this or how he had come to think of that. He had always found himself a very poor source of information concerning the genesis of his own ideas. Einstein believed that the historian is likely to have a better insight into the thought processes of a scientist than the scientist himself.

Einstein's interest in Newton had always been centered on his ideas, which are to be found in every textbook of physics. He had never made a systematic examination of all Newton's writings, in the manner of a thorough historian of science, but of course he had an appreciation of Newtonian science that could come only from a scientific peer of Newton. Yet Einstein was keenly interested in the results of scholarship in the history of science, such as the development of some of Newton's fundamental opinions in his successive revisions of his major works, the *Opticks* and the *Principia*. In our correspondence on this subject, the question had arisen as to whether there was any sense in which Einstein might have "revived" a Newtonian concept of light in his paper on photons in 1905. Had he ever read Newton's writings on light before that year? He told me: "As far as I can remember I had not studied, or at least not studied profoundly, the original before I had to write the little foreword for the *Opticks*. The reason is, of course, that everything that Newton ever wrote is alive in the later works in physical science." Furthermore, "younger people are very little historically minded." Einstein's main concern had been his own scientific work; he had known of Newton primarily as the author of many of the fundamental concepts in classical physics. But he had encountered Newton's "utterances of a philosophical character"; these were cited again and again.

In 1905 Einstein knew that Newton had espoused a corpuscular theory of light, a fact which he must have found in Drude's famous book on light, but he had evidently not known until many decades later about Newton's attempts to blend a corpuscular and wave theory. Einstein knew of my interest in the *Opticks*, especially in the influence of this book on the later course of experimental physics. When I remarked on the greatness of Newton's intuition about the study of light being the key to exact knowledge of the corpuscles of matter, Einstein misunderstood what I had said. He replied that we must not take too seriously the historical accident that Newton's corpuscular view of light with wave aspects sounds something like modern statements. I explained what I had meant: Newton had attempted to infer from what we call interference or diffraction phenomena the size of the corpuscles of matter. These intuitions might be very profound, Einstein agreed, but not necessarily fruitful. For example, he said, Newton's thoughts on this subject did not lead anywhere; he could not prove his point nor derive precise information about the structure of matter.

Einstein was actually more interested in the *Principia* and in Newton's views on hypotheses. He greatly esteemed the *Opticks*, but primarily for the analysis of color and the magnificent experiments. Of this book he had written that "it alone can afford us the enjoyment of a look at the personal activity of this unique man." Looking back over all of Newton's ideas, Einstein said, he thought that Newton's greatest achievement was his recognition of the role of privileged systems. He repeated this statement several times and with great emphasis. This is rather puzzling, I thought to myself, because today we believe that there are no privileged systems, only inertial systems; there is no privileged frame—not even our solar system—which we can say is privileged in the sense of being fixed in space, or having special physical properties not possible in other systems. Due to Einstein's own work we no longer believe (as Newton did) in concepts of absolute space and absolute time, nor in a privileged system at rest or in motion with respect to absolute space. Newton's solution appeared to Einstein ingenious and necessary in his day. I was reminded of Einstein's statement: "Newton, . . . you found the only way which, in your age, was just about possible for a man of highest thought and creative power."

I remarked that Newton's genius was displayed in his adopting as a "hypothesis" in the *Principia* the statement about the "center of the system of the world" being fixed, immobile in space; that a lesser man than Newton might have thought he could prove such an assertion, either by mathematics or by experiment. Einstein replied that Newton probably did not fool himself. He was apt to know what could be proved and what could not; this was a sign of his genius.

Einstein then said that the biographical aspects of scientists had always interested him as much as their ideas. He liked to learn the lives of the men who had created the great theories and performed the major experiments, what kind of men they were, how they worked and how they treated their fellow men. Reverting to an earlier topic of our conversation, Einstein observed how many scientists seemed to have suffered from vanity. He pointed out that vanity may appear in many different forms. Often a man would say that he had no vanity, but this too was a kind of vanity because he took such special pride in the fact. "It is like childishness," he said. Then he turned to me and his booming laugh

Along this street Einstein walked to the Institute

filled the room. "Many of us are childish; some of us more childish than others. But if a man knows that he is childish, then that knowledge can be a mitigating factor."

The conversation then turned to Newton's life and his private speculations: his investigations of theology. I mentioned to Einstein that Newton had essayed a linguistic analysis of theology, in an attempt to find the corruptions that had been introduced into Christianity. Newton was not an orthodox Trinitarian. He believed his own views were hidden away in Scripture, but that the revealed documents had been corrupted by later writers who had introduced new concepts and even new words. So Newton sought by linguistic analysis to find the truth. Einstein remarked that for him this was a "weakness" in Newton. He did not see why Newton, finding his own ideas and the orthodox ones at variance, did not simply reject the established views and assert his own. For instance, if Newton could not agree with the accepted interpretations of Scripture, why did he believe that Scripture must nevertheless be true? Was it only because the common point of view was that fundamental truths are contained in the Bible? It did not seem to Einstein that in theology Newton showed the same great quality of mind as in physics. Einstein apparently had little feeling for the way in which a man's mind is imprisoned by his culture and the character of his thoughts are molded by his intellectual environment. I did not press the point, but I was struck by the fact that in physics Einstein could see Newton as a man of the 17th century, but that in the other realms of thought and action he viewed each man as a timeless, freely acting individual to be judged as if he were a contemporary of ours.

Einstein seemed particularly impressed by the fact that Newton had not been entirely satisfied with his theological writings, and had sealed them all up in a box. This seemed to indicate to Einstein that Newton was aware of the imperfect quality of his theological conclusions and would not present to public view any writings that did not measure up to his own high standards. Since Newton obviously did not wish to publish his speculations on theology, Einstein asserted with some passion that he personally hoped no one else would publish them. Einstein said a man has a right to privacy, even after his death. He praised the Royal Society for having resisted all pressure to edit and print writings of Newton which their author had not wanted to publish. He believed that Newton's correspondence could justly be published, because a letter written and sent was intended to be read, but he added that even in correspondence there might be some personal things which should not be published.

Then he spoke briefly about two great physicists whom he had known well: Max Planck and H. A. Lorentz. Einstein told me how he had come to know Lorentz in Leiden through Paul Ehrenfest. He remarked that he had admired and loved Lorentz perhaps more than anyone else he had ever known, and not only as a scientist. Lorentz had been active in the movement for "international cooperation," and had always been interested in the welfare of his fellow men. He had worked on many technical problems for his own country, an activity which was not generally known. This was part of Lorentz' character, Einstein explained, a kind of nobility which made him work for the well-being of others, preferably in anonymity. Einstein also expressed great affection for Max Planck. Planck was a religious man, he said, and always sought to reintroduce the absolutes—even on the basis of relativity theory. I asked Einstein whether Planck had ever fully accepted the "theory of photons," or whether he had continued to restrict his interest to the absorption or emission of light without regard to its transmission. Einstein stared at me for a moment or two in silence. Then he smiled and said: "No, not a theory. Not a *theory* of photons," and again his deep laughter enveloped us both—and the question was never answered. I remembered that Einstein's 1905 paper, for which (nominally) he had been awarded the Nobel prize, did not contain the word "theory" in the title, but referred instead to considerations from a "heuristic viewpoint."

There are fashions in science, Einstein said. When he had studied physics as a young man, one of the major questions being discussed was: Do molecules exist? He remembered how important scientists, men like Wilhelm Ostwald and Ernst Mach, had been explicit in stating that they did not really believe in atoms and molecules. One of the greatest differences between physics then and now, Einstein observed, was that today nobody bothers to ask this particular question any more. Although Einstein did not agree with the radical position adopted by Mach, he told me he admired Mach's writings, which had had a great influence on him. He had visited Mach, he said, in 1913, and had raised a question in order to test him. He asked Mach what his position would be if it proved possible to predict a property of a gas by assuming the existence of atoms—some property that could not be predicted without the assumption of atoms and yet one that could be observed. Einstein said he had always believed that the invention of scientific concepts and the building of theories upon them was one of the great creative properties of the human mind. His own view was thus opposed to Mach's, because Mach assumed that the laws of science were only an economical way of describing a large collection of facts. Could Mach accept the hypothesis of atoms under the circumstances Einstein had stated, even if it meant very complicated computations? Einstein told me how delighted he was when Mach replied affirmatively. If an atomic hypothesis would make it possible to connect by logic some observable properties which would remain unconnected without this hypothesis, then, Mach said, he would have to accept it. Under these circumstances it would be "economical" to assume that atoms may exist because then one could derive relations between observations. Einstein had been satisfied; indeed more than a little pleased. With a serious expression on his face, he told me the story all over again to be sure that I understood it fully. Wholly apart from the philosophical victory over what Einstein had conceived Mach's philosophy to have been, he had been gratified because Mach admitted that there might, after all, be some use to the atomistic philosophy to which Einstein had been so strongly committed.

Einstein said that at the beginning of the century only a few scientists had been philosophically minded, but today physicists are almost all philosophers, although "they are apt to be bad philosophers." He pointed as an example to logical positivism, which he felt was a kind of philosophy that came out of physics.

Now it was time to leave. I was horrified to realize it was a quarter to 12. Knowing that Einstein tired easily, I had meant to stay only half an hour. Yet every time I had gotten up to depart he had said, "No, no, don't go yet. You have come to see me about your work and there is still more to talk about." Yet at last I was taking my leave. Miss Dukas joined us as we walked toward the front of the house. As I neared the stairs, I turned to thank Einstein, missed a step and almost fell. When I had recovered my balance, Einstein smiled and said, "You must be careful here, the geometry is complicated. You see," he continued, "negotiating stairs is not really a physical problem, but a problem in applied geometry." He chuckled and then laughed out loud. I started down the stairs and Einstein began to walk down the corridor toward the study. Suddenly he turned and called: "Wait. Wait. I must show you my birthday present."

As I returned to the study Miss Dukas explained to me that Eric Rogers, who teaches physics at Princeton, had made a gadget for Einstein as a present for his 76th birthday, and that Professor Einstein had been delighted with it. Back in the study, I saw Einstein take from the corner of the room what looked like a curtain rod five feet tall, at the top of which was a plastic sphere about four inches in diameter. Coming up from the rod into the sphere was a small plastic tube about two inches long, terminating in the center of the sphere. Out of this tube there came a string with a little ball at the end. "You see," said Einstein, "this is designed as a model to illustrate the equivalence principle. The little ball is attached to a string, which goes into the little tube in the center and is attached to a spring. The spring pulls on the ball, but it cannot pull the ball up and into the little tube because the spring is not strong enough to overcome the gravitational force which pulls down on the ball." A big grin spread across his face and his eyes twinkled with delight as he said: "And now the equivalence principle." Grasping the gadget in the middle of the long brass curtain rod, he thrust it upward until the sphere touched the ceiling. "Now I will let it drop," he said, "and according to the equivalence principle there will be no gravitational force. So the spring will now be strong enough to bring the little ball into the plastic tube." With that he suddenly let the gadget fall freely and vertically, guiding it with his hand, until the bottom reached the floor. The plastic sphere at the top was now at eye level. Sure enough, the ball nestled in the tube.

With the demonstration of the birthday present our meeting was at an end. As I walked out to the street, I thought to myself that of course I had known that Einstein was a great man and a great scientist, but I had had no idea of the warmth of his friendly personality, his kindness and his rich sense of humor.

There had been, during that visit, no sense of the imminence of death. Einstein's mind was alert, his wit was keen and he had seemed very gay. On the Saturday following my visit, a week before Einstein was taken to the hospital, a Princeton friend of long standing and intimacy went with Einstein to the hospital to see Einstein's daughter, who was ill with sciatica. This friend writes that after he and Einstein left the hospital that Saturday, "we went for a long walk. Strange to say, we talked about our attitudes toward death. I mentioned a quotation from James Frazer in which he said that fear of death was the basis of primitive religion, and that to me death was both a fact and a mystery. Einstein added, 'And also a relief.' "

THE MUTATION OF VIRUSES

Viruses provide a simple example of the basic process of biological change. Some recent experiments suggest that it may soon be possible to alter their inborn characteristics predictably by chemical means

by C. A. Knight and Dean Fraser

In 1918 and 1919 influenza, known for centuries as a distressing but seldom fatal disease, suddenly turned virulent and swept across the world in the greatest epidemic of modern times. Then, just as suddenly, the fatal form of influenza disappeared, leaving some 25 million dead. Where had this scourge come from and where had it gone? At the time there was no accepted answer. We now know that influenza is a virus disease, and we believe that the 1918-1919 pandemic was simply a catastrophic example of biological mutation. The study of virus mutation has been vigorously pursued with the aim of understanding these changes and acquiring knowledge that will enable us to prevent another world-wide disaster. The mutation of viruses is also studied because mutation is the process of hereditary change that links men to all other living things and to their primordial ancestors.

Reproduction is one of the two essential features of life. Mutation is the other. The discovery that viruses share this property with all other living things has opened a new field of scientific investigation: the chemistry and physics of genetics. This field is only about 10 years old, but the information that it has brought to light has already revolutionized our ideas of life processes.

Why are viruses the key to the chemistry and physics of heredity? It has long been known that heredity is determined by the chromosomes, the threadlike bodies in the nucleus of the cell, and by their subunits the genes. The problem of how the genetic material produces its hereditary effects is fundamentally the problem of its chemistry. In most living things the study of this problem is virtually hopeless. In many-celled organisms it takes a specialist just to *find* the chromosomes. The genetic material in such organisms is so intimately involved with other cellular constituents that it is most difficult to separate it. What we need is a simpler creature. It would be best, in fact, to have an organism that is composed solely of genes and has only the function of reproducing them. Viruses come close to having such characteristics.

Viruses live not only in men and other animals but also in plants and bacteria. It is possible to raise plant and bacterial viruses in huge numbers. A virus can be selected for a specific property, such as the ability to attack a certain host or to cause a certain disease symptom. A genetically pure sample of virus can then

TOBACCO MOSAIC VIRUS is the subject of many mutation studies. These three tobacco plants show the effect of J14D1, a "killer" strain of the virus. In the first plant the infection is local; in the second plant it is systemic. The infection has killed the third plant.

be isolated, and a million billion progeny grown within a few days. The techniques are quite similar for both plant and bacterial viruses. The essence is to mix a small number of virus particles with a large excess of host cells. In plants this is done by spreading a thin solution of virus on a leaf; in bacteria, by adding perhaps 100 virus particles to a million cells immobilized on the surface of a nutrient medium in a glass dish. Where a cell has been attacked by a virus, the progeny of the virus spread to neighboring cells until a "lesion" of infected cells is produced on the leaf or in the carpet of bacteria. Since there were so few virus particles and so many host cells, we can be sure that each infection was caused by a single virus particle, and that each area of dead cells contains the progeny of this single original particle. By removing a bit of such a lesion and repeating the process of infection we can very quickly obtain a strain of virus that is genetically more than 99 per cent pure.

Once we have obtained this pure strain of virus, we can set about looking for mutants. To do this we need only place a sample of the pure colony in a slightly different environment in which the parent strain will not grow. Under these conditions only a very few lesions will appear—perhaps one per million virus particles. These lesions represent the progeny of mutants that are capable of living in the new host cell.

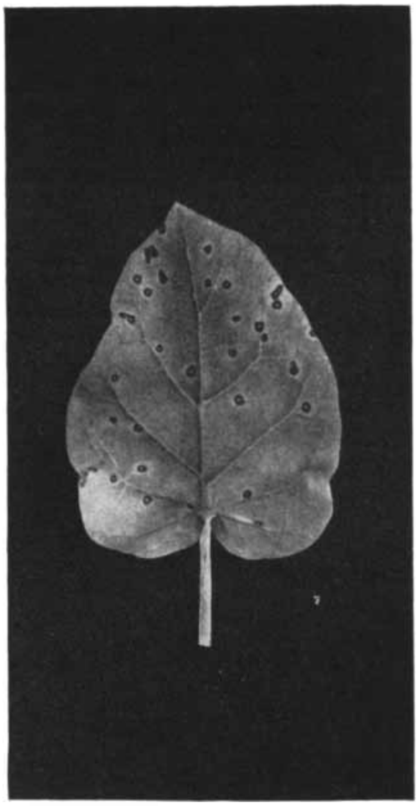
What chemical events occur when a virus mutates? To answer this question we must briefly review some other things we know about viruses. All known viruses have two chemical constituents: protein and nucleic acid. Like other proteins, virus proteins are very large molecules composed of much smaller units, the amino acids. The protein can easily be broken down into these units, and it is found that there are only some 20 different amino acids in even the most complex protein. Nucleic acids, found in all living cells, are also huge molecules. They can similarly be broken down into a few simple components: inorganic phosphate, two sugars and five organic bases. To the best of our present knowledge, these simple constituents of proteins and nucleic acids (with a few exceptional derivatives and close relatives) are the building blocks both of all viruses and of the chromosomes of all living things.

Now we can ask another question: If the biological properties of a virus differ from those of its parent, is this difference reflected in the make-up of its protein? This question was investigated with the famous virus that causes the mosaic disease of the tobacco plant. The original strain of the tobacco mosaic virus, purified and crystallized in 1935 by the Nobel prize winner Wendell M. Stanley, has descendants which vary in their virulence. Six of these variants were chosen for study; each had a distinctive effect on the Turkish tobacco plant. One strain, for example, caused a mosaic pattern, another caused extensive yellowing, a third caused thin white rings or lines. Each strain had been carefully segregated and was believed to be genetically pure. In order to obtain enough material for chemical analysis, 600 tobacco plants were infected with each strain by rubbing a little infectious juice on their leaves. After about three weeks the fully infected plants were frozen and ground in a meat chopper; juice was then extracted from the thawed pulp. Now virus was removed from the juice. This was done by whirling the juice in a centrifuge which was first run at low speed to separate the larger impurities, and then at a higher speed, developing a force 60,000 times gravity. Under these conditions the virus separates from smaller impurities in the juice. After repeated centrifuge runs the pure virus was isolated as a white powder. This could now be subjected to chemical analysis.

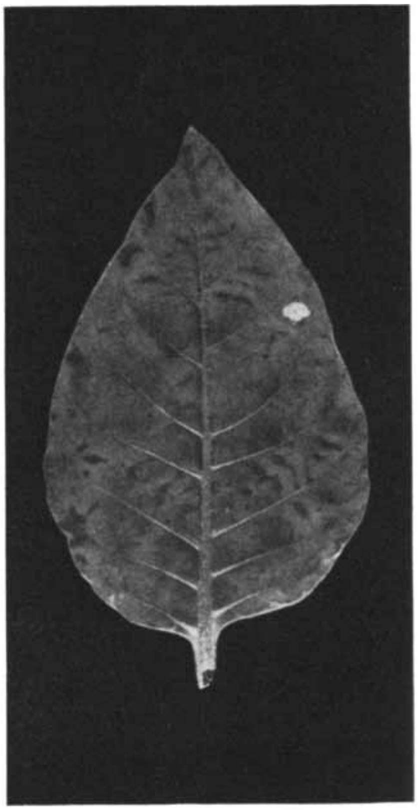
The results were immediately encouraging. The six virus strains were analyzed for their content of three amino acids: tyrosine, tryptophan and phenylalanine. It was discovered that the strain which caused the white rings contained relatively more tyrosine and less tryptophan.

At this point the arrival of a new analytical technique made it possible to analyze, not three amino acids in a virus strain, but all of the 20-odd amino acids. Called microbiological assay, the technique is based on the fact that certain strains of bacteria will grow only if specific amino acids are added to their nutrient. To analyze a protein by this technique, it is broken down into amino acids and added to the nutrient of a bacterial strain. The bacteria then select the amino acid they need and grow in proportion to its amount. One advantage of the method for virus research is that very little protein is needed. About a thousandth of an ounce is enough for a triplicate analysis.

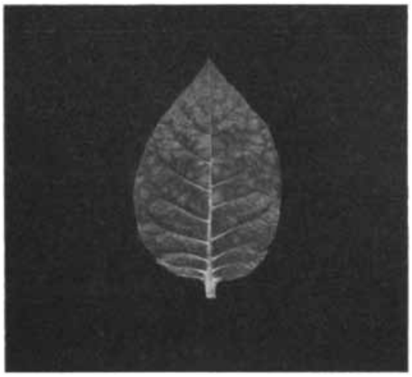
Thirteen strains of the tobacco mosaic virus were now analyzed for their amino acid content. Eleven differed from the original tobacco mosaic strain. The differences were mainly in the proportion

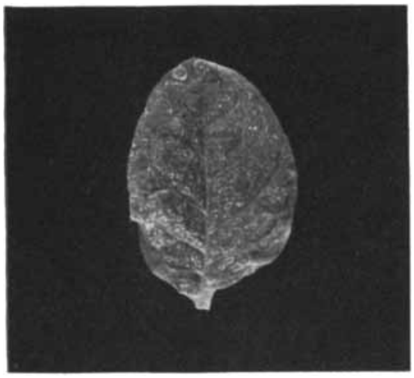


MANY LESIONS occur on the surface of a tobacco leaf when a dilute solution of the tobacco mosaic virus is spread over it.



ONE LESION on the surface of a leaf indicates a colony descended from the spontaneous mutation of a tobacco mosaic virus.





CHARACTERISTIC SYMPTOM of the tobacco leaf is produced by each of four strains of the tobacco mosaic virus. Top: the original strain. Second from top: strain M. Third: strain J14D1. Bottom: strain HR.

of amino acids, but one strain possessed two amino acids entirely lacking in the other strains. In general the strains that were most closely related in their biological effects were most similar in their protein composition. One strain called M apparently did not differ chemically from the original strain. Whether this is due to the limitations of the analysis or to subtle structural differences that are not detectable by present chemical means is not clear.

One of the most interesting results came out of the comparison of the original tobacco mosaic strain and a "killer" strain called J14D1. Young Turkish tobacco plants infected with the original strain suffer a characteristic mottling of the leaves accompanied by a certain amount of blistering, distortion and stunting. However, the plants continue to grow, reach maturity, flower and bear viable seed. Identical young plants infected with J14D1 are rapidly killed. Yet the killer strain differed from the original one only in its proportion of two amino acids: glutamic acid and lysine. Even in this proportion it differed from the original strain only by 10 to 20 per cent. In all other respects the two strains seem identical. This is a striking illustration of how small the chemical difference between a mild strain of virus and a killer may be.

It is tempting to suppose that the sudden conversion of a mild strain of the influenza virus to a disastrous lethal strain may have involved just such a minute alteration. It would be interesting to test this idea experimentally, and to determine whether differences such as those found in the tobacco mosaic virus exist between the mild and lethal forms of the influenza virus. Unfortunately in 1919 it was not even known that influenza was a virus disease, and the lethal strain has not been preserved. However, two major types of currently epidemic influenza virus have been analyzed. Their proteins are remarkably alike, but their content of five amino acids is distinctly different. This suggests that the changes which accompany mutation in plant viruses are also found in influenza and other animal viruses.

A difficulty which limits the usefulness of plant and animal viruses in mutation studies is that at present we cannot be sure of the precise genetic relationships among strains. To put it another way, we cannot demonstrate the number of mutational steps involved in going from one strain to another. Thus we cannot relate chemical findings to specific mutational steps. This suggests that we turn to the bacterial virus called T2, which infects the bacterium *Escherichia coli.* Exact genetic relationships have been determined among several mutants of T2.

A few years ago it would have been impossible to analyze the chemical constituents of a bacterial virus. Where we can isolate as much as a pound of some plant viruses, with bacterial viruses we must frequently work with amounts 1,000 times smaller. This difficulty was overcome by improved methods of culture and isolation, and by the development of chromatography, the technique that sensitively fractionates mixtures of things which are very much alike [see "Chromatography," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, March, 1951]. With chromatography it is possible to analyze the complete amino acid content of two or three milligrams of virus protein.

Chromatography is now used to analyze the proteins in the T2 virus and others that attack *E. coli.* Preliminary results show that two unrelated *E. coli* viruses have proteins quite different in composition. Two closely related viruses are chemically so much alike that it is difficult, even with the accuracy of chromatographic analysis, to be sure that they differ at all. These results, then, parallel the much more extensive evidence from plant viruses.

The problem of different strains of apparently identical composition may not be unsolved much longer. Techniques currently under development hold the promise of indicating not only the quantity of each amino acid, but also of the sequence of amino acids in the protein chain. These methods hold the key to the complete solution of the relationships of protein structure in the virus strains.

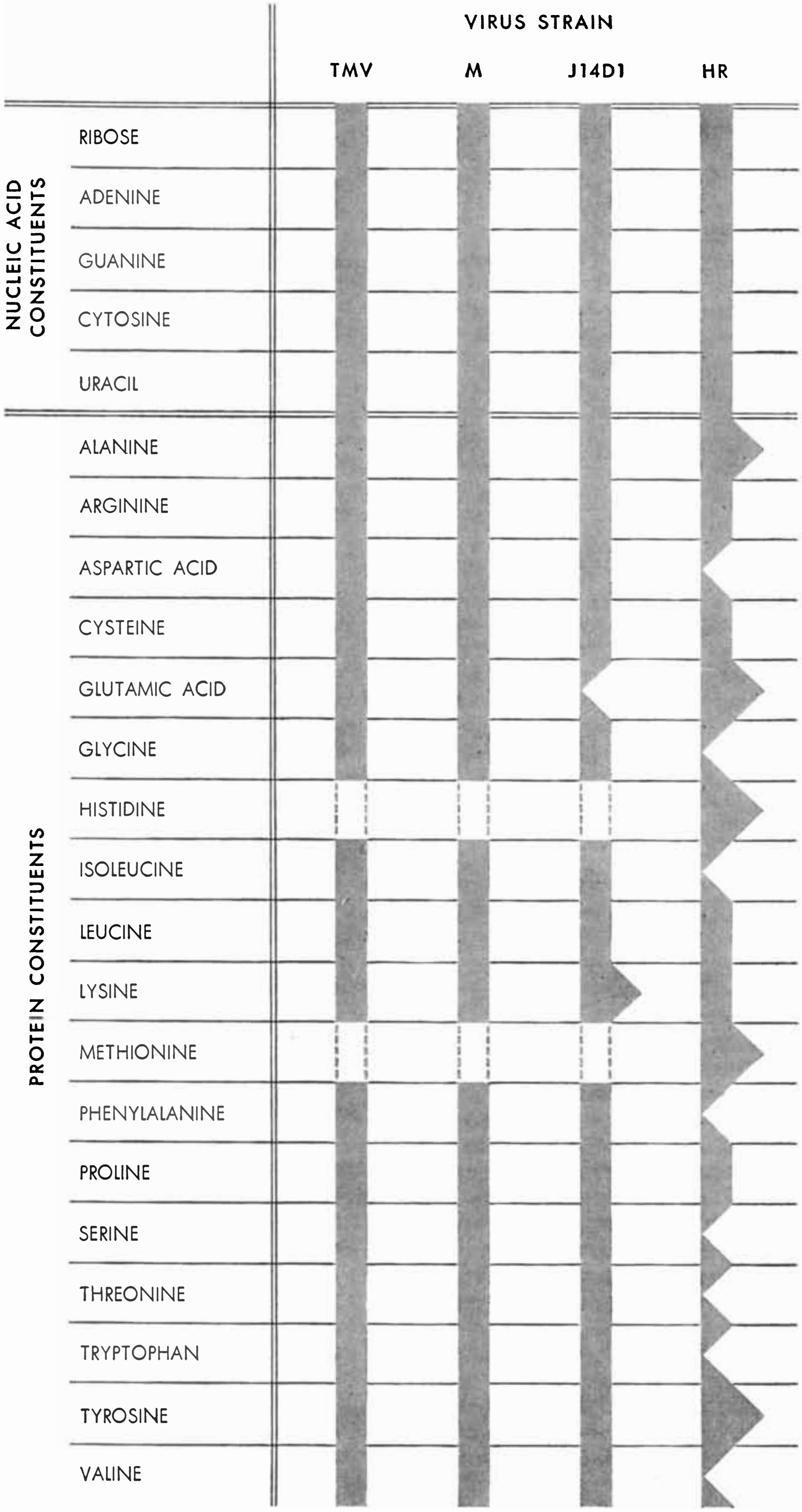
So far we have discussed the protein component of viruses. What about the nucleic acid component? It has been demonstrated that, when a T2 virus infects a bacterium, the nucleic acid of the virus enters the bacterial cell and the bulk of the viral protein remains outside. This indicates that the nucleic acid initiates the production of new virus particles and determines their characteristics. Because nucleic acids, like proteins, are made of relatively few subunits, hereditary variations in their composition can also be sought. Using chromatographic and spectrophotometric methods Roy Markham and J. D. Smith at the University of Cambridge have analyzed the nucleic acids in four strains of the tobacco mosaic virus and in four other plant viruses. The results indicate that the nucleic acids of unrelated viruses differ in chemical composition, and that the nucleic acids of the tobacco mosaic strains are very much alike. One of the authors and his collaborators in the Virus Laboratory at the University of California continued this investigation. They extended the analyses to many more strains of the tobacco mosaic virus and to other plant viruses. The results were essentially the same as those obtained by Markham and Smith.

These viruses all contain ribose nucleic acid (RNA). What is the situation among viruses containing deoxyribose nucleic acid (DNA)? The studies of S. S. Cohen of the Children's Hospital of Philadelphia and G. R. Wyatt of the Laboratory of Insect Pathology in Canada suggest that the same relationships apply to DNA-containing viruses. The nucleic acids of diverse insect viruses and of unrelated bacterial viruses were found to differ in composition; the nucleic acids of three related strains of bacterial virus were indistinguishable in composition, even to containing the unique base hydroxymethylcytosine.

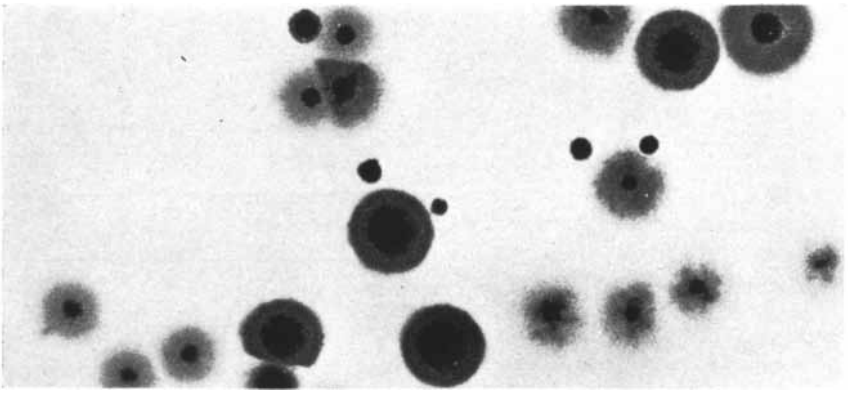
Despite the difficulty in demonstrating chemical differences between closely related viruses, it seems more than likely from the present picture that the differences exist. If this is the case, can we cause these chemical changes artificially? That is, can we change one virus into another?

An answer to this question is suggested by the behavior of certain bacterial viruses. It is known that the protein of a bacterial virus forms a sort of coat around the nucleic acid. It is also known that the protein coat determines the specificity of the virus, *i.e.*, whether or not it will attack a certain bacterium. Now when the similar bacterial viruses T2 and T4 are added to a culture of *E. coli*, viruses of both kinds may simultaneously attack a single bacterium. Sometimes this causes a biochemical mix-up in which the viral progeny have T4 protein coats and T2 nucleic acid. Such a virus will attack a bacterium which is normally infected only by the T4 strain. The progeny of this infection, however, are only of the T2 strain. This suggests that we might at least be able to modify the protein coat of a virus so that it would attack a new host. Although this has not actually been done, certain experiments lead in that direction.

Some years ago Wendell M. Stanley and G. L. Miller tried to modify tobacco mosaic virus by treating it with various



AMINO ACID AND NUCLEIC ACID COMPOSITION of four strains are compared. The original strain (TMV) is arbitrarily represented as a straight vertical bar. The differences in the other strains are shown by peaks and notches indicating more or less of a particular component. The peaks and notches are of equal size and have no relationship to quantitative differences. The masked strain (M) shows no differences. The killer strain J14D1 has less glutamic acid and more lysine. The Homes ribgrass strain (HR) shows many differences.



T4 VIRUS made these plaques in a bacterial culture prepared by A. H. Doermann of the University of Rochester. Each plaque pattern is made by a different mutant of the virus.

organic compounds which were known to react with amino acids. They found that in this way it was possible to make thousands of structural alterations in a single virus particle. The remarkable thing is that these alterations did not change the behavior of the virus. Moreover, the progeny of such a virus were normal. Most of the structural changes made by Stanley and Miller were alien to living material; it is possible that the plant cells reversed them. Today we are able to make changes that are more characteristic of normal protein molecules. H. Fraenkel-Conrat of the Virus Laboratory has shown that by suitable chemical treatment he can attach to the protein of each virus particle 4,000 more molecules of the amino acid leucine than they normally have. The change in leucine content is about 10 per cent—more than some of the differences between mutants of quite perceptibly different properties. Yet the properties of the virus are unchanged, and, again, the progeny of infection with the modified virus are normal virus without extra leucine.

One of the authors has tried making changes in the opposite direction. Working with J. I. Harris of the University of California, he has subjected tobacco mosaic virus to digestion with the enzyme carboxypeptidase. This enzyme removes amino acids from the ends of protein chains. To our surprise only one amino acid—threonine—was removed. Its amount was reduced about 8 per cent. Yet again the altered virus acted like normal tobacco mosaic virus, and the progeny of the infection were normal.

We might also try to modify the nucleic acid of viruses. This becomes more likely as we learn more about the chemistry of nucleic acid. In viruses, however, nucleic acid is apparently protected from chemical attack by the protein coat.

Another approach to the chemical modification of viruses is to induce the virus to incorporate alien subunits in the course of reproduction. Attempts to modify tobacco mosaic virus in this way have been made by R. E. F. Matthews in England and by R. Jeener and J. Rosseels in Belgium. The technique used is to infect plants with tobacco mosaic virus and then to apply an alien subunit analogous to one normally found in the virus. The hope was that the plant would find it more convenient to use the alien compound than to make the normal one. This was possible to some extent, but the process reduced the infectivity of the virus, and it was impossible to tell whether the particles that were still infective contained the alien analogue. Recently D. B. Dunn and J. D. Smith of the Molteno Institute in Cambridge, England, succeeded in replacing almost completely another of the nucleic acid subunits in some of the bacterial viruses. Again the resulting viruses are apparently noninfectious.

These experiments would seem to indicate that it is indeed possible to trick the metabolic apparatus of the infected cell into incorporating unusual substances into the nucleic acid of the reproducing virus, but that our changelings are not cleverly enough disguised to fool another cell. That the unusual compounds are incorporated at all raises great hopes for this method.

Whether the immediate future holds the prospect of making artificial changes in the genetic material of living viruses cannot, of course, be certainly predicted. It is obvious that techniques which are being currently developed in the chemistry of both protein and nucleic acid justify a prediction of great progress in the near future toward understanding the detailed chemical-structural basis of heredity. The possibility of being able to alter the heredity of living organisms by deliberate chemical modification does not seem nearly as visionary as it did only a few years ago.

THE PLANET EARTH

This picture of the earth was taken from the U. S. Navy Viking Rocket 11. Altitude: 154.8 miles. Horizon: 1120 miles distant. The view: from Texas across Mexico to the Gulf.

Announcing an issue of SCIENTIFIC AMERICAN

describing the state of knowledge of our planet

on the eve of the International Geophysical Year

to be published in September, 1955

DISLOCATIONS IN METALS

Many important properties of metals are now understood to result from a kind of imperfection in crystal lattices that is called a dislocation. The theory is helping to transform metallurgy from an art to a science.

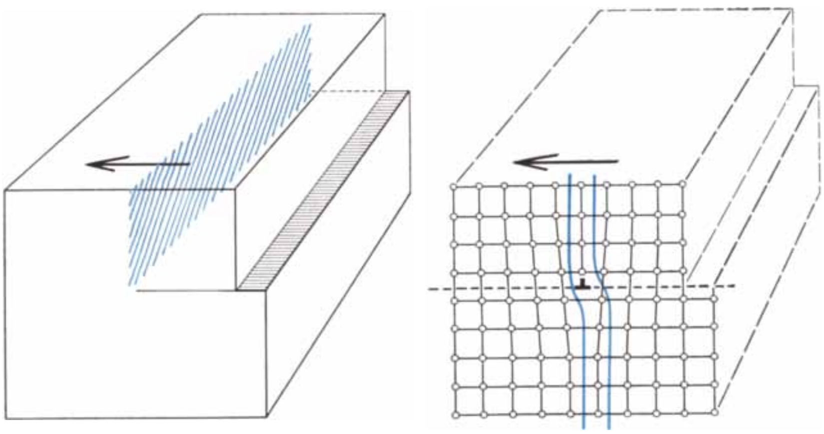
by Frank B. Cuff, Jr., and L. McD. Schetky

The word "crystal" conjures up a picture of infinite orderliness—billions upon billions of identical atoms stacked in perfect array. Actually, of course, nothing is perfect. In a real metal or other crystalline substance the order is marred by a missing atom here, a foreign particle there and other departures from regularity. However, these imperfections are rare, and one might suppose that they could be disregarded in calculating the properties of the material.

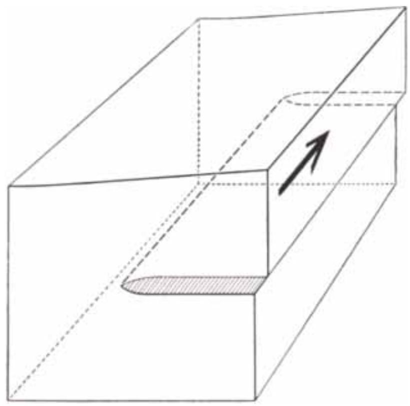
For a long time they were. On the assumption of a perfectly filled crystal lattice, metallurgists were able to make a number of accurate predictions about metallic behavior. They also got answers that were entirely wrong. One of the most annoying failures came in trying to account for the strength—or rather the weakness—of metals. For example, the theory said that a stress of some two million pounds per square inch would be required to deform pure iron plastically, that is, beyond the limit of elastic recovery. In fact it takes only 30,000 pounds per square inch.

This discrepancy, and others even bigger, remained wholly unresolved until about 20 years ago. Then it was suggested that resistance to plastic deformation depends not on the average properties of the almost perfect lattice, but on the individual properties of a previously unknown kind of imperfection. This weakest link, known as a dislocation, was proposed independently in 1934 by G. I. Taylor in England and E. Orowan, then in Germany and now at the Massachusetts Institute of Technology. Since then the hypothesis has become the basis for an entirely new and promising theory of the plastic behavior of metals. A large group of properties which previously could be studied only in an empirical way are now beginning to yield to rational analysis.

The dislocation idea is most readily visualized in terms of the deformation it was invented to explain. The simplest type of plastic deformation in a crystal may be likened to the distortion produced when a perfectly stacked deck of cards is pushed askew. The planes of atoms, like the cards, slip over one another. In the old theory the stress necessary to produce this deformation was calculated as the force required to slide whole planes of atoms over each other. Now suppose that the planes do not actually move as rigid units. Imagine that a slip can occur in part of a plane, as shown in the first diagram below. The next diagram shows what would happen at the atomic level. Here the upper right portion of a crystal has been moved one atom spacing to the left with respect to the lower right portion, while the left half of the crystal has remained undisturbed. Except near the boundary of the slip, the lattice arrangement is unimpaired, and the atoms are in register. In the boundary region, however, the arrangement must be upset—dislocated. Obviously there must be one more vertical plane of atoms above the slip surface than below. The imperfection which oc-



EDGE DISLOCATION (*symbolized by inverted T*) occurs at the boundary of slip between layers of a crystal, the slip direction (*arrows*) being perpendicular to the boundary line. Colored vertical plane (*left*) represents the extra row of atoms appearing above the dislocation line when the vertical layers are subject to distortion shown in the second drawing.



SCREW DISLOCATION occurs when the slip direction (*arrow*) is parallel to the slip boundary. Like the edge dislocation, it is a region of distortion and high energy.

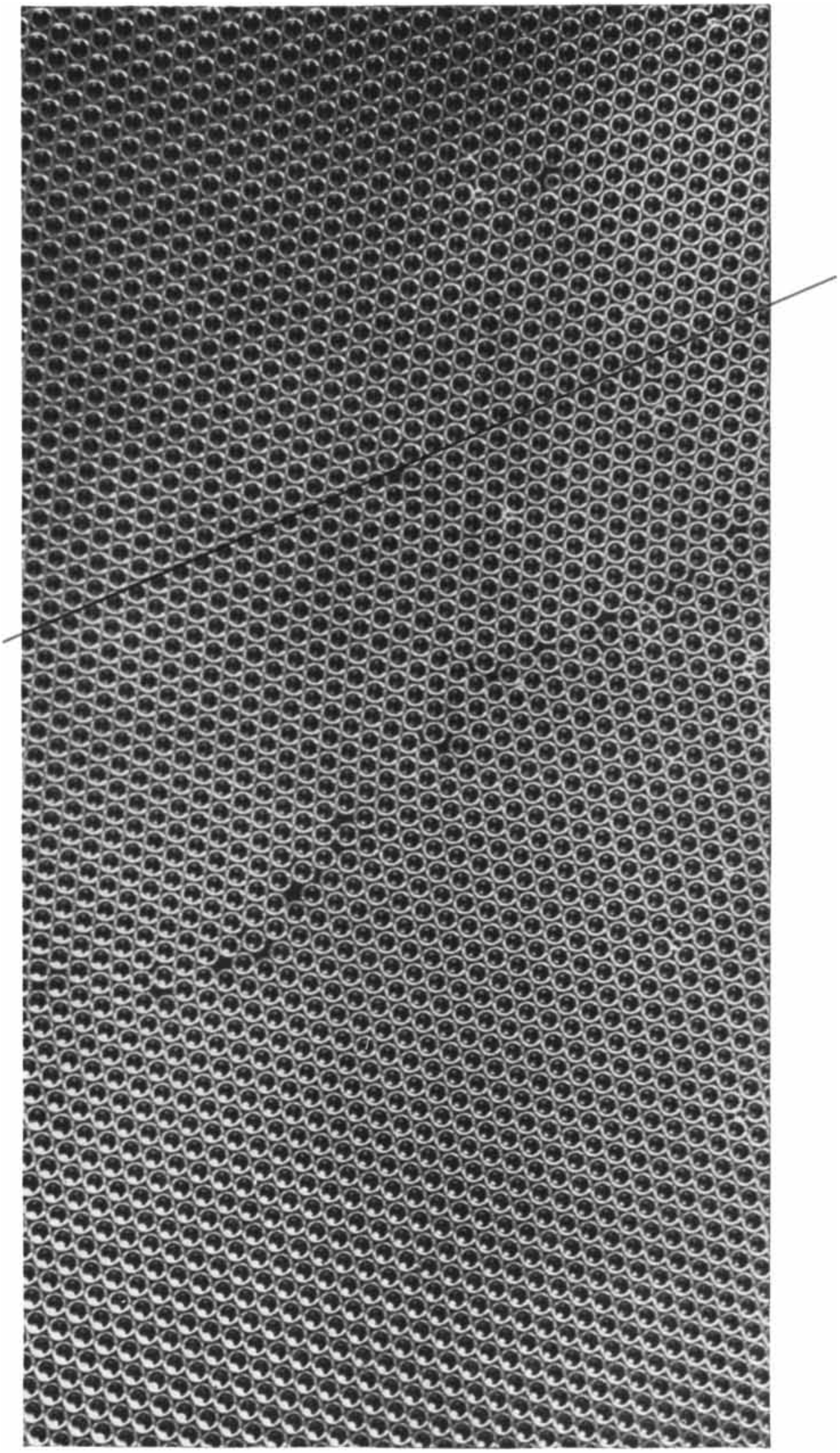
curs along the bottom of this extra row of atoms is called an edge dislocation. A model of this kind of atomic derangement is provided by the layer of bubbles in the photograph at the right.

The bubbles show what could happen in an array of atoms, but they do not prove that it does happen. For some years after Taylor and Orowan published their conjecture a number of authorities doubted the existence of dislocations. Now, as we shall see, the weight of favorable evidence has become so great as to leave no room for uncertainty. Dislocations exist, and they play a central role in determining many properties of metals. To appreciate their effect on metallic behavior we need to know a bit more about the properties of the imperfections themselves.

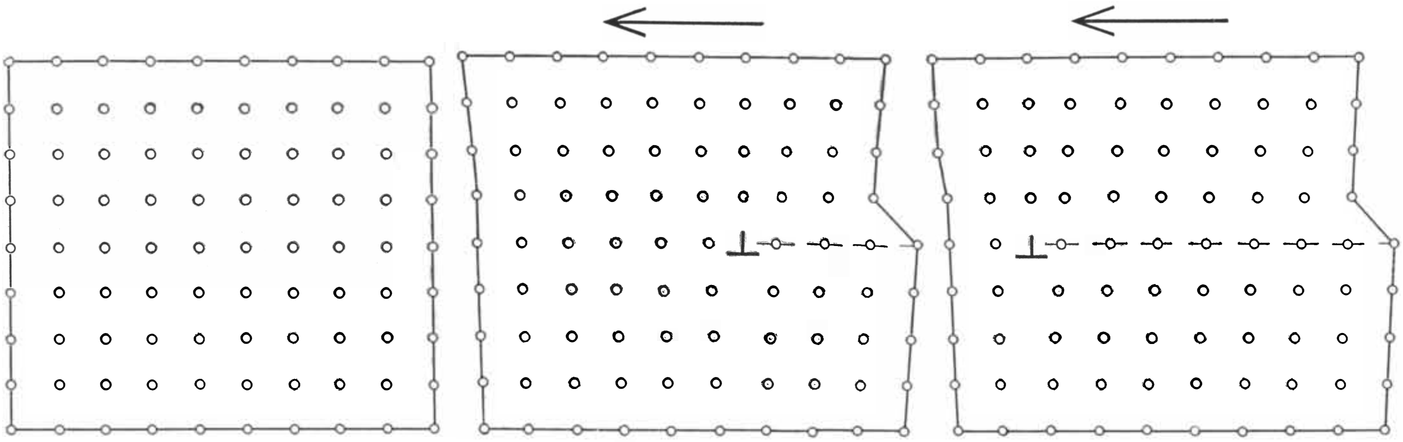
We think of a dislocation as a line running through a crystal (although it is really a region of small but finite cross section). Around such a line is a region of energy higher than in the rest of the crystal. This is because the lattice is crowded, or compressed, in the neighborhood of the extra atom plane, and pulled out, or in tension, on the opposite side. Both conditions represent an increase in potential energy over the undistorted region of the lattice. Because of nature's universal preference for the lowest possible energy states, a dislocation line acts like a stretched elastic string. It tends to be as short as possible since this makes the high-energy region as small as possible. Thus a dislocation line resists being bent or curved.

The line of an edge dislocation is perpendicular to the direction of slip. As the diagram at the right on the opposite page shows, this is not the only possibility. The slip may be parallel to the boundary of the slipped area (the dislocation line), in which case a screw dislocation is produced. This type of dislocation was discussed in detail by R. L. Fullman in his article on crystal growth [SCIENTIFIC AMERICAN, March]. For our present purpose it is sufficient to note that screw dislocations are also regions of distortion and hence of high energy, and that their effects on crystal properties are the same as for edge dislocations.

What are these effects? First of all, as Taylor and Orowan originally pointed out, dislocations make metals weak. It is not hard to see why this should be so. As the diagrams at the top of the next two pages indicate, pushing one dislocation entirely across a slip plane has the effect of shifting the adjacent layers



SOAP BUBBLES floating on liquid provide a two-dimensional model of the arrangement of atoms in a crystal. The slanting colored line runs through an extra row of bubbles in the left-hand half of the picture. At the end of this row is an edge dislocation. An inch or two below the line and roughly parallel with it can be seen the bubble counterpart of a grain boundary. The bubble method was invented by W. L. Bragg and J. F. Nye. This example of the technique was prepared by Marsbed Hablanian, Massachusetts Institute of Technology.



SHEARING ACTION, in which a pair of crystal layers slip over each other by the amount of one atom spacing, is the result of moving a single dislocation through the crystal. The effect on the lattice is the same as if one whole horizontal plane of atoms had moved over the other. After

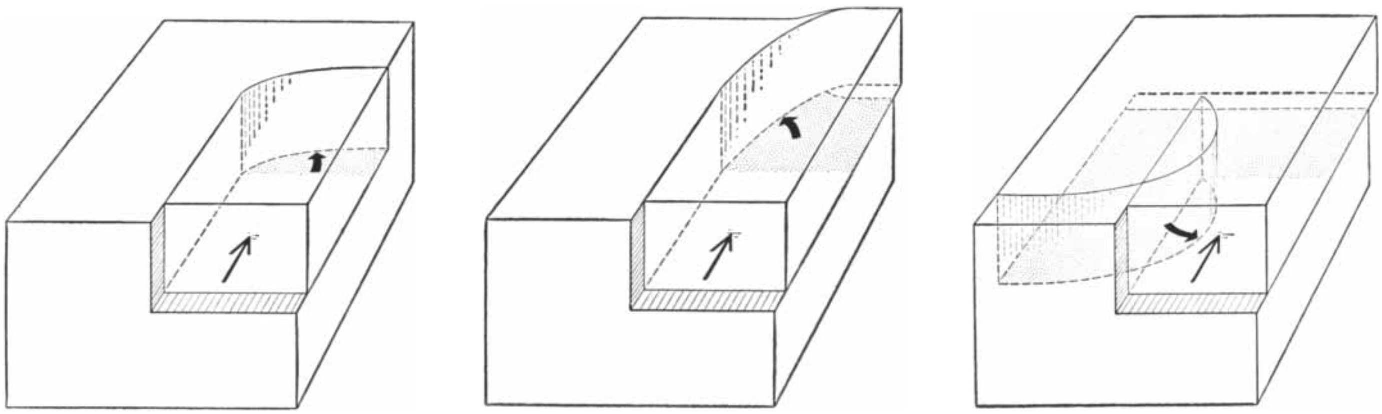
by one atom spacing. But at any moment the only atoms actually in motion are those in the region of the dislocation itself. Obviously it should be much easier to move these few particles than to push one whole plane of atoms across the other. Moving entire planes would be like dragging one sheet of corrugated iron across another; each row of atoms would have to climb a hump to drop into its new position. In a dislocation the climbing is restricted to a few rows at a time. As a matter of fact, a detailed calculation of the force necessary to move a dislocation showed that if it were the controlling factor in plastic behavior, metals would be a great deal weaker than they are. The dislocation hypothesis seemed to have done its work too well.

The explanation of this new problem is that crystals contain many dislocations which interact with each other. For example, consider what would happen if one dislocation were pushed toward another whose extra plane of atoms lay on the same side of the slip plane. (Such a pair of dislocations are said to have the same sign.) The two overcrowded regions would move closer together, thus aggravating their compression, and the stretched regions would similarly be under greater tension. Obviously there would be resistance to such a motion. Dislocations of like sign repel each other. On the other hand, if the extra atoms lie on opposite sides of the slip plane (dislocations of unlike sign) the overcrowded region of one dislocation "fits into" the stretched region of the other. These dislocations attract each other. Therefore, regardless of sign, interacting dislocations tend to immobilize themselves.

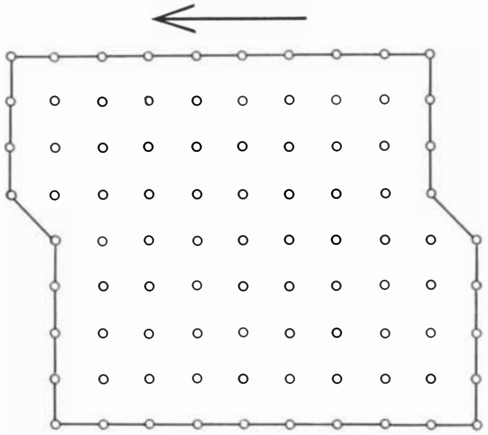
Interacting dislocations provide the first rational explanation for the effect of work hardening, *i.e.*, strengthening a metal by subjecting it to some form of plastic deformation. Imagine a series of dislocations, all of the same sign and all lying on the same slip plane, moving in response to an applied force. If the leading dislocation encounters a disturbance such as a flaw in the lattice or a foreign atom, it may be unable to move past this barrier. If the dislocation is stopped, its repulsive force will block the dislocation behind it. The dislocations will pile up like automobiles at a red light. Now no further slipping can occur unless the force is made large enough to dislodge the first dislocation. In other words, the metal is stronger.

Strengthening also results when two dislocations of opposite sign come together on the same plane. The two cancel each other, their extra atom planes combining to form a regular layer in the crystal lattice. When dislocations disappear, the path of easy deformation is lost and the metal is strengthened. Work hardening can more than treble the strength of a material. It is the basis of such standard metallurgical processes as rolling, swaging, forging and drawing.

We have seen that in the process of deformation, dislocations move to the edge of a crystal and disappear. It might be supposed that eventually all the dislocations in a metal would be lost, and that it would acquire the strength of a perfect crystal. This never happens. Apparently there is some continuing source of dislocations in every crystal. The nature of the source was a great puzzle until F. C. Frank of the University of Bristol and W. T. Read of Bell Telephone Laboratories proposed the ingenious



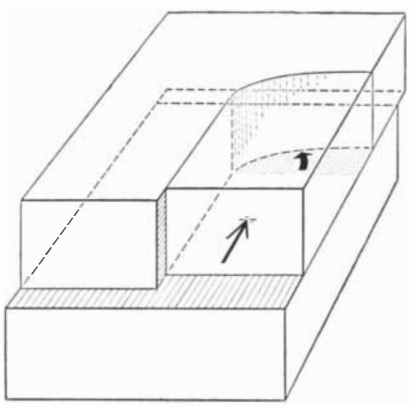
DISLOCATION SOURCE which can give rise to unlimited amount of slip is diagrammed above. The light arrow represents the direction of the applied force; the heavy arrow, the direction of motion of the horizontal dislocation line. The left end of the line has encountered a barrier



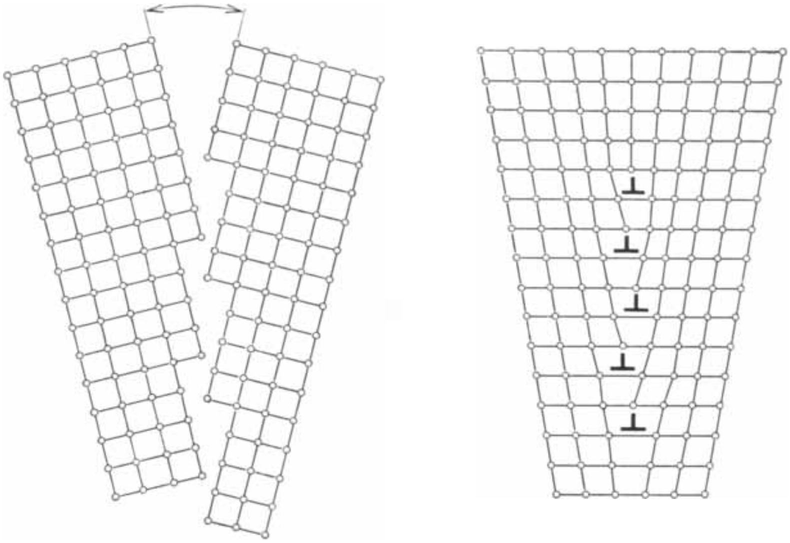
the deformation the rows of atoms on opposite sides of the slip plane are again in register (*last diagram*).

mechanism illustrated below. If a moving dislocation line meets an obstruction that stops it at an end point, the rest of the line may continue to move by pivoting around the fixed point. The diagrams show how such a line will form a spiral, which sweeps repeatedly over the slip plane, producing a slip of one atom spacing for each revolution. Thus the dislocation is never "used up." A similar sequence results if both ends of the dislocation are anchored, except that the successive waves of dislocations have the form of closed loops rather than spirals.

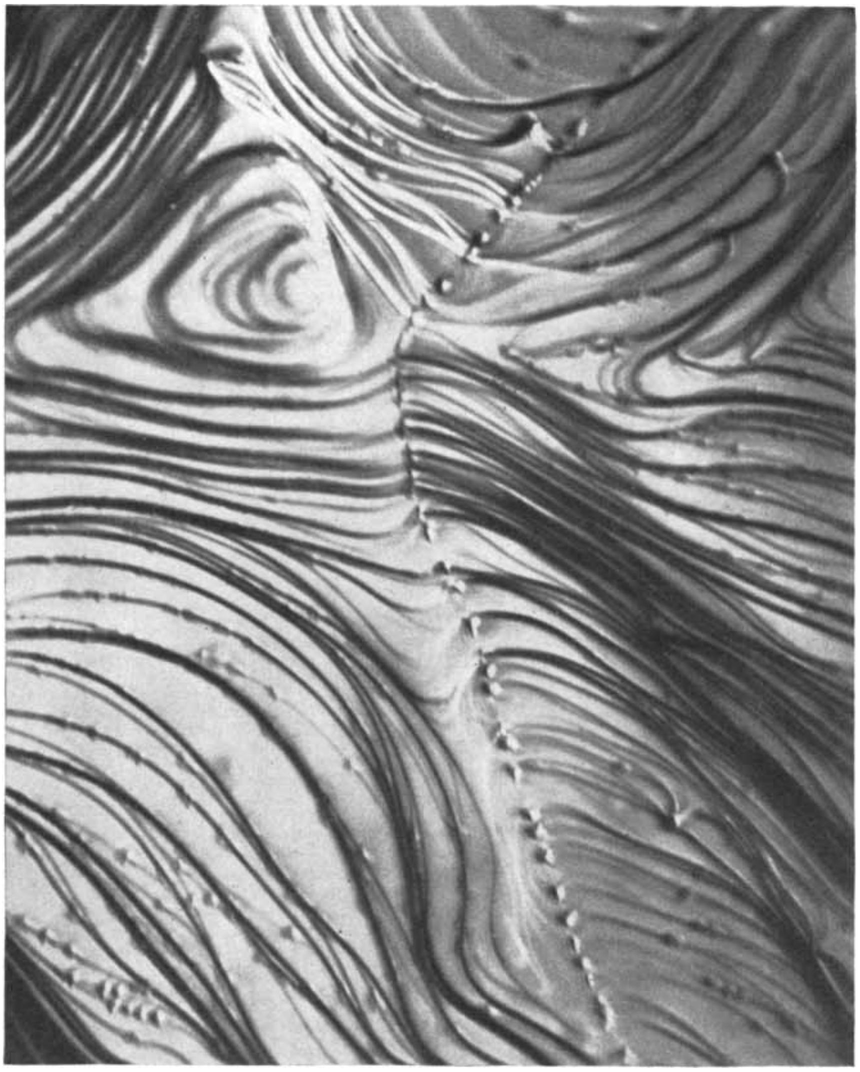
Because of their distortion of the lattice, dislocations tend to attract the foreign atoms in a crystal, such as the carbon atoms in steel. A foreign atom that is larger than the lattice atoms will tend to move to the tension side of a dislocation, where there is more room between neighbors. Similarly a smaller foreign atom will tend to migrate to the compression side of a dislocation. This effect was first pointed out by the British metallurgist A. H. Cottrell; the concentration of foreign atoms is called a Cottrell atmosphere. It explains for the first time



which arrests its motion. The dislocation pivots around this barrier point in a never-ending spiral.



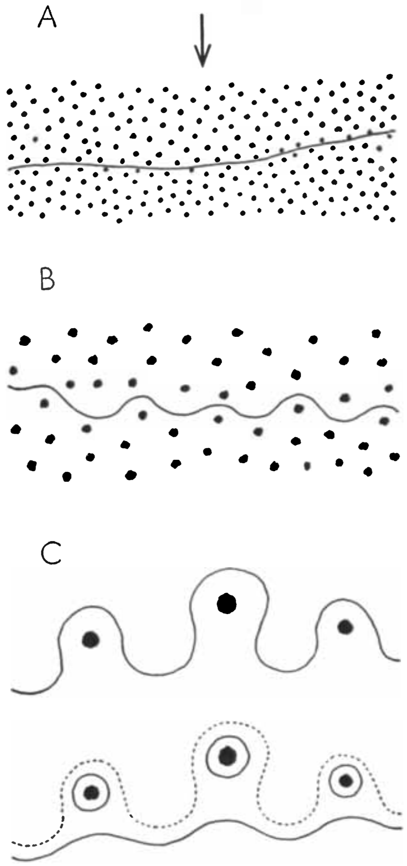
GRAIN BOUNDARY between contiguous particles of a polycrystalline metal is shown schematically at left. The structure is equivalent to an array of edge dislocations as at right.



ACID ETCH PITS, which occur at dislocations, outline a boundary between grains of a polycrystalline metal. The spacing between pits depends on the angle between the grains.

the phenomenon in metals known as the yield point. When a distorting force is applied to a metal, the deformation grows steadily greater as the force increases until the yield point is reached. Then the metal suddenly gives way, and the deformation continues to increase even if the force is reduced. The yield point marks the transition from elastic to plastic behavior. The theory is that in the elastic range the forces are not large enough to pull the dislocations loose from the Cottrell atmospheres. At a certain critical value the dislocations are torn from their anchor, and may then be kept in motion by a smaller force. Metals without abrupt yield points are now being made simply by purifying them enough to eliminate the Cottrell atmosphere from all but a few of their dislocations.

An important method for strengthening certain alloys, especially light ones such as Duralumin, is known as age hardening or precipitation hardening. In this process the metal is made very hot and suddenly quenched. Then it is held at a moderate temperature for an extended period. The result is that small particles of a second structure precipitate out of the lattice of the parent metal. Why this should strengthen the material was not clear until the advent of dislocation theory. Then it was pointed out that the precipitated particles do not fit exactly into the lattice, and so produce a region of stress around themselves. When a moving dislocation encounters such an assemblage of particles it finds that some of the stress fields oppose its passage while others tend to aid it. Before aging, the particles are very fine and closely spaced. Hence along every small section of its length the dislocation encounters about as many helping stresses as hindering stresses [*see first diagram on the opposite page*]. The effect of aging is to consolidate the precipitated particles into larger units farther apart [*second diagram*]. In such a region a dislocation would take on a wavy form bending around the centers that oppose its motion. But, as we have seen, a dislocation resists bending, so that now it is harder to move and the material is strengthened. Overly long heat treatment usually results in the state depicted in the third diagram, where the particles have conglomerated and separated so far that the long lengths of dislocation between them can bend comparatively easily and pass along, leaving dislocation loops surrounding each particle. Now the material is said to be overaged, and it has lost its hardness.



AGE HARDENING takes place when fine, closely spaced particles of a second structure (*top*) coalesce into larger particles as the result of aging (*middle*). If the process goes too far (*bottom*) the material is overaged.

Thus the dislocation theory has provided the first reasonable explanation for a number of time-honored but purely empirical metallurgical methods. But these successes are not the only evidence for the hypothesis. In the past few years more direct evidence for believing in dislocations has been uncovered.

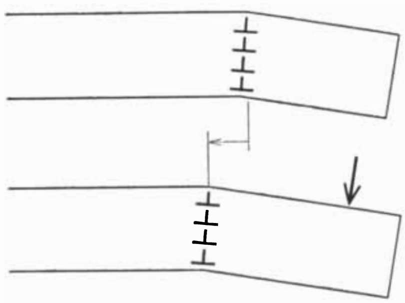
In the first place the theory implies that a crystal without dislocations should be very strong. However, no one could figure out how to make such a crystal. Then Conyers Herring and J. K. Galt of Bell Laboratories found one in a faulty piece of telephone equipment. The tin in a certain capacitor was discovered to have grown tiny whiskers, about a fifty-thousandth of an inch in diameter, as the result of corrosion. These tin whiskers ruined the capacitor, but as Herring and Galt realized, they were worth far more than their weight in gold as research material. Within their tiny diameter there was no room for dislocations. When their strength was measured, they turned out to be nearly as strong as perfect crystals are supposed to be.

Another striking corroboration for dis-

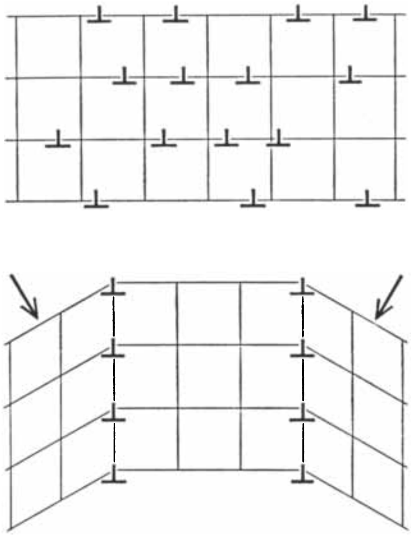
location theory concerns the boundary between adjacent crystal grains in a metal. Almost any piece of metal large enough to handle consists not of a single crystal, but of a large number of separate crystalline grains. The boundaries between these units are regions of misfit [*see boundary in bubble photograph on page 81*]. When the angle between grains is small, say less than 10 degrees, the boundary may be regarded as an array of edge dislocations, as shown in the diagram on page 84. Now it has been established that when a metal is treated with an acid, the rate of etching is higher in regions of higher energy. Therefore dislocation should be attacked more strongly than surrounding parts of the lattice. When a polished polycrystalline metal sample was treated with acid, the grain boundaries revealed a row of discrete etch pits or pips, each representing a single dislocation [*see photograph on page 84*].

The most convincing experiment thus far was performed in 1952 by E. R. Parker and J. Washburn of the University of California. Calculations indicated that when a metal is subjected to a shearing force, the rows of dislocations at grain boundaries should move in a direction perpendicular to the force. An ordinary polycrystalline sample is too complicated to analyze. Parker and Washburn grew two zinc crystals in a carefully controlled manner so as to produce a single low-angle grain boundary. This boundary behaved exactly as the theory predicted when a force was applied to the crystal pair.

Under some conditions the individual grains of a polycrystalline metal have been found to develop a fine network of subgrains. This state, called polygonization, usually results when a cold-worked metal is partially annealed (held at a moderately high temperature for a short



BOUNDARY between a pair of large single crystals should move horizontally if a vertical shearing force (*arrow*) is applied as shown. Actual crystal boundaries have now been proved to behave as the theory predicts.



POLYGONIZATION means the formation of tiny subgrains within each grain of a polycrystalline metal. It occurs when randomly spaced dislocations line up to give an arrangement of minimum strain in the lattice.

time). Its effect is to strengthen the metal.

The mechanism behind this phenomenon can be seen in the diagram above. The first picture shows a metal lattice which contains a random distribution of dislocations. When such a metal is heated and deformed into an arc, the thermal agitation of the atoms makes the dislocations more mobile and they move to the more stable positions shown in the second picture. These positions are preferred because they involve the least distortion in the crystal. The process resembles what takes place when a thin, flexible steel ruler is bent. As the curvature increases, the ruler will suddenly spring into two straight sections forming a sharp angle—a more stable configuration under the imposed stresses. Since the polygonized structure represents a more stable position for the dislocations, they will now be harder to move. Hence the metal is stronger.

Metallurgy, one of the oldest arts, is only now coming into its own as a science. The dislocation idea is proving one of the most powerful tools of this new discipline. As yet its usefulness is chiefly theoretical, although the theory is already being applied in a few instances. For example, polygonization is a new method for strengthening certain metals. In general, however, it is beyond our powers to predict the actual behavior of the enormous number of interacting dislocations in a real metal. But as the theory develops we approach ever closer to the goal of a true understanding of metals and alloys.

Polarized Light and Animal Navigation

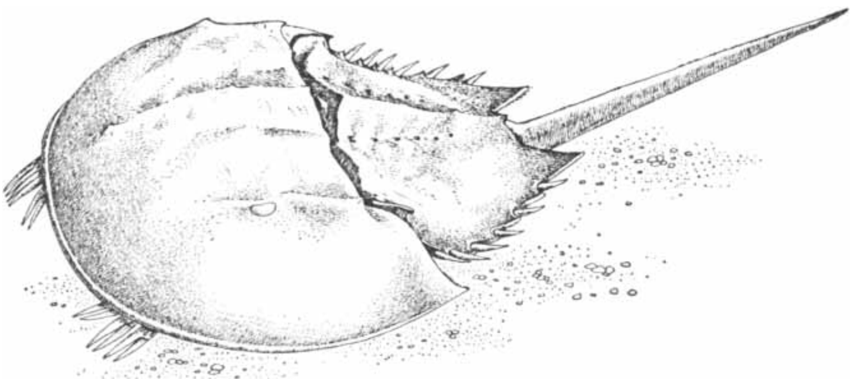
A number of land-dwelling animals can guide themselves by means of polarized light from the sky. Underwater light is polarized also, and some aquatic organisms may use it as an aid to navigation

by Talbot H. Waterman

A sense of direction is an important asset to any animal. Without it, in fact, effective movement or locomotion is scarcely possible. It is small wonder that the development of sensory and behavioral mechanisms concerned with orientation has been a crucial aspect of animal evolution. The resourceful and sometimes astonishing means by which animals find their way about are a fascinating field of study for the comparative physiologist and psychologist.

The most spectacular examples of such adaptations are perhaps the long breeding migrations of animals like the common eels of northeastern America and western Europe or the golden plover of the Pacific. Here the performance of the animal rivals that of a skilled human navigator. Obviously the fishes and birds do not have the compass, chronometer and sextant ordinarily required by man for navigation. In the absence of such instruments the animal's sense organs must provide the necessary information by somehow detecting environmental cues that show the way.

Although man has relied for centuries on the magnetic compass, he can roughly determine direction on the earth's surface by referring to the sky. With experience, but without instruments, he can interpret the position of the sun, the moon and the constellations in terms of azimuth, or compass direction. We now know that many animals have an equal or superior ability to use such a celestial compass. With its aid a number of creatures can steer a fixed terrestrial course by reference to the moving sun [see "The Sun Navigation of Animals," by Hans Kalmus; SCIENTIFIC AMERICAN, October, 1954]. Some of them can do so even when the sun is invisible. The author's research has for several years centered on this latter faculty.



HORSESHOE CRAB is an underwater animal whose compound eyes are sensitive to polarized light. The small, kidney-shaped outline below the center of the shell is one of the eyes.

Sun navigation was first observed in 1911 by the Swiss zoologist F. Santschi. He proved that some species of ants use the sun as a reference point in walking a straight path along the ground. Santschi also noticed that certain desert ants seemed to depend on the sky for maintaining their direction even after the sun had set. To check this implausible observation, Santschi tried cutting off the ants' view of the sky immediately overhead. When he did this, the insects became disoriented. Yet a screen which cut off their view of the sky near the horizon (as well as any possible local landmarks) had no effect on their sense of direction.

Santschi's explanation was that the insects could navigate by stars in the twilight sky that were invisible to man. This seemed so unlikely that other scientists remained unconvinced, and little further attention was paid to the matter. We now know that Santschi's observations were quite correct, but that his interpretation of them in terms of stellar navigation was wrong.

Twenty-five years passed before the right answer came from the brilliant work of the German zoologist Karl von Frisch. Working in Austria in the years immediately after World War II, he found that honeybees could sense compass direction when the sun could not be seen. As long as there was a small patch of blue sky visible, the insects could navigate about as well as ever. Von Frisch reasoned that some optical or other physical property of the sky was responsible for this.

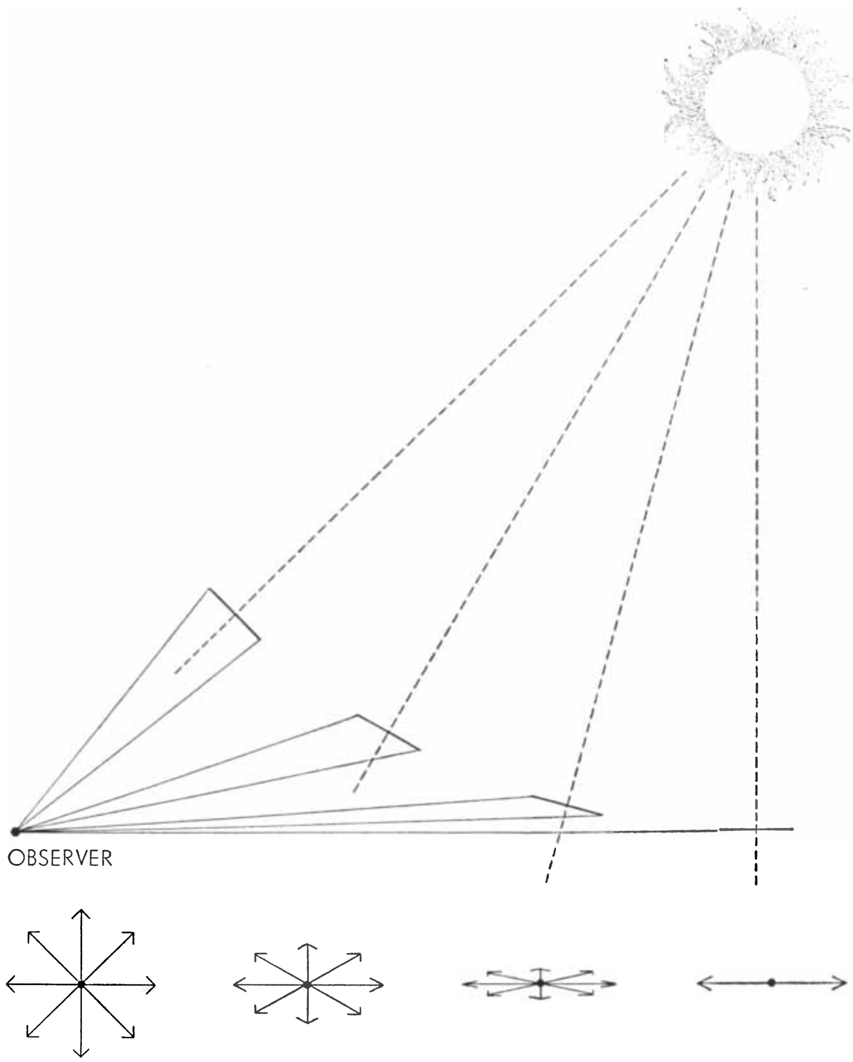
By the ingenious use of screens and

mirrors von Frisch showed that, whatever this clue was, it was different in various parts of the sky and could be influenced by inserting a light-polarizing filter between the eye of the bee and the sky. When the filter was rotated, the insect's sense of direction was affected in a systematic way. Von Frisch concluded that the polarized light produced by the filter must be perceived as such by the honeybee. He also proved that under certain circumstances the natural polarized light of the sky provides an adequate clue for the orientation of the insect.

To appreciate how the polarization pattern of the sky can give directional clues, we must understand clearly what polarized light is, and how sky light is polarized. For this purpose we may view light as a wave phenomenon and ignore its particle-like properties treated in quantum theory. We know that light consists of electromagnetic waves emitted by atoms and molecules. The waves are transverse, which means that their oscillations are at right angles to the direction in which the light travels. In this respect light waves resemble water waves, in which the water moves up and down while the wave travels horizontally toward the shore.

In the case of unpolarized light the electromagnetic waves oscillate in every possible direction perpendicular to the beam's path. Polarized light, in contrast, consists of wave trains all or most of which are oscillating in one of these directions. If the oscillations are entirely restricted to one direction, the light is completely polarized; if they are mainly but not entirely so, the light is partly polarized.

Now direct sunlight is unpolarized, but the reflected sunlight that we observe in the blue sky is partly polarized. This polarization arises from the scattering of light by the molecules of the air. When unpolarized sunlight passes through the earth's atmosphere, it causes the air molecules to vibrate. Any particular molecule vibrates in the same direction as the light wave which forces it to move. Thus molecules in the atmosphere are set into vibration by sunlight in all directions within a plane at right angles to the sun's rays. Then these molecules scatter some of the light energy which set them in motion. In so doing they act like minute antennas radiating light of different intensity in every direction. The direction of vibration of each scattered wave train and the consequent polarization of this light depends on the vibration of the particular air molecule which radiated it.

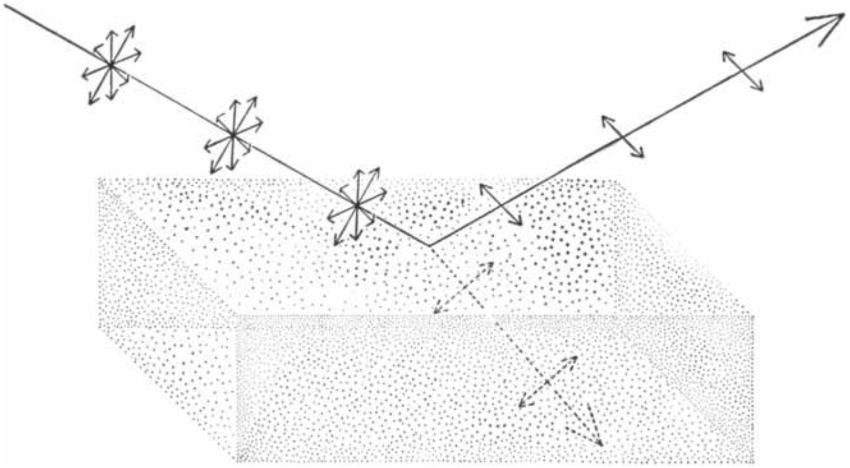


SKY POLARIZATION depends on the angle between the sun's rays to a particular point in the sky and an observer's line of sight to that point. Arrows at bottom represent the observer's view of vibrations in the light waves scattered by air molecules at various points.

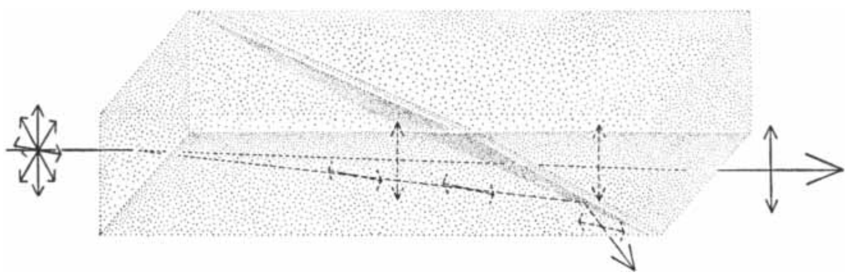
The complex light pattern resulting from this process may be visualized with the help of the diagram on this page. Here the transverse oscillations of air molecules in a beam of sunlight are represented by two-headed arrows. If we look directly along a sunbeam, the arrows appear to have the same length in all directions and their ends lie on a circle. This illustrates the fact that equal numbers of air molecules are oscillating in all directions within the transverse plane because the wave trains of sunlight are oscillating similarly. As a consequence the scattered light observed in this direction is unpolarized.

When we see a beam from an angle instead of head-on, the circle formed by the ends of the arrows appears as an ellipse. This means that there is a preponderance of waves oscillating in the direction of the long axis of the ellipse. The scattered light then appears partly polarized from this direction. The greater the angle of the beam to a line between the observer and the sun, the flatter the ellipse looks and the more strongly polarized the scattered light. Finally, when the angle is 90 degrees, the circle is viewed edge-on and is seen as a straight line. In this direction the scattered light is completely polarized. As the diagram shows, the direction of polarization at any point—the long axis of the ellipse—is always perpendicular to the line from that point to the sun.

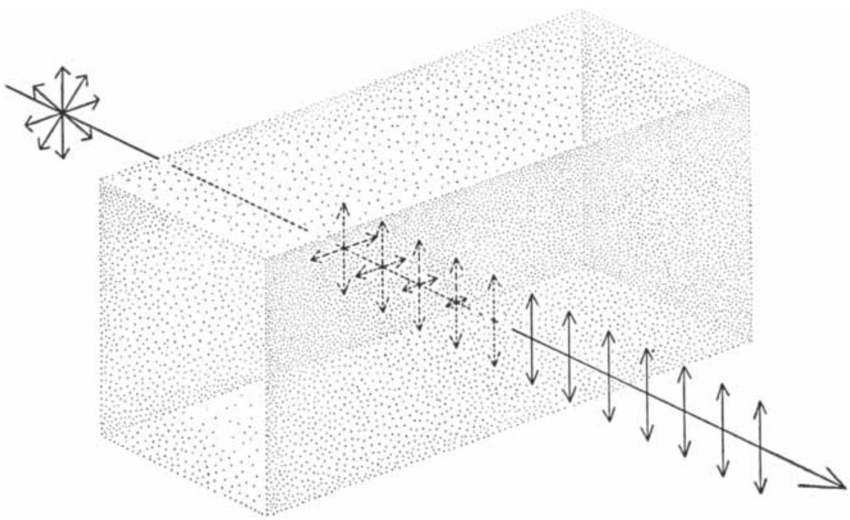
At any time of day the light coming from various parts of the sky should be characterized by specific amounts and directions of polarization arising in this



REFLECTION from a transparent material produces polarization in both reflected and refracted rays. If the incoming light were polarized horizontally it would all be reflected.



NICOL PRISM consists of two pieces of double-refracting material cemented together. One polarized ray passes through the cemented surface, the other is totally reflected away.



DICHROIC MATERIAL, such as tourmaline or Polaroid, contains particles that absorb light polarized in one direction, but not light polarized at right angles to this direction.

fashion. At sunrise and sunset, for example, the sun's rays are horizontal and the light from the zenith should be completely polarized. Similarly, toward the sun or away from it the scattered light should be completely unpolarized. The actual pattern is not quite so simple as this because many factors other than the primary molecular scattering of sunlight enter in. Nevertheless the degree and direction of polarization of light from the sky do depend primarily on the relation between the point observed and the position of the sun. This is so even when the sun is obscured by clouds or is somewhat below the horizon. To the human eye the celestial pattern of polarization is of course almost wholly invisible.

The reason for inserting "almost" is that, contrary to general belief, most people can learn to recognize strongly polarized light and even to determine its direction of polarization with the unaided eye. When they look at polarized light, they can see in the center of their field of vision a faint blue and yellow figure called "Haidinger's brushes." The orientation of the brushes depends on the direction of polarization. They can be seen most easily by looking at a large, uniform cloud through a polarizing filter and slowly rotating the filter. Having learned to see the figure in this way, many people can find it with the naked eye in parts of the blue sky that are strongly polarized; for example, the zenith at sunrise or sunset.

The first animals known to use polarization for navigation were the bees investigated by von Frisch. Then the ants that Santschi had studied were reexamined at von Frisch's suggestion. They too exhibited this behavior. It is now known that a variety of other insects and their larvae use sky polarization to maintain their sense of direction. Obviously these animals all have some highly effective means for recognizing polarized light and determining its direction.

Animals that live on the ground or in the air are not alone in their ability to analyze polarized light. It has recently been discovered that aquatic animals also have this faculty. In 1950 the author demonstrated that *Limulus*, the horseshoe crab, was sensitive to polarized light. This was done in the following manner. Part of the eye and the optic nerve were dissected out of a horseshoe crab. The nerve was connected to a sensitive detector of electric currents. The eye segment was then exposed to light and a polarizing filter slowly rotated over it. It was discovered that the frequency of impulses in the nerve was related to the direction of polarization.

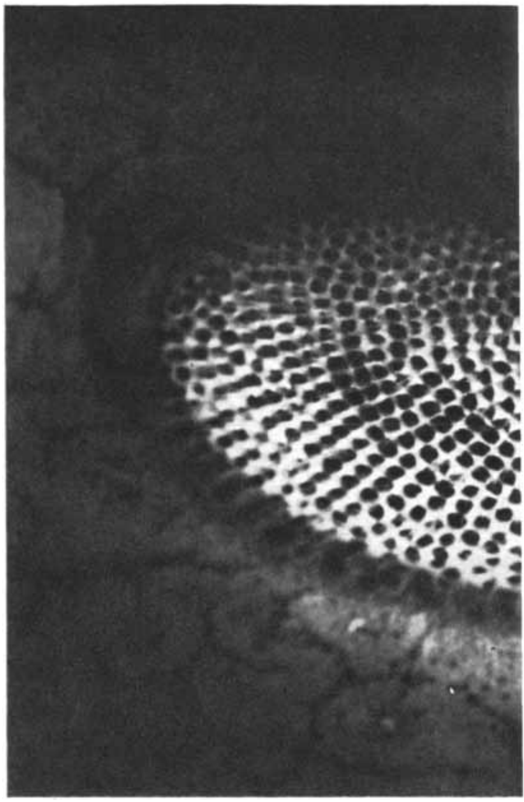
More recently E. R. Baylor and F. E. Smith of the University of Michigan have found a response to polarized light in the behavior of certain fresh-water invertebrates. They have shown that the orientation of many such animals is related to the direction of polarization. The water flea *Daphnia*, for example, can be made to swim in a predictable direction merely by changing the polarization of a vertical beam of light to which it is exposed.

But is underwater light normally polarized? And, if so, do water-living animals actually make use of this property to guide themselves? To answer the first of these questions the author did some skin diving off Bermuda last summer. A simple optical instrument was used to detect polarized light. It turned out that underwater light is definitely polarized in a complex pattern. This is mainly the result of scattering of the sun's directional rays by the water. Both the direction and amount of polarization are related to this essentially as in the atmosphere. In addition to the polarization arising within the water itself there is another factor near the surface. Here the sky polarization can be seen when one looks up. It is interesting that while only the hemisphere of the sky is polarized for terrestrial animals, the complete visual background of underwater animals is polarized. As in the case of the sky, the pattern of light polarization under water will change with the sun's position and also with the amount of cloud cover, particularly any that obscures the sun.

Just how deep in the sea these phenomena may penetrate remains to be determined. The author has observed readily detectable polarized light at a depth of 45 feet, even though in turbid water sky polarization could no longer be observed directly at this depth. Presumably the polarization originating in the water should extend down to the deepest layers where a significant amount of directional sunlight penetrates—between a quarter- and a half-mile in the clearest water of the open ocean.

So we now know that underwater light is polarized and that certain aquatic animals can orient themselves by means of polarized light. Whether they do so in their everyday orientation and migration remains to be determined. From what we know so far, it seems not at all unlikely.

Also still to be determined is how the eyes of animals detect polarized light and signal its direction to the central



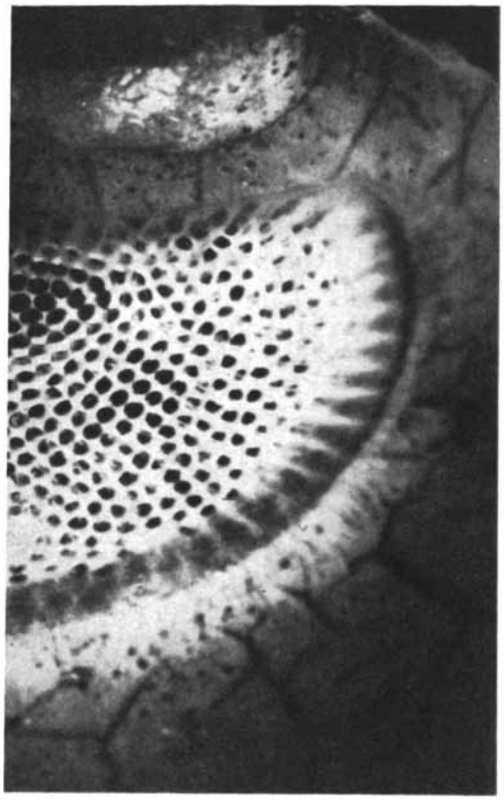
COMPOUND EYE of the horseshoe crab is seen magnified 20 diameters, showing the

nervous system. These problems have been central to the author's research for several years. The final answers are yet to come, but a considerable body of pertinent information is accumulating.

From an optical point of view there are a number of ways by which polarized light may be detected. Perhaps the simplest is to pass it at a certain critical angle from one transparent medium to another. Generally light polarized parallel to the boundary between two media is reflected, and light polarized perpendicular to this direction is refracted [*see diagram at top of page 90*]. For other polarized beams the relative strength of the reflected and refracted portions depends on the direction of polarization: if it is nearly parallel to the surface, most of the light is reflected; if it is nearly perpendicular, most of it is refracted.

Baylor and Smith have suggested that arthropods use a reflection-refraction mechanism to analyze polarized light. This hypothesis has been supported by G. C. Stephens, M. Fingerman and Frank A. Brown, Jr., of Northwestern University, who worked with the fruit fly *Drosophila*.

More familiar methods of analyzing



separate ommatidia of which it is composed. The structure forms a mosaic image.

polarized light depend on double refraction, a characteristic optical property of certain ordered molecular structures like crystals. When unpolarized light traverses a double-refracting medium, it is split into two beams which travel in different directions and are polarized at right angles to each other. By eliminating one of the beams we can obtain a good polarizing device. And any device that polarizes light can detect and analyze light already polarized: the percentage of polarized light it transmits depends on the angle between its polarizing direction and the light's direction of oscillation.

Practical polarizing and analyzing devices which depend on double refraction include the Nicol prism, tourmaline crystals and Polaroid. In the Nicol prism the unwanted beam is suppressed by reflecting it out of the optical path. In tourmaline and Polaroid one ray is absorbed by particles in the solid, while the perpendicularly polarized ray is not [*see diagrams on page 90*]. This property of differential absorption is known as dichroism. It is considered the most likely explanation for Haidinger's brushes. The dichroic element in the human eye is thought to be the yellow pigment in the center of the retina.

Now in the eyes of various animals both reflection and refraction obviously take place; also both double-refracting and dichroic structures have been found in the cornea, lens and the light-sensitive cells in specific cases. But which of the mechanisms are actually employed in the discrimination of polarized light is far from clear.

The compound eye of insects and other arthropods, for instance, consists of hundreds or thousands of elementary structures called ommatidia. These resemble simple eyes in having a lens that focuses a tiny image on a cluster of photosensitive cells lying beneath it. Is each one of these units able to analyze polarized light, or does the analysis depend on their joint action? H. Autrum, working in Germany, obtained evidence that a single facet of the bee's eye is able to analyze polarized light by virtue of differences in the responses of its various photosensitive cells to light of a given polarization.

On the other hand the author's recent studies in collaboration with C. A. G. Wiersma of the California Institute of Technology indicate that at least in the horseshoe crab this cannot be so. All the photosensitive cells in each ommatidium connect with a single active fiber in the optic nerve; thus the nerve output must be the sum of the responses of all the cells. We have also found that the sensitivity of a single ommatidium to polarization depends on the angle of the incident light. The smaller the angle of the light to the axis of the ommatidium, the less sensitive the organ is.

One of the chief obstacles to a deeper understanding of the polarized light response is our ignorance of the comparative physiology of vision in general. Not only are we unclear as to how the arthropod eye responds to polarized light, but also there are embarrassingly large gaps in our knowledge of how it works at all. Much of the author's recent work, although aimed at the polarized light problem, has perforce been directed to more general questions.

At present we have only a few scattered pieces of the puzzle. It is still too early to tell whether these will fit together in a single unified pattern or whether indeed different animals use quite different means of seeing polarized light. Certainly we need to know much more to decide. Yet the tantalizing prospect of understanding this remarkable kind of animal navigation should supply the needed spur for progress.

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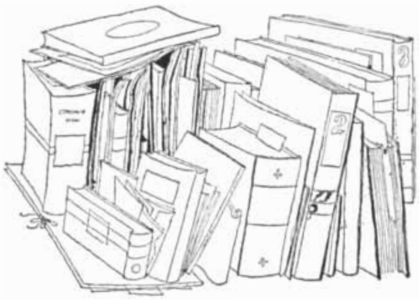


BOOKS

Three novels about the lives and moral problems of physicists in an atomic age

by James R. Newman

THE NEW MEN, by C. P. Snow; Charles Scribner's Sons ($3.50). THE ACCIDENT, by Dexter Masters; Alfred A. Knopf, Inc. ($4.00). THE HOUND OF EARTH, by Vance Bourjaily; Charles Scribner's Sons ($3.50).

In a critical article a few months ago C. P. Snow, the British novelist who used to practice physics, considered the position of the storyteller in our scientific society. For some time past, said Snow, "the novel has been going underground and it is the influence of science which has driven it there." In our period novelists are in retreat; in a society whose "dominant expression" is science, the novel has lost its prestige and its influence. The reason for this decline is not that science is evil or inhuman, but that it has been scandalously successful. Science has not only increased beyond man's dreams of his control over nature; "it has seemed to know all the answers." Art, like religion and philosophy, has had to give ground. None of these can any longer compete with science as a creative achievement or a key to truth.

How have fiction writers responded to the scientific climate? Some, says Snow, have taken refuge in a "trivial kind of belles-lettres, made up of snobbery and nostalgia"; others, especially poets and the more academic and intellectual novelists, have picked up the jargon of science. The most unfortunate response has been the rise of the "moment-by-moment, total recall" novel exemplified in the writings of Dorothy Richardson, Virginia Woolf, Henry Green, Carson McCullers and James Joyce. This variety of writing is in Snow's opinion an attempt to imitate in fiction the specialization of science. He believes that it has narrowed the scope of the novel; it has sacrificed the "reflective mind" and the relation of men and women to society; it has enlisted great talent in what appears to be the "most hopeless *cul-de-sac* in the novel's history."

It is difficult to take seriously these slam-bang judgments on the psychological novel and the complex relationship of literature and science. Snow overestimates the influence of science on the novelist and the poet, just as he underestimates the effect on literature and other art forms of economic and political upheavals, wars, social disorder and the world-wide climate of personal insecurity. His essay reflects no awareness of what the new psychology of the unconscious has meant to the novelist. His appraisal also lacks historical perspective in that it overlooks the contemporary impact on writers of fiction and poets of scientific achievements in other ages. (I have in mind particularly the response to Newton's discoveries.)

But it is not my intention to devote this piece to Snow's criticism. I am more interested in what he has to say about the future of the novel than about its past, how he estimates the response of storytellers to the atomic age rather than how he values the response of the last generation to its own despairs.

That "wretched discovery"—as one scientist described the nuclear bomb—has given us all something to think about. It has given the novelist, says Snow, another chance. If this is true, it is no cause for regret. For whatever the merits of the psychological novel, the time has come for the fiction writer to turn his beam, to look freshly upon a world which the latest technological advances promise to alter even more drastically than the industrial revolution altered the 18th-century world. We are anxious to hear what men of sympathy and imagination have to say about the threats and promises of our period. Politicians, statesmen, military men, social commentators, publicists and journalists have ventilated their views, but not the novelist. We expect of him a new sensitivity, a new feeling of responsibility, a new awareness—what E. M. Forster has described as "a fresh coat of quicksilver for the mirror." The psychological novel need not disappear, but the practitioner of this form would do well to remember that his hero is not the only one in trouble; we are all in the same boat. Storytellers should tell stories; the characters should not be permitted to brood too long, to waste time (in Forster's words) running up and down ladders in their own insides.

Snow believes there are signs of hope, that these reforms are taking place, that the novelist is seizing his chance, that the novel is returning to life. The three books that I review here are pertinent evidence. They treat a common theme; they are concerned with the sense of guilt in those responsible for the most fateful scientific advance of all time. It is a guilt that all of us must share, yet for the atomic scientist with a conscience the burden must be personal and overwhelming.

Snow's own novel, *The New Men*, is a memorable literary achievement. It is the fifth volume in a cycle which when complete will comprise 10 or 11 books concerned with various aspects of British society, the chief theme being the "intricate, labyrinthine and unassuageable rapacity . . . of the love of power." The "new men" are the atomic scientists—those actually engaged in research, as well as those who supervise, administer, "make policy." (The latter constitute that class so aptly described by the French as *les savants officiels*.) Upon these new men circumstances have conferred tremendous power. Tinkering with atoms is child's play, and the problem of understanding their behavior is simple compared with that of understanding man's behavior and his relation to society.

The narrator of the story is Lewis Eliot, who holds an important wartime post in the British government. His brother Martin is a physicist working at Barford on a uranium project. The first part of the story is concerned with the feverish attempts to make a workable atomic pile. After many minor disappointments and one dramatic failure, the group reaches its goal. The pile is self-sustaining and the weapon within reach. But now that they have succeeded, Martin and the others are suddenly appalled at the potentialities of their handiwork.

From the very beginning the question had haunted the scientists: "If we manage to get a bomb, what do we do with it then?" Those with a lesser capacity for self-deception had no doubt that, if a bomb could be made, it would be used; others, including Martin, thought such a course incredible. "We'd better see that the scientists are ready to assert themselves in case there is any whisper of nonsense," says Mounteney, a Nobel prize physicist advising on the project. Not, he adds, that scientists are better than other men, but they can "imagine the consequences . . ." and "no one could do it if they could imagine the consequences." Despite the misgivings and fears, no one proposed that the work be stopped. The thirst of curiosity was too strong. The bomb had to be made. The scientists had to have their triumph. The skeptical politicians had to be refuted.

But now that the bomb is here (its feasibility demonstrated at Barford, the thing itself in being at Los Alamos) the decision must be made whether to use it. The Barford group has no control over the actual decision, but this fact does not lessen its sense of responsibility. The majority of its members feel it would be immoral to drop the bomb on Japan without warning, without exhausting other possibilities. If, as one scientist observes, "it is used at once to destroy, neither science nor the civilization of which science is bone fibre, will be free from guilt again."

The climax of the story comes after Hiroshima. Martin is horrified, and drafts a letter of protest to the newspapers. "The actual use of the bomb in cold blood . . . is the most horrible single act so far performed. States like Hitler's Germany have done much wickedness over many years, but no state has ever before had both the power and the will to destroy so many lives in a few seconds." Lewis persuades his brother not to send the letter. It is useless; it would ruin Martin, and Lewis has always wanted much for him. The doubts raised in Martin's mind by these arguments dilute his resolve. As the brothers are walking together Martin suddenly recalls a ghastly tale of tactics:

" 'There was a good deal of discussion,' he said, 'about how to drop it with maximum results. One ingenious idea was to start a really spectacularly pretty flare a few seconds before the bomb went off.'

" 'Why?'

" 'To make sure that everyone in the town was looking up.'

" 'Why?'

" 'To make sure they were all blinded.'

"I cried out.

" 'That's where we've got to in the end,' he said. He added: 'But I agree with you; now I've got to let it go.' "

As if to revenge himself on Lewis for having thwarted his protest, Martin turns to the game of power, seeking to gain the top position at Barford. He joins in the task of extracting a confession from Sawbridge, a scientist who has leaked information to the Russians. But when Sawbridge finally breaks down and Martin is offered the directorship as a reward for his handling of the case, he declines and returns to academic life. Thus he throws away his only chance to gain a reputation—for his talents as a physicist are not exceptional. Nevertheless he is content, because by refusing any longer to work on atomic energy he has achieved a kind of moral redemption.

The New Men is beautifully constructed and succinctly told. Snow's style is a pale blade; it does not glitter but it is delicate and sharp. Motives, conflicts, self-doubts, dark ambitions are masterfully exposed. Written in a low key, flowing elegantly and without strain, the book achieves tremendous peaks of tension. Snow has genuine compassion for human weakness, but he is never sentimental. The complex relation between the two brothers is shown as a mixture of love and resentment, of selfishness and generosity, of pride and dependency, of guilt and stubbornness and fatal wordlessness. Lewis' mother loved him more than Martin and we are made to see the psychological effects of this preference on both men. Sawbridge is one of the few plausible Communists of fiction. His virtues are the more unglamorous ones—"reliability, abstinence, honesty in private relations. Nearly everyone found him dislikeable but in a dull, unspecific fashion." He is a man essentially without conflict: simple, tough, courageous, prepared to accept the loneliness of cutting himself off from other people, impelled not so much by a sense of devotion to the Soviet Union as by the feeling that in carrying on his dangerous work he would "in the long run be doing his duty to the people around him." Faith, hope and hate: "that was the troika which rushed him on." How he despised the liberal men who succumbed to rationalizations of what they knew to be evil, who rushed to the barricades but toppled over "at the first whistle of danger."

Snow's novel breaks down a dark paradox of human conduct. It helps us understand not only why decent men were willing to work on the bomb in the first

place but also why they continued the work long after the war was over. Patriotism, an unwillingness to be out of things, curiosity—were originally the main motives. The dread consequences of reaching the goal were resolutely put out of mind. It is painful but important to remember that the gentle Einstein justified his originating the undertaking by arguing that if the Nazis were working on a fission bomb we had to beat them to it. The fact is that none, not even Einstein, would face the reality of what the bomb would do until it was too late; by then, indeed perhaps even long before then, events had got too big for men. "No one can really tell," Lord Lindsay once wrote, "how near he can go to the edge of the precipice without falling over unless he goes so near that he does fall over."

The hero of *The Accident*, by Dexter Masters, is Louis Saxl, a brilliant Jewish nuclear physicist. Saxl comes to Los Alamos at the beginning, plays an important part in the making of the bomb, and then stays on to continue research on weapons. One of his assignments is to construct a critical assembly of fissionable material. This hair-raising experiment is done by hand, without use of remote controls. Before the first bomb was built the exercise was necessary, but now it is idiotic as well as dangerous. No one seems to know why the work is being done. But Saxl has done it many times before and is a skillful technician. This time, however, the exercise goes awry and to save the lives of others standing in the room Saxl knocks down the little pile of lethal blocks with his bare hands. The massive radiation to which he exposes himself by this gallant, though instinctive, action burns him to a crisp—internally. It takes him eight days to die. Masters describes the ordeal, which is also the reader's.

The Accident is a long book. The author tries to do two things: to explain why the accident happened and to give a minute, reporter's account of Saxl's illness. Saxl blundered, we are given to understand, not because he was clumsy, but because, subconsciously at least, he wanted to blunder. Like Martin Eliot he is dazed by the moral shock of the bomb. Yet he cannot bring himself to give up the work. Why? The reasons are not very plain. While he lies dying the novel takes us on many twisting journeys in time and space. They deal with Saxl's grandfather and his heart trouble, with Saxl's parents, school days, friendships, love life, aspirations and misgivings. He is a brooding, inward, rather tiresome fellow who is not very good to his girl.

What makes this novel especially unattractive is Masters' preoccupation with radiation pathology and materia medica. Every harrowing detail of Saxl's physical disintegration is furnished. No clinical item, however minute, no stench or pain is withheld. You are there but you soon wish you weren't.

The task of reading is not lightened by the style. Neither tense, nor syntax, nor grammar stay the author from the completion of his appointed rounds. A single example may be permitted:

"Perhaps, in fact, an ancient Pueblo sage, resident at the time somewhere south of what would one day become Santa Fe and being made aware of certain new developments in the war-making potential of his tribe, recalled that in his youth he had once ridden north along the Rio Grande to test the hunting, and had come out upon a mesa so isolated, so advantageous to the private development of private achievements, as he could now see, that, having thought of it, he at once led the warriors back to it, there to set up a secret camp, which flourished for awhile before going to ruin under forces now forgotten (although conjectures might be made)."

The hero of Vance Bourjaily's crisply written and fast-moving novel *The Hound of Earth* is less confused as to his moral obligations than either Martin Eliot or Louis Saxl. He knows what he has done and feels he cannot expiate his crime even by the most terrible form of self-punishment. Allerd Pennington is a young physicist and a first lieutenant in the army who disappears within a few hours of the radio announcement of Hiroshima. He was stationed at an installation near Oak Ridge and had participated in the building of the bomb. But both he and his associates are presented as innocent participants in the program. Eddie, the chemist, thought he was working on a "death ray"; Pete, the physicist, on a system of "energy transmission." Pennington had no idea what he was doing, so it is perhaps just as well that he was not at Oak Ridge itself or at Los Alamos. He had a wife whom he cherished and two small children; he was reasonably happy; his record was good and his prospects were excellent. Yet the sudden realization that he had been working on an atom bomb engulfed him in guilt and horror. "I felt sick, I didn't want to look at Eddie. He was still intent on the radio, with the others. I didn't want them to look at me. I didn't want to hear one of them say, 'Hey, this is what we did.' I don't think I'd have cared if I never heard another human voice again saying anything, as long as I lived. I went out without their noticing, and got in my car. I drove to the gate; I had a special kind of pass to let me out. I drove a hundred miles. I came to a city. I got out, found a branch post office and mailed the car keys to Frances."

He becomes a "living suicide," trekking from town to town in an erratic course to elude the F.B.I., never communicating with his family (so that his wife at last believes him dead and remarries), taking odd jobs for a few weeks at a time, living in rooming houses, going to an endless series of double-feature movies, permitting himself neither love nor companionship, getting drunk, reliving his past in dreams and reveries. The beginning of the story—the past is unfolded in flashbacks—finds him at the Christmas season in charge of the stockroom of the toy department of a large San Francisco department store. His manner—ironical, guarded, wry—rouses suspicion, as do the evasive answers on his employment questionnaire. It is easily seen that he is an educated and cultured man, incongruously placed as a stock clerk. He makes friends among the employees, and enemies. He enters the life of a college girl, a temporary sales clerk earning money during her Christmas vacation to pay for an abortion; of an attractive adolescent boy who is his helper; of a brash and noisy but likable toy buyer; of a broken-down old actor who plays a department-store Santa Claus. He attracts the malign attention of the service manager, Dolly Klamath, a sadistic, half-demented virgin who takes drugs mixed in milk and imbibes the mixture through the nipple on a baby bottle. This is a macabre, compelling story set in the frenzied atmosphere of the holiday season in a big store. Gradually a web closes in on Pennington. His kindness and sympathy for his fellow workers, even for Dolly, cause him to lower his guard, to become fatally entangled in the problems of others. He realizes what is happening to him, perceives the mounting danger to his freedom, but he no longer cares. Subconsciously he wants to be caught, to be sent to prison for desertion. He is tired of running. Fate is unkind to this strange and lovable man. When he is finally arrested, he has become involved, though innocent, in half a dozen crimes from assault to murder.

"There is no possibility of telling whether the issue of scientists' work will prove them to be fiends, or dreamers, or angels," said Lord Rayleigh in 1939. They are of course neither fiends nor angels; dreamers, perhaps. Now they have bad dreams. This is the *leitmotif* of the three novels, the stories of three tormented men. What they all came to realize is well expressed in *The New Men* by the journalist Hankins: "The chief virtue of this promising new age, and perhaps the only one so far as I can tell, is that from here on we needn't pretend to be better than anyone else. For hundreds of years we've told ourselves in the west, with that particular brand of severity which ends up in paying yourself a handsome compliment, that of course we cannot live up to our moral pretensions, that of course we've established ethical standards which are too high for men. We have always assumed . . . we have taken it for granted that, even if we did not live up to those exalted ethical standards, we did a great deal better than anyone else. Well, anyone who says that today isn't a fool, because no one could be so foolish. He isn't a liar, because no one could tell such lies. He's just a singer of comic songs."

Short Reviews

INDIA: PAINTINGS FROM AJANTA CAVES; EGYPT: PAINTINGS FROM TOMBS AND TEMPLES; AUSTRALIA: ABORIGINAL PAINTINGS—ARNHEM LAND. The New York Graphic Society ($15.00 each). Each of these folios, published under the auspices of UNESCO, presents 32 color plates of rare art masterpieces. The India volume, first in the series, reproduces magnificent 15-century-old paintings found on the walls of the rock-cut temples of Ajanta in the State of Hyderabad. Of far greater antiquity are the paintings from the tombs of the Nile valley, which portray in brilliant color mythological, funerary and religious themes as well as vivid scenes of daily life in Egypt. The secular subjects include bird-hunting with a boomerang, fishing, feasting, dancing, playing music, and the practice of various trades and crafts—carpentry, shipbuilding, pottery, laundering, shoemaking, tanning. Even the fine details of facial expression are visible; for example, the craftsmen are seen "exchanging jokes" as they work. The Australian collection is perhaps the most interesting of the group, because the aborigines of the remote northern plateau "still practice an art comparable with that of our stone-age ancestors of Europe." Thus, as Sir Herbert Read points out, we are afforded possible clues to various types of creative expression whose origins are lost in prehistory. For the Arnhem Land people their art is "the vital medium through which they keep alive their philosophies, their laws and the stories of their creation." The plates in this volume consist of rock and bark paintings—some old, some contemporary. The older monochromatic drawings of men and women in action—running, fighting, hunting, carrying their food vessels—though in line convey a marvelous sense of movement; the more recent drawings are polychromatic and static. They are executed in what is called the X-ray style, in which the internal as well as the external details of animals are portrayed. The series thus far is a distinguished achievement.

MODELS OF DAILY LIFE IN ANCIENT EGYPT, by H. E. Winlock. Harvard University Press ($7.50). In 1921 the Egyptologist Herbert Winlock, later director of the Metropolitan Museum of Art, made a major discovery while excavating in the necropolis of ancient Thebes. Breaking into an antechamber of the tomb of the Pharaoh's chancellor Meket-Rē he came upon a remarkable collection of wooden miniatures, part of the funerary offerings to insure a repetition of the departed's life on earth. Meket-Rē, who died about 2000 B.C., was a rich and powerful noble—his full title was "the Hereditary Prince, the Count, the Treasurer of the King of Lower Egypt, the Hereditary Prince at the Gateway of Gēb, the Great Steward, the Sole Companion and the Chancellor"—and could afford to supplement the usual tomb decorations and deposits by models of his earthly activities. They show the chancellor's residences, ships and servants; they portray the bakers on his estate making bread, the weavers and spinners making cloth, the stables where his cattle were fattened and the butcher shop where they were slaughtered. They reproduce scenes of Meket-Rē on his yacht sailing down the Nile; taking his ease under the shade of a canopy; smelling a lotus flower while listening to a singer accompanied by a blind harpist; and of the great man—seated in his pavilion surrounded by his stewards, retainers and scribes—watching his cattle being paraded before him. Protected against deterioration in their airless hiding place, the tiny sculptures are so well preserved that the paint retains its luster and delicate shadings. Several of the linen sails, as well as some of the ships' ropes, are intact. Even more astonishing is the fact that, when Winlock's group first inspected the models, they found them covered with the fingerprints of the Egyptians who had placed them in the tomb 4,000 years ago. Many illustrations.

AMERICAN THOUGHT, by Morris R. Cohen. The Free Press ($5.00). Felix Cohen explains in the preface to this book that as early as 1926 his father had planned to publish a volume on contemporary American thought. Various circumstances, not the least of them the older man's characteristic conviction that he had to enlarge his already encyclopedic knowledge before undertaking so ambitious an appraisal, delayed its completion. Now it appears, with both men dead, a legacy of the father's richly stocked and spirited mind, of the son's devotion and uncommon editorial skill. The range of the book is almost beyond belief. It discusses symbolic logic and jazz, the economic theories of Frederick Winslow Taylor and the poetry of Walt Whitman, the Spanish dances of Moszkowski and the statute of *Quia Emptores*, the architecture of the Chicago *Tribune* building and the legal briefs of Justice Brandeis, the philosophy of Charles Sanders Peirce, the Erie railroad and the treatises of Hippocrates. This sweep is too much even for Morris Cohen; many of the pieces are scrappy, trivial and glib. Nevertheless this is an endlessly interesting book which conveys perhaps better than any other of his writings the liveliness, wisdom and sensitivity of an illustrious teacher and philosopher.

K2—THE SAVAGE MOUNTAIN, by Charles S. Houston, Robert H. Bates and Members of the Third American Karakoram Expedition. McGraw-Hill Book Company, Inc. ($6.00). K2, also known as Mount Godwin Austen, was climbed by an Italian party in 1954. The second highest mountain in the world (28,250 feet), K2 is located in Pakistan in the wild Karakoram range, which has 33 peaks over 24,000 feet. In 1902 the first attempt was made to reach the summit of this black monster, only 750 feet lower than Everest and considered by some experts even more difficult and dangerous to climb. Another unsuccessful effort was made in 1909 by a group under the famous Italian explorer the Duke of Abruzzi. Since 1938 three American expeditions have tried to gain the peak. The first, headed by Dr. Houston, reached 26,000 feet, ran out of food and had to turn back, but not before finding a route which promised success in the future. The second, a year later, got 1,000 feet higher, but was denied victory when one of its members, Dudley Wolfe, was trapped and died on a tiny snow shelf. Two Sherpa porters also perished in a heroic attempt at rescue. In 1953 the third expedition, again led by Dr. Houston, was also defeated by tragedy. After six weeks of grim exertion, eight climbers reached a camp 2,750 feet from the top with food and fuel to last for 10 days. This was an ample supply for the final assault. Then a monsoon blizzard enveloped the group, pinning the members in their tents for nine days. So violent were the winds that the men could not speak with each other, though with a walkie-talkie they were able to communicate with the base camp 9,000 feet below. On the ninth day Arthur Gilkey, a geologist, became ill and it was imperative to carry him down. A new storm beat back the party carrying Gilkey on a stretcher, but the next day their desperate situation forced another try. The descent was a nightmare, but the men pushed on. At 25,000 feet one of the climbers slipped, carrying four others with him. "It was like falling off a slanting Empire State Building six times as high as the real one." By an incredible effort on the part of another climber all, including Gilkey, were saved. But an hour later, while his companions were trying to gather strength after their fall, the wind tore loose the ice axes from which his stretcher was suspended and he plunged into an abyss. The K2 story is superbly told in this book. It is one of the great accounts of mountaineering. The Houston-Bates expedition may not have been the best-planned and most scientific of modern climbing attempts, but the character of its members, the record of their achievement, the solidarity and cooperativeness of the group in the face of adversity compose a shining page of human adventure.

OXFORD ECONOMIC ATLAS OF THE WORLD. Oxford University Press ($4.80). This compact and very useful reference book prepared by the staff of the Clarendon Press consists mainly of commodity maps accompanied by statistical tables, population charts and related information. The maps are simple and clear, and together with the supporting data tell you quickly where manila hemp is made, bananas are grown, chromium is mined, goats are raised, rubber is planted, radio receivers are used, tractors are manufactured, tobacco is cultivated, uranium is found, nylon is produced, ships are sailed—and who trades what with whom in the world scramble for existence.

LA MÉCANIQUE AU XVII^{e} SIÈCLE, by René Dugas. Dunod (5300 francs). A masterly monograph on the evolution of mechanics from Kepler to Newton. Dugas is the author of a comprehensive survey of this branch of physics, which appeared in 1950; the present volume focuses closer attention on the classical epoch whose leading figures are Galileo, Descartes, Pascal, Huygens, Newton and

Leibniz. The particular merit of Dugas's study is that it brings out clearly the influence of metaphysical ideas on scientific thinking, recalling E. A. Burtt's noted work *The Metaphysical Foundations of Modern Physical Science*. The 17th century provides an unusually fertile period for investigations along these lines because it is characterized by a conflict between two major intellectual tendencies: on the one hand the foremost scientists of the time had not succeeded entirely in ridding themselves of a scholastic cast of thought, an undue emphasis on first causes and the why rather than the how of phenomena; on the other hand, the period is marked by increased reliance on observation as a source of knowledge and a vigorous expansion of the experimental method. Dugas deepens our understanding of the men and the ideas involved in this conflict and makes an imaginative contribution to the history of science. Louis de Broglie's preface to this excellent book is itself a model of lucidity.

THE EXPLORERS OF NORTH AMERICA, by John Bartlet Brebner. Doubleday Anchor Books ($1.25). GROWTH AND STRUCTURE OF THE ENGLISH LANGUAGE, by Otto Jespersen. Doubleday Anchor Books (95 cents). Two notable additions to the excellent Anchor series of reprints. Brebner's standard work embraces the exploration of America from Columbus to Lewis and Clark; it deals with the men and the drama of their exploits as well as with the physical appearance of the country they opened up, the habits of the Indians they encountered, the social and political consequences of their discoveries. Jespersen's classic first appeared in 1905 and is here reproduced in its ninth edition. It is a superb account, for both the plain reader and the scholar, of the anatomy, functioning and evolution of the English language.

AIRPLANES OF THE WORLD, by Douglas Rolfe and Alexis Dawydoff. Simon and Schuster ($2.95). ALL ABOUT AIRCRAFT, by D. M. Desoutter. John de Graff, Inc. ($5.00). These two volumes make a very handy little aviation reference library. Rolfe and Dawydoff cover the history of airplanes in text and 1,000 drawings from Leonardo da Vinci's ornithopter to the latest supersonic jets. Desoutter's oblong manual crams a good deal of information into its 450 pages: fundamentals of aerodynamics, problems of supersonic flight, the operation of jet and piston engines, airplane fuels, aircraft structure and materials, special equipment for aviation, helicopters, missiles, the history of flight, aviation medicine, aviation research and development, international flight records. It also contains a useful glossary, an index and many illustrations.

Brief Notes

FATIGUE OF METALS, by R. Cazaud. Chapman & Hall, Ltd. (60 shillings). Dr. Cazaud, a leading French authority, surveys the general characteristics of the fatigue of metals under various influences of stress, temperature and the like, the inherent resistance of metals and alloys to fatigue and the prevention of fatigue failure.

AS I REMEMBER HIM, by Hans Zinsser. Little, Brown and Company ($5.00). Reissue of a readable, sentimental, popular autobiography of a well-known medical scientist and teacher who died some 15 years ago. Dr. Zinsser, who also wrote *Rats, Lice and History*, disguised the autobiography as the story of a physician whom he knew intimately: R.S. (Real Self?).

EVOLUTION AS A PROCESS, edited by Julian Huxley, A. C. Hardy and E. B. Ford. The Macmillan Company ($4.25). Nineteen leading biologists, zoologists, geneticists, statistical theorists and other workers in evolutionary research contribute essays on the state of knowledge in their field just 50 years after the rediscovery of Mendel's laws. Some of the essays are quite specialized; some, like Julian Huxley's introductory piece, can be enjoyed by anyone.

ADVANCES IN FOOD RESEARCH: VOL. V, edited by E. M. Mrak and G. F. Stewart. Academic Press, Inc. ($11.50). Monographs on current investigations: deterioration and preservation of meat, fruit and vegetable products; organic constituents of wines; the color problem in foods; statistical methods in food research.

THE HELICOPTER AND HOW IT FLIES, by John Fay. Pitman Publishing Corporation ($2.50). The fundamental features of rotary-wing flight simply explained. Excellent line drawings. A very satisfactory little book.

THE LANGUAGE OF TAXONOMY, by John R. Gregg. Columbia University Press ($2.50). This interesting little volume deals with the application of the symbolic methods of modern formal logic to the study of systems of classification in botany, zoology and related sciences. The first part of the book is an elementary exposition for taxonomists and biologists of set theory; the second applies these methods to neo-Linnaean taxonomy.

OXFORD JUNIOR ENCYCLOPEDIA: VOL. XII, THE ARTS, edited by Laura E. Salt and Robert Sinclair. Oxford University Press ($8.50). The 12th volume of this young people's reference work covers architecture, painting and sculpture, music, poetry, prose and drama. Especially noteworthy are the many excellent illustrations, including fine full-page black-and-white and color plates.

CLIMATIC ATLAS OF THE UNITED STATES, by Stephen Sargent Visher. Harvard University Press ($9.00). More than 1,000 maps and diagrams portraying for all parts of the U. S. the principal climatic features: temperature, wind, sunshine, humidity and precipitation, climatic regions and climatic changes. A valuable compendium.

LIFE ON OTHER WORLDS, by Sir Harold Spencer Jones. The Macmillan Company ($3.00). For the revised edition of this popular book, the best and also the least sensational of its kind, the Astronomer Royal has furnished additional information gathered in the last 10 years on the evolution of the atmosphere of the earth, the conditions on Venus and the origin of the solar system. Photographs.

THE GYROSCOPE APPLIED, by K. I. T. Richardson. Hutchinson's Scientific and Technical Publications (30 shillings). A description of "what the gyroscope is, how and why it works . . . how and why it has come to play such an important part in scientific progress, especially in marine and aeronautical transportation and military operations."

ARCHITECT'S YEAR BOOK 5, edited by Trevor Dannatt. British Book Centre ($9.00). The fifth volume of this British annual contains 20 articles on the history of architecture, painting, town planning, technical aspects of building and kindred topics. Several of the articles and many of the photographs of architectural developments throughout the world are of unusual interest.

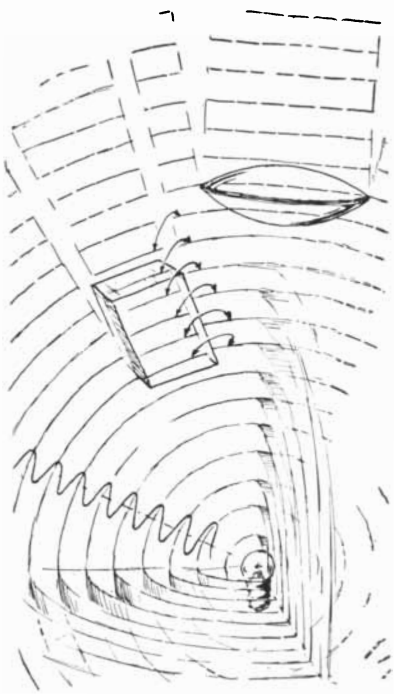
THE STORY OF PAPERMAKING, by Edwin Sutermeister. R. R. Bowker Company ($5.00). A straightforward semi-popular account of the subject. Excellent illustrations.

THE AMATEUR SCIENTIST

Concerning microscope illumination and an unusually steady telescope mounting

The art of stage lighting has come a long way since the days of the showman P. T. Barnum and the microscopist Ernst Abbe. These pioneers knew that organisms, whether human or microscopic, rarely look their best in the head-on glare of white light. Both workers recognized the advantages of proper background illumination and learned to bring out modeling through the use of oblique light. The intervening decades have brought their techniques to a high state of development. Today's impresario can multiply his effectiveness by mastering these techniques whether he presides over the stage of a theater or that of a microscope.

"When I started to use my first microscope," writes John De Haas, an amateur microscopist of New York City, "I thought the only way you could see significant detail in an animal of microscopic proportions was to kill and stain it. I was interested in studying protozoa, particularly the flagellates. But the application of make-up to my performers ended the show before the curtain went up. I wanted to study the internal structures of my animals as they swam, fed and reproduced. That meant that I had to work with light alone. As things developed, Rheinberg color illumination, dark-field lighting and even an inexpensive version of phase-contrast microscopy all proved within easy reach of my facilities. Astonishing increases in effective resolving power, I learned, are possible even with bright-field illumination. You simply block off 95 per cent of the light from certain directions. Beginners often make the mistake of flooding their specimens with light and thereby washing out all detail.



Light waves from a point source

"The effect is easy to demonstrate. Assume that you have a medium-priced microscope fitted with an eight-millimeter objective, an Abbe condenser and an eyepiece capable of giving the instrument a magnification of 150 diameters or so. Put a slide of diatoms under the objective. Focus on one of them carefully and fiddle with the lamp, mirror and condenser adjustments until maximum detail appears. The chances are good that you will see the diatom in sharp outline against the bright field. The body will show little detail beyond a fuzzy pattern of striations. Substituting an eyepiece of higher power will not help much. The striations will appear bigger—but proportionately fuzzier. At this point many amateurs decide they need a better microscope. There is another way out, and it costs much less.

"Cut a disk of black cardboard to fit the filter carrier of the substage and make a quarter-inch hole in the disk midway between the center and the edge. Without disturbing the adjustment of the instrument, slip the disk into the substage. You will find a position where, despite the lower intensity, an astonishing amount of detail comes into view. The striations stand out sharp and clear and, depending upon the structure of the diatom, you will observe that the striations are rows of objects still more minute. By moving the disk slightly up and down or sideways, or rotating the stage, even smaller details can be resolved."

This technique, De Haas explained, is a form of oblique bright-field illumination. Nothing is coming though the eyepiece that was not there before. When the iris of the condenser is wide open, contrasting details of light and shadow in the image are submerged in glare because the deviated rays comprising the first- and lower-order spectra, that carry the fine details of the specimen, are faint when they are compared with the direct or zero-order rays.

It is interesting to examine and manipulate the spectra because this enables you to predict the resolution even before you look at a specimen. To view the spectra you observe the back lens by removing the eyepiece and substituting a pinhole. You will also need a series of opaque disks punched with a quarter-inch hole, the position of which progresses through the series from the center to the edge.

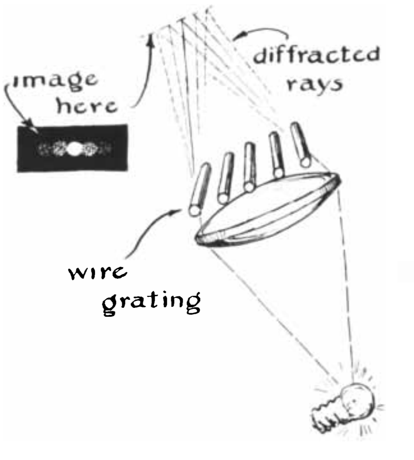
With the iris of the condenser wide open, focus the microscope on the diatom as described in the De Haas experiment and look through the pinhole at the back lens of the objective. The lens will be flooded with light to its edge. Now slowly close the iris. As the image of the iris in the back lens becomes smaller and smaller, the edges of two colored disks will appear at opposite sides of the field. The edges nearest the white disk will be an intense violet that shades into blue. These are images of first-order spectra. The fine structure of the diatom is acting as an amplitude diffraction grating, and hence some of the rays are deviated from the central beam. Now insert one of the opaque disks which has been perforated slightly off center into the filter holder and open the iris wide. The radius on which the perforation lies should be lined up with that of the spectra. The pinhole will now show that one of the colored images has in effect advanced into the field of view, while the white image and the other colored one have retreated an equal amount. Substitute in the filter holder the remaining opaque disks of the series one at a time for the initial disk. In effect this moves the perforation successively farther from the center. Observe that as the first-order spectral image advances more and more into the field, it shades through the colors of the rainbow and that, as it comes fully into view, a fainter companion appears at the edge. This companion is the second-order spectra. Depending upon the characteristics of your objective and the specimen, you may be able to entice as many as three orders into view before the white zero-order disappears. Moreover, by rotating the specimen or adjusting its lateral position slightly you may be able to bring other spectra into view at right angles to those already in the field. When you have accomplished this, substitute an eyepiece for the pinhole. The specimen will bristle with detail!

The explanation of why high resolution is associated with spectra is found in the wave nature of light. Except for shadows of gross objects cast by zero-order rays, the microscopic image is formed by interference at the focal plane of the eyepiece between rays that have been diffracted at the object, as shown in Roger Hayward's drawing at the upper right on this page.

The technique of increasing effective resolution by the use of an off-center diaphragm may be considered a form of annular illumination, in which the specimen is lighted by a hollow cone of light. Most of the cone is missing in the above experiment, but it would be complete if a ring of perforations were extended all around the opaque disk. A luminous cone would then surround a solid cone of darkness. If the base of the dark cone were made wide enough, no direct light from the condenser would enter the objective; and in the absence of a specimen, the field would appear dark. A specimen would reflect some of the rays into the objective and thus cause it to stand out in bright contrast against the dark field. Such reflection is greatest at points where the refractive property of the specimen changes abruptly, as at its edges. Hence the usefulness of dark-field illumination is limited to specimens characterized by sharp contrasts in refractivity.

This is also true, for the same reason, of Rheinberg color illumination. Although Rheinberg illumination has limited value as a research tool, the fascinating results justify setting it up as an experiment. Essentially it is annular illumination in which an outer cone of colored light surrounds an inner cone of light in a contrasting color. As in the case of dark-field illumination, unless a special condenser is used, Rheinberg illumination works best with low-power objectives, preferably those of 16 millimeters or more used in combination with a five-power eyepiece. To prepare a Rheinberg setup, cut a disk of colored gelatin or other plastic to fit the filter holder. Red is a good color for this disk. Perforate the center with a half-inch hole. Next cut a five-eighths-inch disk of contrasting color, say blue. Cement this disk over the perforation in the larger disk. The difference in size between the small disk and perforation allows for a sixteenth-inch overlap. Insert the assembly in the filter holder and rack up the condenser until it is focused on the object plane. The field will now appear uniformly blue because the objective is immersed in the central blue cone of light. Now place a small amount of water on a slide and drop in a grain of some effervescent substance such as Bromo Seltzer. The eyepiece will present a striking display as myriad bubbles bend red rays into the objective—like fireballs rising through a sea of blue.

Of greater interest to the advanced worker is the relatively new technique of phase-contrast microscopy, devised in 1934 by the Dutch physicist Frits Zernike. Phase contrast, like dark-field lighting, may be considered a form of annular illumination. Unlike other forms of annular illumination, however, Zernike's technique produces contrasts in the image by exploiting minute differences in phase between direct waves from the light source and those deviated by the specimen. On the opposite page Hayward depicts concentric waves of light radiating from what may be considered a point source. The amplitude or brightness varies inversely with the square of the distance from the source, as suggested by the sine wave extending to the left from the lamp. The velocity of waves intercepted by the glass block (*upper left*) is retarded by the refractive property of the glass and, in this case, the light emerges from the block a full wavelength behind that propagated through the surrounding air. Although both sets of waves are spherical, those that have traversed the glass block are now said to "lag" 360 degrees behind those of the source. The lens (*upper right*) intercepts the spherical waves and, by virtue of its thickness increasing toward the center, retards the spherical



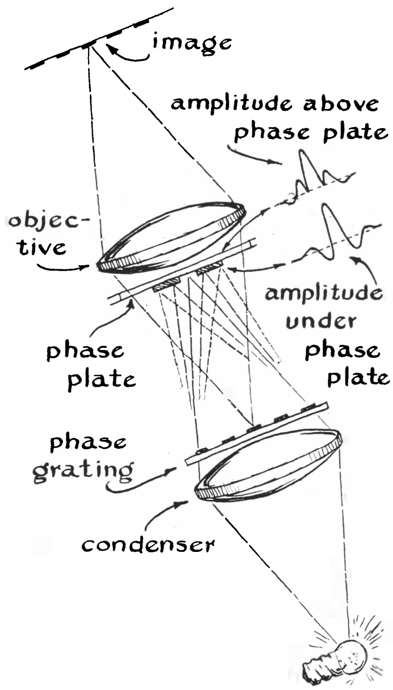
An amplitude diffraction grating

wave fronts just enough so that they emerge as plane waves.

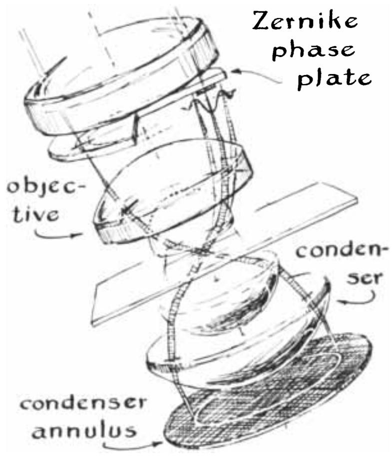
Many microorganisms are transparent and, like glass, can retard the velocity of light. Unfortunately the refractivity of many interesting ones nearly matches that of the medium in which they live. The eye is sensitive only to changes in amplitude or brightness. Hence microorganisms that cause only small differences in phase between light transmitted through them and through the surrounding material are invisible. Prior to the invention of phase microscopy they could be seen only after being stained or immersed in a fluid of substantially differing refractive index. These alternatives either killed them or seriously interfered with their natural processes.

The phase-contrast technique makes such objects visible by transforming small differences in phase into small differences in amplitude or brightness—to which the eye is sensitive. The trick is accomplished by retarding part of the light (passing it through a thin sheet of glass or similar material called a phase plate) so that all light arrives at the focal plane of the eyepiece in phase or 180 degrees out of phase. The crests and troughs of the waves are thus made to coincide or cancel. They "interfere," or combine their energies, and thus set up amplitude differences that constitute an image of the object.

The fine details of the image are carried by spectral orders of phase. These correspond to the spectral orders of amplitude that account for image resolution in ordinary bright-field work, as demonstrated by the experiment in oblique lighting and illustrated by Hayward's drawing of an amplitude grating on this page. A phase grating, consisting of alternate strips of transparent material which differs slightly in refractivity from the intervening material, works much like the amplitude grating illustrated in the top drawing on this page. Transparent specimens can be considered phase gratings because the refractivity of their structure varies; rays transmitted through those portions of higher refractivity are deviated with respect to those transmitted by portions of lower refractivity. Thus two sets of waves enter the objective, distinguished only by their phase difference. It can be demonstrated mathematically that a third wave can be found which represents the phase difference between the direct and deviated ray. This difference wave is always just 90 degrees out of phase with the wave emerging from the specimen. A value of amplitude can be assigned to the difference wave so that when it is added to the wave deviated by the specimen, the sum equals the direct wave transmitted by the surrounding material. Zernike looked for the difference wave in nature—and found it! It is the phase spectra set up by the specimen and it carries the specimen's phase image.



A phase diffraction grating



The annular phase plate

As observed in the experiment with oblique lighting, the spectral orders spread across the aperture of the objective's back lens and converge at the plane of the eyepiece. The condenser is adjusted so that direct rays from the source meet at the back focal plane of the objective, as shown by the top drawing on this page. Hence rays which pass through the center of the back focal plane and those transmitted through the complementary area (the spectral orders) are out of phase by 90 degrees. When this difference is adjusted so that the two arrive at the focal plane of the eyepiece precisely in or out of phase, interference takes place and an amplitude-contrast image results as in conventional bright-field illumination.

Zernike corrected the phase difference by inserting an annular phase plate in the path of the direct wave, as shown in the bottom drawing on this page. In addition he coated the plate with a layer of light-absorbing material just dense enough to reduce the intensity of the direct wave to that of the deviated wave so that complete addition or cancellation would take place. This prevents the image from being masked by the excess light of the direct wave. As subsequently improved, plates are designed either to advance or in effect retard the direct wave and thus result in either constructive or destructive interference. Constructive interference causes a bright object to appear against a neutral background. Destructive interference reverses the effect. A set of phase plates, together with accessories including a condenser annulus and a telescope for aligning elements in the optical train sells for about $200. De Haas devised a form of phase contrast for the amateur which approximates the results of the Zernike technique and costs less than $20. It works well where phase difference amounts to a 20th of a wave or more.

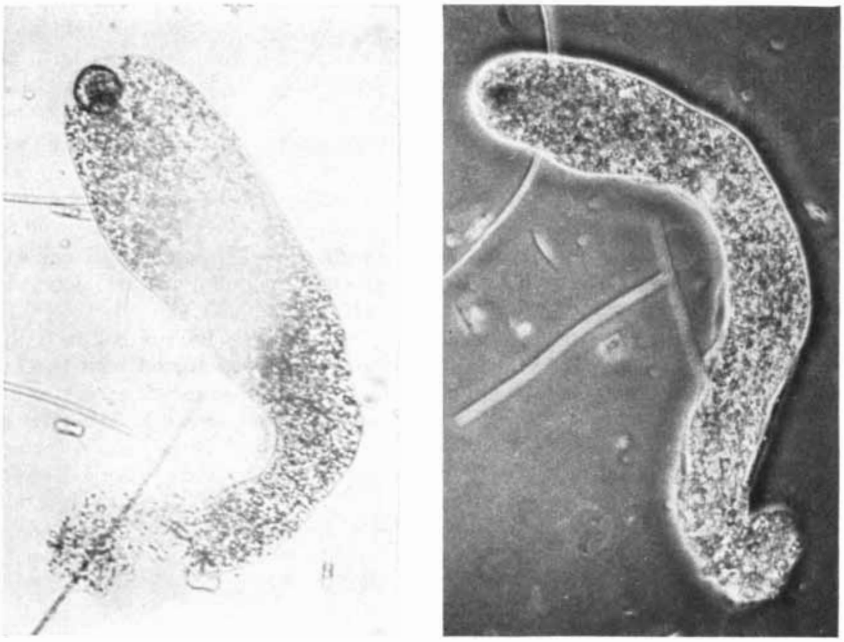
De Haas's project was supported by a grant from the Pennsylvania Academy of Science and was reported in the Academy's journal last year. His setup requires a three-element Abbe condenser with the top lens removed, an iris or Davis diaphragm for use with a four-millimeter objective of the dry type, a 16-millimeter objective and individual stops (made with opaque lacquer on daylight filters of medium shade) for each objective. These are inserted in the filter carrier beneath the substage condenser. The size of the stops must in general be determined experimentally. For a 16-millimeter objective of .25 numerical aperture the stop diameter should be 19/64 inch. A four-millimeter objective of numerical aperture .65 requires a stop of 21/32 inch.

An appropriate stop is inserted in the filter holder, the eyepiece removed and the image of the stop carefully centered by eye in the back lens of the objective. The lamp must also be centered on the optical axis. A specimen is then placed on the stage and focused. A position of the condenser will then be found where details of the specimen stand out in sharp contrast—lighter or darker than the surrounding field depending upon the adjustment. When using the four-millimeter objective, the position of the Davis iris influences the result and the best adjustment must be found by trial and error.

The technique contrasts with dark-field microscopy, where the condenser must lie in exact focus at the object plane and in which the object is always brighter than the field. The De Haas system appears to work on the principle of fringes diffracted by an edge—the stop providing the edge. The objective diaphragm probably acts on these fringes and those from the specimen so that they get added as in the Zernike system. De Haas has not attempted a theoretical analysis of the system. His optical train is shown on page 108. Photomicrographs showing a specimen of *Amoeba limax* made with ordinary transmitted light and by the De Haas system appear on the opposite page.

Correspondence reaching this department during recent months reflects concern among amateur astronomers with the design and construction of rock-solid mountings for their telescopes. This is particularly true of amateurs who go in for celestial photography, variable star observing, the precise timing of lunar occultations and so on. Knife-sharp photographic negatives and clear photoelectric recordings cannot be made with an instrument that jiggles.

In general the problem of achieving the desired stability has been attacked in two ways. The first reduces the difficulty by exchanging a pronounced slow wobble for a less-pronounced fast one.



An amoeba seen with transmitted light (left) *and with the De Haas phase system* (right)

Low amplitude is bought at the price of high frequency. Axes are made heavier and overhang is reduced to a minimum. In other words the "pendulum" is stiffened and shortened. It is possible to increase the rate of vibration of six-inch instruments to as much as 10 cycles per second by using stubby shafts for axes and appropriately light materials in the construction of the tube and its accessories. However, even this relatively high frequency is well within the range of a good photoelectric recorder. It can easily mask the subtle features of occultation recordings. Thus most designers tackle the problem by the second method: increasing the effective diameter of the axes. A now-classic example of this type of design is represented by the Springfield mounting introduced 35 years ago by the late Russell W. Porter and described in *Amateur Telescope Making–Advanced.* But even though the Springfield axes are defined by plates as broad as the telescope's mirror, physicists of the Army Map Service found it necessary to substitute oversized ribbed castings before the design would yield useful occultation records. Perhaps the simplest way of increasing the effective diameter of axes is to adopt one of the numerous yoke designs. They are cumbersome, of course, and troublesome to move. But if you are willing to sacrifice portability for stability of operation, a good yoke mounting is your dish.

W. P. Overbeck, of Aiken, S. C., has built one that he swears can function simultaneously as a trapeze and a precision photometer. He built the mounting for far less than the patterns alone of a Springfield would cost.

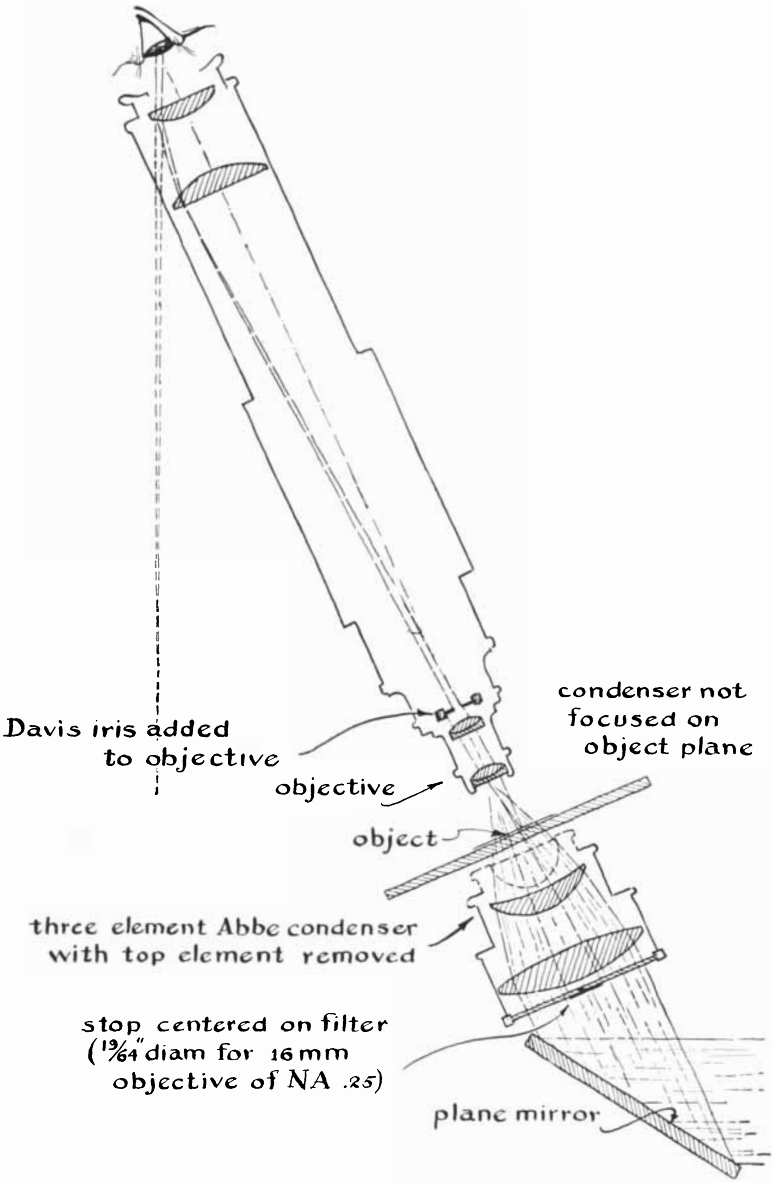
"My enjoyment of astronomy," he writes, "lies in calculating positions of objects or timing astronomical events and subjecting the results to accurate measurement. This provides relaxation from other activities which are not capable of such precise evaluation. Of course the professional astronomer does not define astronomy in such simple terms; he is most interested in phenomena which are very difficult to measure. But the amateur can take delight in finding things within a small fraction of a degree of where he expects to find them or in timing events within a few seconds, particularly when he has built his own instrument.

"To satisfy the desire for accuracy, I soon came to the conclusion that it would be necessary to build a telescope which could be permanently, and very solidly, mounted outdoors. It was difficult to see how reproducible measurements could be obtained with a portable telescope. Secondly, having meager facilities for precision machining, it became clear that I must use a type of mounting in which the principal axes are supported on widely spaced bearings so that any play in the bearings would have a minimum effect on angular motion. Finally, a permanent outdoor mounting must be weatherproof unless one wishes to add the cost of building an observatory complete with dome."

The answer to all these requirements is shown on page 110. Writes Overbeck: "The telescope tube and its declination axis are mounted in a yoke with bearing points spaced about a foot apart. The yoke is similarly mounted between two heavy A-frames with bearings about eight feet apart. With a 'slop' of less than .0005 inch in the bearings, the declination axis is fixed to within .0024 degrees and the polar axis to within .0003 degrees. The A-frames are fastened down with heavy bolts set in a four-inch concrete slab. The arrangement is so solid that one can climb on the frame while making observations. The principal timbers of the mounting are four by six inches. They were measured and cut with considerable care to obtain the correct angle of tilt for the latitude of the site. Each piece was then thoroughly shellacked and painted and finally assembled with half-inch lag screws, most of which were six to eight inches long. Preliminary alignment of the slab and frames was done by first establishing a true north-south line. This was accomplished by suspending a long plumb line from a temporary support and marking off the position of its shadow as the sun passed through the meridian. By referring other measurements to this line, it was possible to get everything lined up to within a small fraction of an inch and minimize the more precise alignment work required later.

"The yoke was built of half-inch plywood, heavily reinforced with two-by-six- and two-by-four-inch pieces at the points requiring strength. The sides of the yoke, as well as the main A-frames, are built so that they provide 'bearing boxes' at the points where the bearings are to be located."

The detail at the lower left on page



The optical train of the De Haas phase system

110 shows the arrangement of bearing, clutch and driving gear at one side of the telescope tube. The bearing is made up of three-quarter-inch pipe fittings which were machined down to get a good fit and alignment. Starting from the right, the detail shows a partial section of the tube, which at this point has a double wall for strength. A flange is fastened to the tube and holds a tubular bearing shaft made from a six-inch by three-quarter-inch pipe nipple. The shaft passes through a second flange which is fastened to a two-by-four-by-eight-inch wood block which fits snugly inside the bearing box and is held in position by two lag screws. The lag screws pass through clearance holes in the sides of the box, permitting a small amount of adjustment. On the outer end of the bearing shaft is a third flange, faced with rubber, which forms half of a disk-type clutch. The other half of the clutch is separately assembled with the driving gear on a steel bushing which slides into the outer end of the tubular bearing shaft.

Overbeck continues: "To control the clutch, a long quarter-inch steel rod, having a collar fastened to it, extends through the center of the entire assembly and is threaded into a steel plug at the inner end of the bearing shaft. In the actual assembly the two clutch faces remain in contact. They are surfaced with thin, smooth gasket rubber and require very little release of pressure to change from a locked condition to one which permits free motion. The drive for both declination and right ascension is provided by miniature electric motors which are geared 500,000 to 1 and are housed in the bearing box along with the clutch and gear.

"This makes it easy to maintain good alignment between driving gear and shaft. The box is sealed by a rubber strip which is tacked inside a four-inch hole in the face toward the telescope and which fits snugly against the side of the telescope. A second seal closes the opening around the clutch control rod. It took much longer to invent this assembly than it did to build it. One of its greatest advantages is that it can easily be taken apart, piece by piece, from the outer face of the box.

"The assembly above described is duplicated at one end of the polar axis. The other two bearing assemblies have no clutch or gear but simply have a graduated circle fastened to the flange which forms the inner clutch-face. The outer covers for these bearing assemblies have glass inserts."

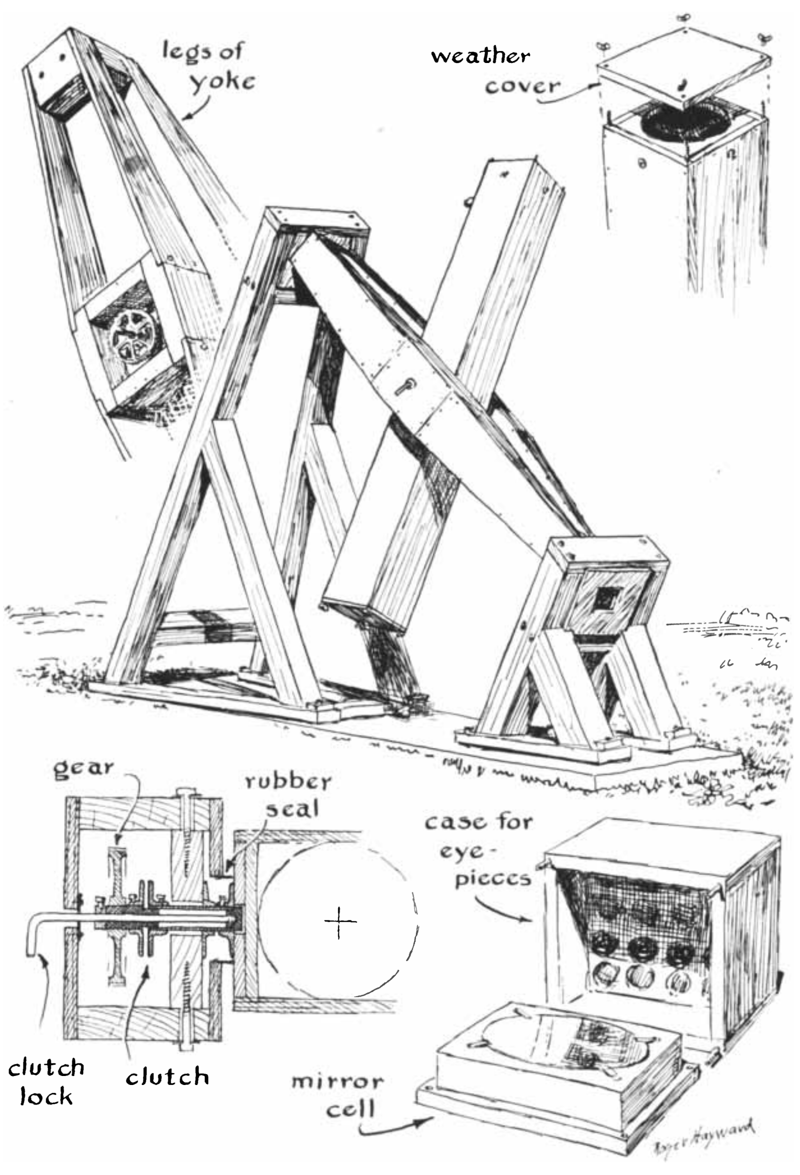
The telescope tube is made of half-inch plywood reinforced by several internal "ribs" which are pieces of plywood seven inches square with six-inch holes cut in them. When the tube is not in use, both ends are covered with simple plywood lids such as the one shown in the detail at upper right in the drawing.

A plywood box for carrying the eyepieces is also shown in the drawing. It was carefully built to the same dimensions as the tube. The mirror assembly can be used as a lid for the box when storing the optical parts indoors, or may be quickly installed in the end of the telescope when one wishes to make observations. The diagonal mirror and spider assembly at the other end of the tube is well protected from the weather and remains installed at all times.

Says Overbeck: "After final assembly, precise alignment of the telescope becomes a simple matter. First, the optical axis of the mirror was aligned with the dimensional axis of the tube. This was done by careful sandpapering of the end of the tube that supports the mirror. The alignment is checked by looking through the tube at the mirror from a distance about equal to twice its focal length. From this point one can see an enlarged image of the pupil of one's own eye which, when the mirror is aligned, will be neatly centered on the mounting spider of the diagonal mirror. (My mirror has a small hole in it, when the diagonal is removed, which makes this test very precise.) Second, the polar axis may be aligned by following a star, preferably one near the celestial equator, across the sky and observing apparent changes in declination. This was repeated several times until no apparent change could be seen. Finally the declination axis was checked by making several observations of stars of varying declination to find if there were consistent errors in relative values of right ascension.

"The first adjustments were made by calculating the required motion of various supports and bearings and later adjustments were made 'by feel' during observation. The procedure was successful in bringing the alignment of both axes within about .03 degree of perfect positioning as determined by averaging many individual measurements. This is much better than the precision with which it is possible to read the declination and hour circles, so for practical purposes it is more than adequate.

"Thus the final result is an instrument which is capable of more precise measurement than most telescopes in the $500 to $1,000 price range, which does not suffer from vapor condensation and thermal convection currents as most metal telescopes do and for which the total cost of materials was less than $100. It should be realized, however, that it cost a great deal of time and effort because its precision is largely due to its heavy structure and to the careful attention given to measuring, cutting and finishing of each piece of wood to insure both accuracy and long-term stability of dimensions. For me the effort was well worthwhile in meeting the particular objective I had in mind."



A steady telescope mounting made by an amateur

It is a good bet that no amateur telescope maker gets halfway through his first telescope mirror without wishing that he lived in Springfield, Vt. Three miles outside Springfield is a fir-clad knob called Breezy Hill, the site of the little clubhouse-observatory called Stellafane. This pleasant spot is periodically the epicenter of amateur astronomy. At a chosen time each year amateurs from everywhere get together to "talk and talk and look and eat." These words are quoted from Jim Gagan, chairman of the Stellafane Committee of the Amateur Telescope Makers of Boston. It is this group which arranges the meeting.

Writes Gagan: "The 1955 meeting will take place on August 20. The Vermont corn will be ripe, the moon will be three days old and good seeing (96 per cent) is predicted.

"Come yourself and pass the world along. If you like to rough it, you can camp on Breezy Hill. If not, room reservations can be made through the Hartness House, Springfield, Vt.

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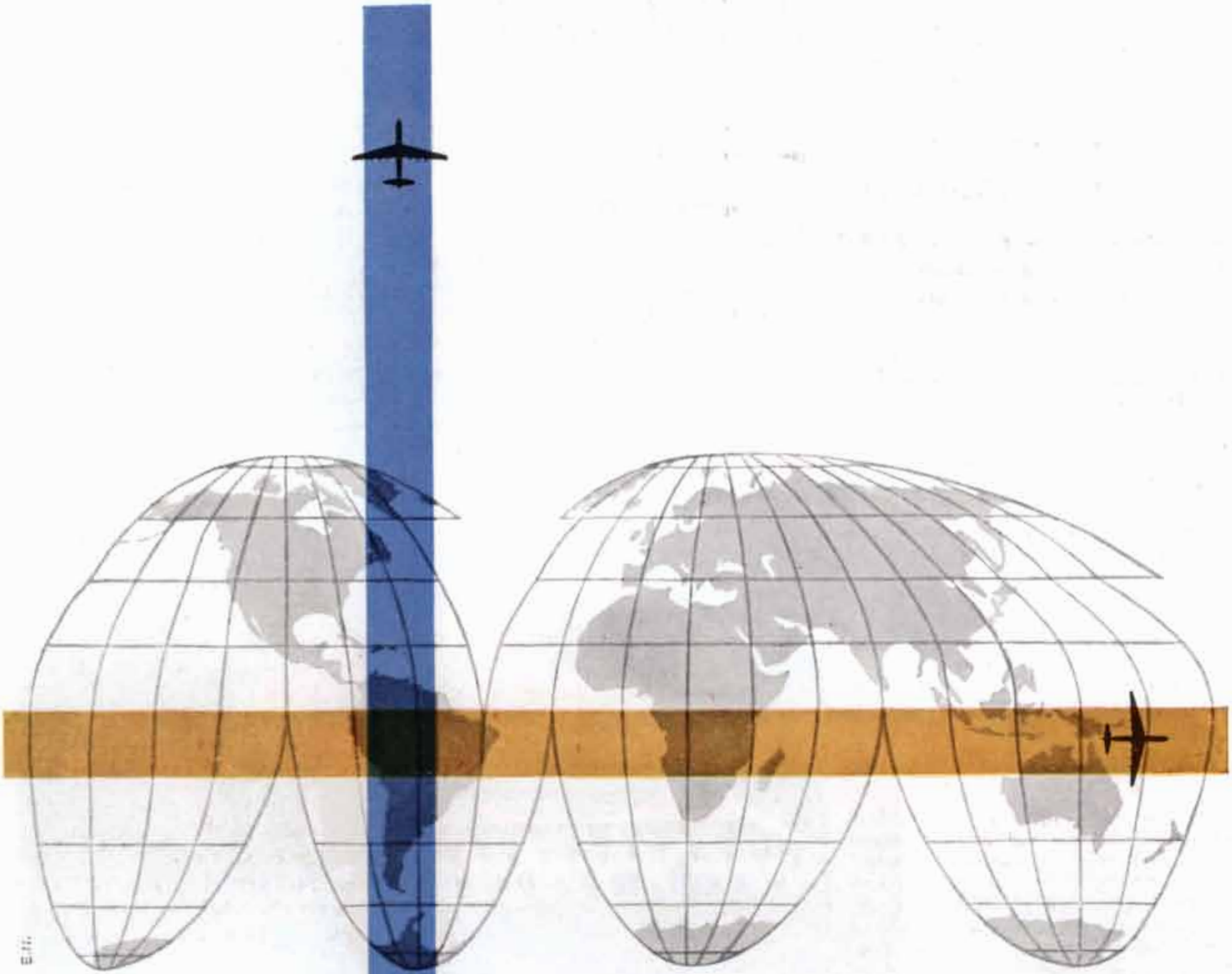

getting atomic power....**off the ground**

Important in the development
of globe-girdling atomic aircraft
is the *portable nuclear reactor*
built and operated by the Convair
Division of General Dynamics
for the United States Air Force.
Shown, at left, suspended in mid-air
for radiation tests, this high-flying
reactor is another dramatic example
of Dynamics' leadership
in the *nucleodynamic* age.

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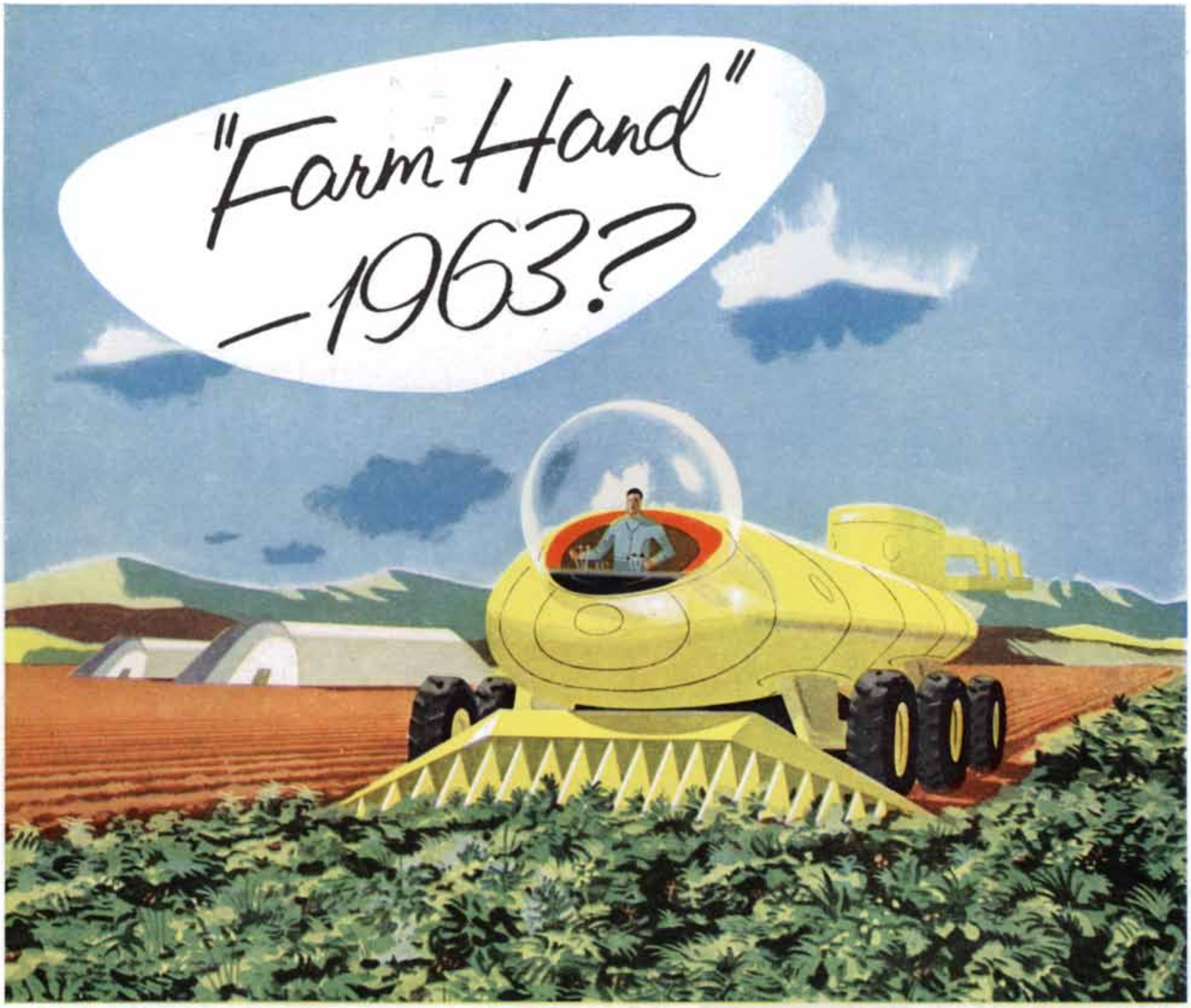
NEW DEPARTURES OF TOMORROW



How you gonna keep 'em away from the farm after they've seen this machine? . . . Chances are, the people who develop this **soil-conditioner, fertilizer-planter unit,** with its air-conditioned control cab, will call on New Departure for ball bearings. Maybe they'll just need New Departures that are already in world-wide use—like the Sealed-for-Life or the double-row angular-contact ball bearings. Or they might want an entirely new type—a "new departure" in ball bearing design.

Either way, New Departure is the answer. Manufacturers everywhere know that New Departure always lives up to its name—being *first* with the finest in ball bearings.

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Today, New Departures are used by almost every manufacturer of farm equipment. That's because New Departure ball bearings have proved their ability to carry *all* loads, preserve accurate alignment of moving parts, cut friction and upkeep.

NEW DEPARTURE
BALL BEARINGS

NOTHING ROLLS LIKE A BALL