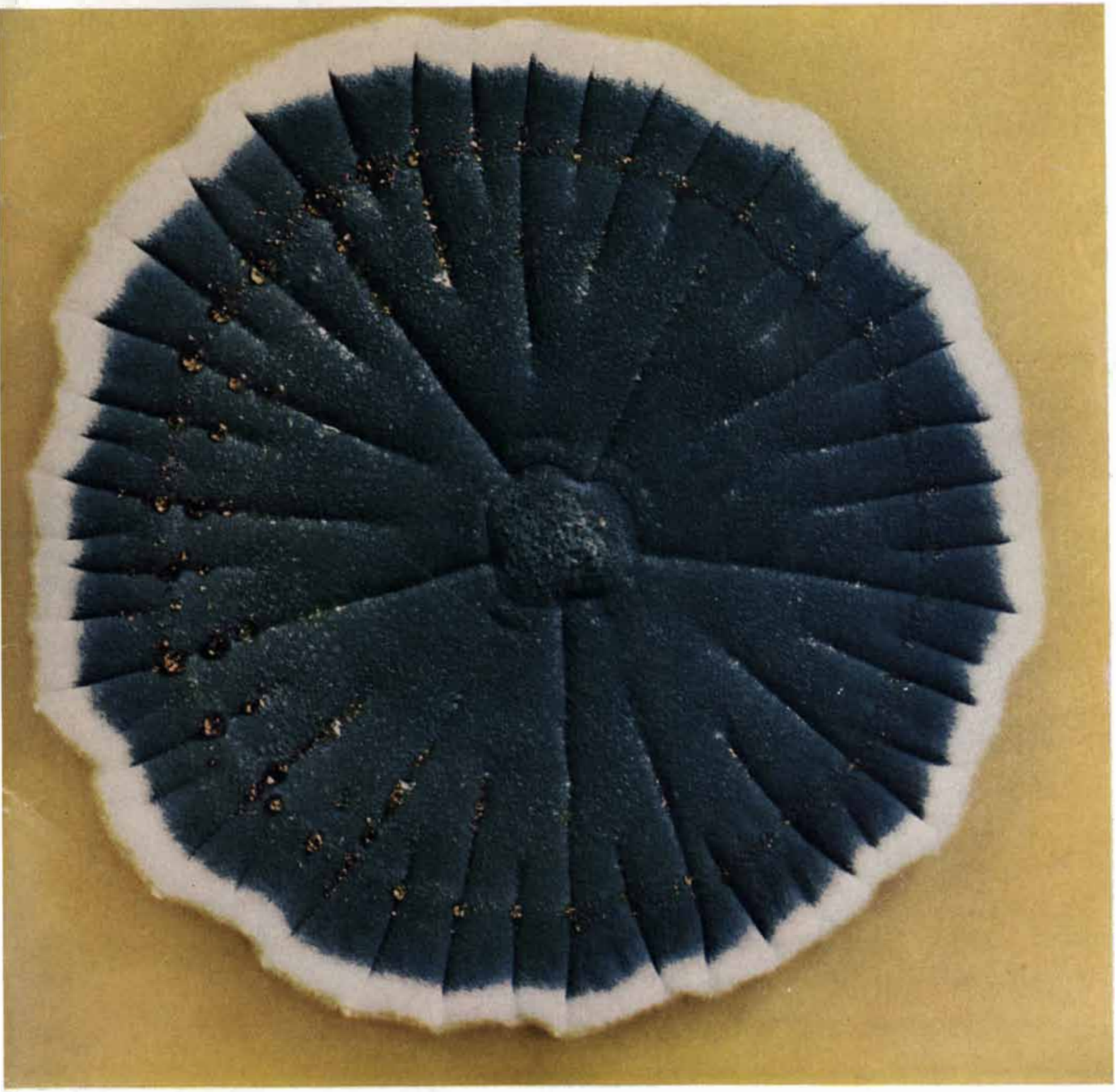
SCIENTIFIC AMERICAN



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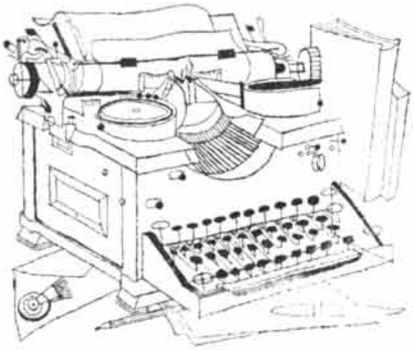
January 1952



LETTERS

Sirs:

The article in your August, 1951, issue by Louis N. Ridenour, properly entitled "A Revolution in Electronics," is most interesting.

The article, however, conveys an entirely erroneous impression: that the three-electrode tube amplifier has virtually come to the end of its career. In fact, there is absolutely no justification for conveying such an impression. At the present time the transistor in its most advanced n-p-n form is a very great distance from proving to be an equivalent of the three-electrode tube.

Dr. Ridenour neglected to state anything regarding the frequency limitations of the transistor, which is, as I understand, limited to a few kilocycles. Under such limitations the transistor cannot begin to compete with the three-electrode tube, or audion, as I first styled it.

The highly amplifying gains of the transistor are indeed remarkable. It will undoubtedly prove a device of very great value where only low frequencies are involved. The collector capacitance of the transistor limits the frequency response at full gain to a few kilocycles. Even if by using a suitable mismatch it is possible to maintain the frequency response flat to at least one megacycle, the general application of the transistor in radio and television receivers is far in the future. There is no definite assurance that these frequency limitations of the transistor will ever be overcome.

And when it comes to other uses, such as power oscillators for broadcasting, radio communication of every sort, and industrial applications, a transistor is, of course, not to be considered.

In view of the above stated facts, as borne out by the paper by Wallace and Pietenpol in the July issue of *The Proceedings of the Institute of Radio Engineers,* Dr. Ridenour's statement, "Thus nearly half a century after deForest's invention of the tube that gave birth to electronics we are brought to the conclusion that there is nothing wrong with electronics that the elimination of vacuum tubes would not fix!," is as totally misleading as it is silly.

LEE DEFOREST

United Engineering Laboratories
Los Angeles, Calif.

Sirs:

I am very pleased to have the comments of the man who made possible the present age of electronics, even though I must take mild issue with some of them.

How far the transistor now is from being a superior substitute for the vacuum tube varies with the nature of the application, and anyhow is to a certain extent a matter of opinion. It does seem impressive, however, that the transistor—a three-year-old infant—can even be considered as a serious competitor for the mature vacuum tube, which has had the benefit of 44 years of intensive development. Even now, there can be little doubt of the superiority of the transistor in certain applications; for example, in hearing aids.

The frequency limitations of the transistor are by no means so serious as Mr. deForest states. There is good evidence that transistors can be used satisfactorily up to frequencies of several megacycles per second, and even this limitation is not regarded as fundamental by the engineers working on transistor development.

The time at which consumer radio and television equipment can use transistors may indeed be some years off, as Mr. deForest says. However, this delay is likely to be due to the inability of rising transistor production to keep up with vast and growing military demands,

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rather than (as he suggests) to any technical inadequacy of the transistor.

I cannot be as pessimistic as Mr. deForest is regarding the prospects for semi-conductor power oscillators. Germanium diodes handling kilowatts of power have been made. It seems entirely possible that power oscillators could be realized. This phase of transistor design has not yet had much attention.

Mr. deForest is entirely justified in regarding as misleading the sentence he quotes from my article. This is a property it shares with all short statements of a complex situation when quoted out of context with the full discussion of the situation. I am not so sure that the sentence quoted is silly. The principal limitations of complex electronic apparatus of today—especially complex military gear—are traceable to the fundamental shortcomings of the vacuum tube, which nearly half a century of development has alleviated, but not cured.

Surely Mr. deForest will understand that the intention of my article was not to depreciate in any way the vast importance of his new invention of the vacuum tube. I did want to call attention to a new invention whose effect on engineering capabilities and techniques promises to be fully as significant.

LOUIS N. RIDENOUR

Laguna Beach, Calif.

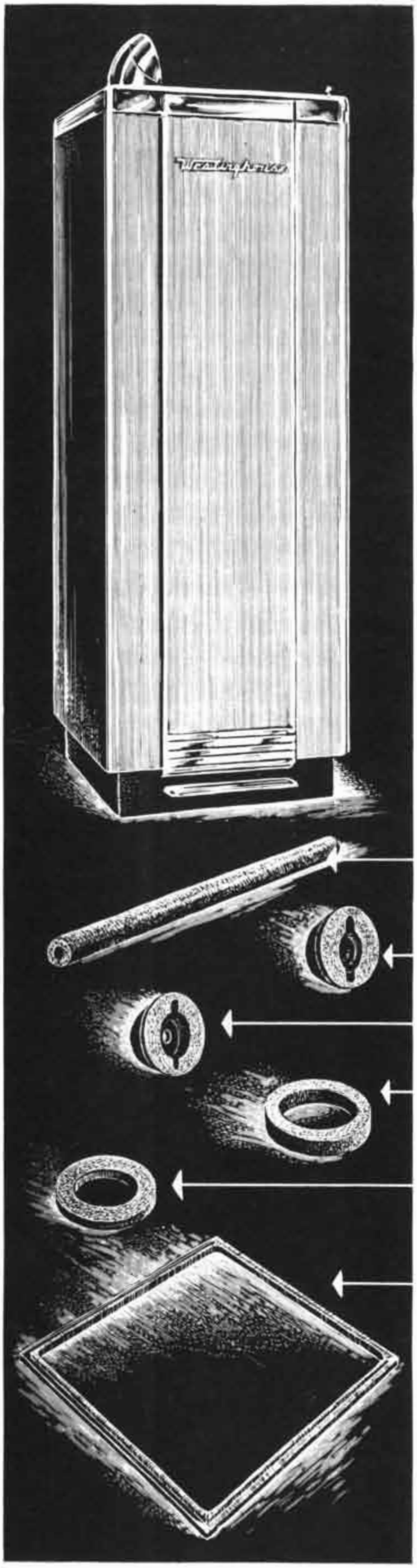
Sirs:

Your recent article "Life in the Depths of a Pond" (SCIENTIFIC AMERICAN, October, 1951) by E. S. Deevey, Jr., reports that the hypolimnion, the lower stratum of a lake, does not circulate and is anaerobic because it does not circulate. The supposition that the pond does not circulate seems to be erroneous unless it is a special case. In the summer of 1949 I found the fastest current in Lake Mendota, Wis., in the hypolimnion, several meters below the thermocline. This is not out of line when one considers the great thermal instability that occurs in the surface layers or epilimnion. This unequal difference in pressure exerted on the hypolimnion sets up definite patterns of water movement in these lower layers.

Professors Bryson and Suomi, University of Wisconsin, reported in 1950 that during heavy rains in summer the hypolimnion may become supersaturated with oxygen. The heavy, silt-laden runoff water due to the rain sinks below the thermocline and carries oxygen to the lower layer of water.

JAMES L. VERBER

Franz Theodore Stone Institute
of Hydrobiology
Ohio State University
Put-in-Bay, Ohio



SCIENTIFIC AMERICAN

50 AND 100 YEARS AGO

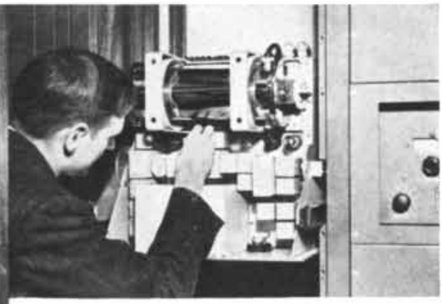
JANUARY 1902. "The curious properties of polonium, actinium and radium are for the most part opposed to all accepted mechanical theories, physical and chemical, for they appear to be spontaneous producers of light and electricity, in a word, of energy. Now, it cannot be admitted that a body can produce energy indefinitely, however small the production, without borrowing from external sources, and without losing from its mass, and yet this appears to be the case with the three new metals. It is difficult to imagine electric conductibility in the absence of every material particle; and as their rays are conductors, it may be supposed that there is an ultimate form of very attenuated matter, which these radio-active bodies may be able to emit indefinitely without losing noticeably from their mass. However it may be, the spontaneity of the radiation remains an enigma, a subject of profound astonishment. There is ground for believing that the discovery of these bodies marks a new stage in the grand history of science, and that it supports the hypothesis of the unity of matter, which has commanded the attention of philosophers for 2,500 years. Science is yet in its crudest manifestations, and our minds are scarcely trained to grasp the fundamental phenomena which incessant researches are gradually unveiling."

"Of late years the efforts of experimentalists in the field of aeronautics have been directed rather to the airship than to the aeroplane. Maxim, Lilienthal and Langley are not heard from so much as De la Vaulx and Santos-Dumont. Santos-Dumont's experiments, which have attracted world-wide attention, had for their objective point the winning of the Deutsch prize of $20,000, offered to the first aeronaut who should successfully make the trip from the Aero Park in the suburbs of Paris around the Eiffel Tower and back again in 30 minutes' time. This indefatigable young Brazilian, after several attempts, in one of which his balloon was completely wrecked, succeeded in winning the prize, with only a fraction of a minute to spare. The airship in which he made the trip is 98 feet in length, 15 feet in diameter and is driven by a gasoline engine of 20 horsepower. A large number of less widely advertised attempts have been made with machines of the aeroplane type. Among these may be mentioned Nemethy's flying machine, driven by a 2½ horsepower gasoline motor; the Hoffman flying machine, driven by a steam motor; and the Whitehead flying machine, which is built after the model of the bat."

"Unquestionably the most important developments in the electrical world in the year just concluded have been those connected with telegraphy and telephony. The announcement of the brilliant conclusion of the course of experiments carried out by Dr. Pupin, in his investigation of the long-distance telephone, which appeared in SCIENTIFIC AMERICAN during 1900, was followed by the announcement early in 1901 that he had disposed of his patents to the American Telephone and Telegraph Company for the sum of $500,000. Dr. Pupin first formulated a mathematical theory of the propagation of electrical waves, and then constructed an experimental cable which verified the theory and opened the way for the construction of a cable suitable to commercial use. Dr. Pupin's first cable was 235 miles long, his second, 500 miles; and his third and most successful cable, 250 miles in length. The inductance coils have been used successfully on a Bell telephone air line of 700 miles in length, and Dr. Pupin considers that by the use of his system telephonic messages may be sent over a 3,000-mile cable."

"Marconi's station at Signal Hill, Newfoundland, will hereafter be memorable as the first place where a transoceanic wireless message was received. Edison believes that success would not have been attained, perhaps, if Marconi had attempted to transmit an entire sentence. Moreover, the receiver was not the ordinary apparatus, but a telephone of the most delicate construction, and most sensitive in operation. Even with this fine instrument the signals are said to have been barely distinguishable. From the reports it would seem that poles were used in Cornwall no greater in height than those commonly employed for the transmission of messages for 50 or 60 miles. The curvature of the earth, formerly considered a formidable obstacle, seems to have but little effect upon the transmitted waves."

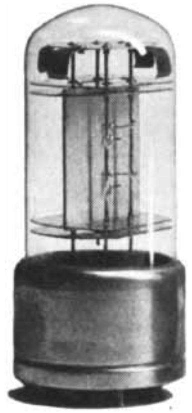
"The great Isthmian Canal problem has reached a stage at which it needs only the exercise of a little common sense



Each crystal is enclosed in a cylindrical oven which holds the crystal temperature to within 1/100 of a degree.

At the A. T. & T. building at 195 Broadway, New York, passersby set watches by the world's most accurate public clock, which is controlled by the master standard.

↑ Front of the new frequency-time standard at Bell Telephone Laboratories. In the rear there are 600 electron tubes and 25,000 soldered connections. Room temperature is maintained within two degrees.



The controlling quartz crystal vibrates in vacuum at 100,000 cycles per second. The standard is powered by storage batteries, with steam turbo-generator standing by, just in case of emergency.

A vibrating crystal keeps master time

Ever since Galileo watched a lamp swinging in the Cathedral of Pisa three centuries ago, steady vibration has provided the practical measure of time. In the 1920s Bell Laboratories physicists proved that the quartz crystal oscillators they had developed to control electrical vibration frequency in your telephone system could pace out time more accurately than ever before.

The Laboratories' latest master standard keeps an electric current vibrating at a frequency that varies only one part in a billion, keeping time to one ten-thousandth second a day.

Through secondary standards, a master oscillator governs the carrier frequencies of the Bell System's ship-to-shore, overseas and mobile radiotelephone services, the coaxial and *Radio Relay* systems which transmit hundreds of simultaneous conversations, or television. In the northeastern states, it keeps electric clocks on time through check signals supplied to electric light and power companies.

The new standard also provides an independent reference for time measurements made by the U. S. Naval Observatory and the National Bureau of Standards. Thus, world science benefits from a Laboratories development originally aimed at producing more and better telephone service.

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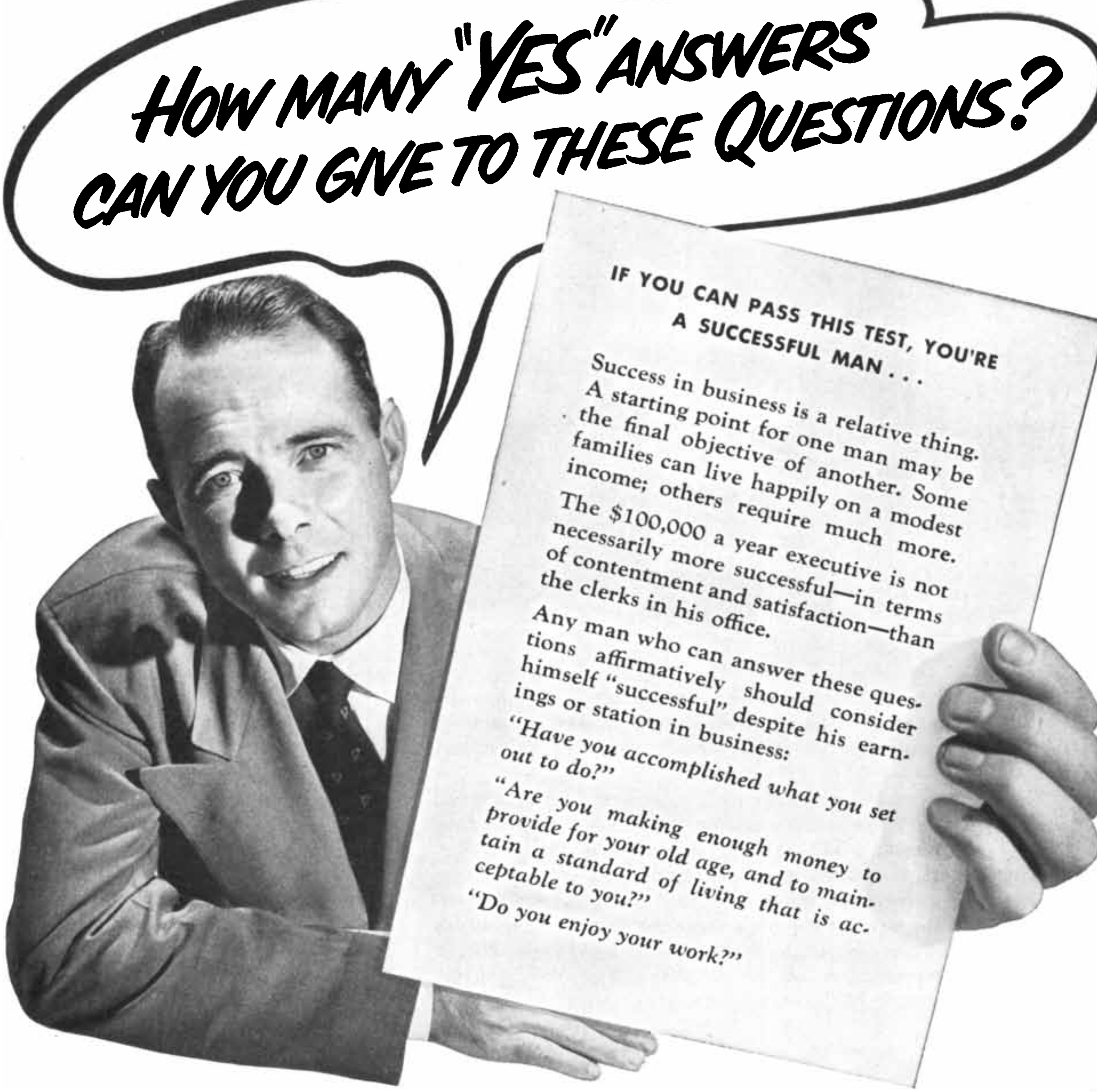
for its satisfactory solution. The question of the proper location for the canal is first and last one of engineering. Judged on the ground of practicability of construction, security, permanence, convenience and ease of operation, and cheapness of first cost and maintenance, the Panama Canal as designed by our engineers is by far the better scheme."

JANUARY 1852. "Since the art of vulcanizing india rubber—an American discovery—was first made, its use has become almost universal. It is used for almost everything in the shape of an airtight and elastic material. The vulcanizing of india rubber is due to sulphur combining with the india rubber, and then submitting the material to a great heat, high-pressure steam, or an oven heat. The elasticity of the india rubber is maintained, while it is rendered waterproof, and remains unaffected by heat; while in its unprepared, unvulcanized state, it is easily affected by the weather."

"In many departments of science our country has recently earned a proud name, but in none so much, we think, as in that peculiar department at the head of which stands Lieut. Maury, U.S.N. The navigation of the seas is at present the most important of all sciences to our country. To this subject Lieut. Maury has devoted himself with all his energy, great learning, and keen perceptive faculties. The Wind and Current Charts of Lieutenant Maury include the Oceanic Currents, the Course of the Winds, and the Temperature. These Charts are constructed upon positive data of observations made by captains of vessels in all the various months of the year, and in the various parts of the oceans of this planet. He has developed a new field of observation, and this field is studded with new, brilliant, and useful discoveries to the marine interests of our great nation and the world."

"There are 10,814½ miles of railroads in operation in the United States, and 10,878½ in progress of construction. New York stands at the head of the list, having no less than 1,826 in operation. There are more railroads in the United States than in all the world beside."

"Encke's Comet was observed simultaneously at the Washington and Cambridge Observatories on Tuesday last. Nearly 30 years have elapsed since the period of revolution was ascertained to be about 40 months or a little more than three years. Its recent returns have therefore been carefully observed by astronomers, as by them the truth of the theory of a resisting medium, proposed by Mr. Encke, will probably be ascertained."



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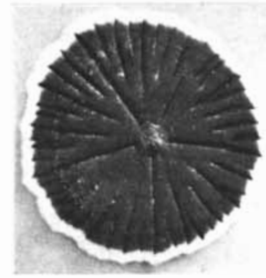

THE COVER

The photograph on the cover shows a colony of *Penicillium notatum*, one of the mold species (*see page* 28). The entire colony is about an inch and a half in diameter. In its center is a small bump; this represents the original planting of the mold. The green surface of the colony is composed of its spores; the white ring around the green area is mycelium that has not yet sporulated. The deep yellow background of the colony is a nutrient agar medium. The golden droplets on the surface of the mold contain products of its metabolism, perhaps including penicillin. For commercial purposes, however, penicillin is not produced by such colonies but in vats. The photograph was made in the laboratories of Chas. Pfizer & Co.

THE ILLUSTRATIONS

Cover courtesy Chas. Pfizer & Co.

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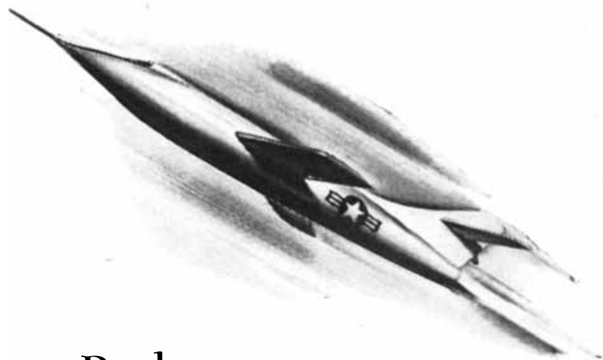
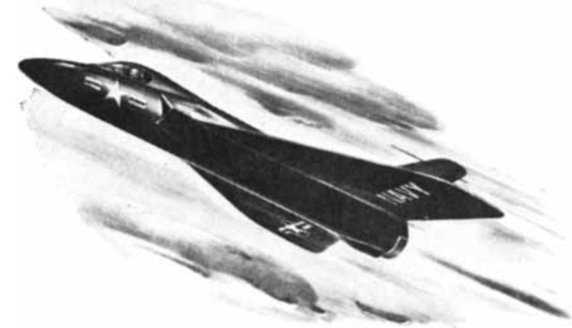


Rocket... World famed Navy-Douglas 558-2 *Skyrocket*, which, on August 7, 1951, set new world records for speed and altitude for airplanes of any type or size.



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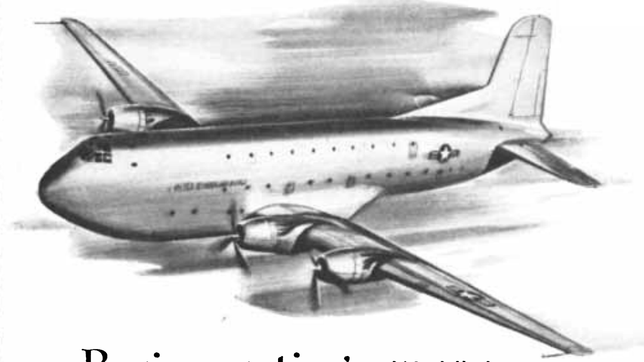
Turbo-prop... First U. S. turbo-prop attack bomber, the A2D *Skyshark*, built for the U. S. Navy and now entering production at El Segundo Division of Douglas.



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DEPARTMENTS

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SCIENTIFIC AMERICAN

JANUARY 1952 VOL. 186, NO. 1

CLOUD SEEDING

It is now five years since dry ice was first used to make rain. An account of the present state of the technique, with special reference to the sowing of silver iodide for large-scale effects

by Bernard Vonnegut

HOW does rain form in clouds? This sounds like a very simple question, but it is one of the least understood in meteorology. The basic experiments in cloud physics during the past five years, however, have yielded important clues to the process, encouraging the hope that man may some day be able to exercise some real control over the weather.

How clouds themselves are formed has been fairly well understood since the turn of the century. When moist air is cooled below its dew point, the water vapor condenses into tiny droplets. Each drop forms around a very small particle of dust, smoke or salt spray. Such particles are always present in the atmosphere in concentrations of hundreds to thousands per cubic centimeter. The cloud droplets, ranging in size from perhaps a hundredth to less than a thousandth of a centimeter in diameter, are so light that they fall very slowly, and they usually evaporate long before they can reach the ground.

The question was: How do the cloud drops get together to form raindrops or snowflakes, which are thousands or millions of times as large as the tiny cloud drops? Clearly they do not build up by simple coagulation, because such a process would take too long to account for the observed rapid formation of raindrops in clouds.

In 1931 the Norwegian meteorologist Tor Bergeron proposed one explanation which is now widely accepted. He suggested that raindrops are formed initially as snowflakes at high altitude in supercooled clouds, that is, clouds in which the droplets do not freeze even though the temperature is far below freezing. It was known that supercooled water has a higher vapor pressure than ice at the same temperature. It followed from this that if an ice crystal were introduced into a cloud of supercooled droplets, it would grow and the droplets would evaporate. Bergeron reasoned that if a relatively few ice crystals were somehow to form in a supercooled cloud, these crystals would rapidly grow into snowflakes. As they fell to lower altitudes, they would melt and form raindrops.

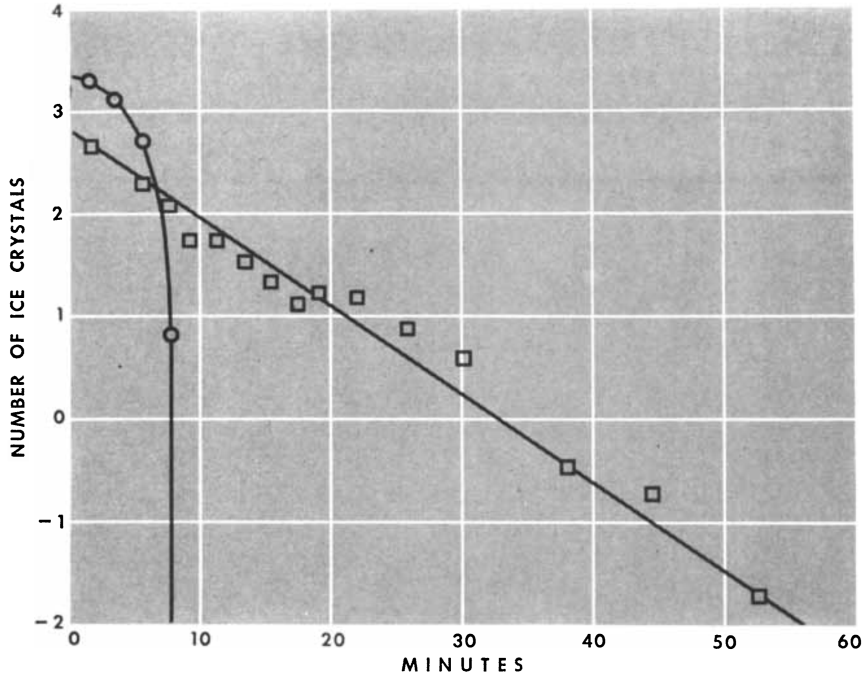
That supercooled clouds often occur was well known to aviators; such clouds are responsible for the icing of a plane's wings. Bergeron's theory accounts for many of the observed facts of rain and snow formation, and it appears to offer a logical explanation for most of our temperate rainfall, though not for some of the rains in the tropics, which often originate in clouds whose temperatures are above freezing.

BERGERON did not explain how the seeding ice crystals came to be formed in clouds in the first place. This became a matter of exciting speculation. The German scientist Walter Findeisen prophetically pointed out in 1938 that "quite minute, quantitatively inappreciable elements," such as certain kinds of dust particles, might initiate rainstorms, and that artificial control of the weather should be possible. "It can be boldly stated," he said, "that at comparatively moderate expense it will in time be possible to bring about rain by scientific means, to obviate the danger of icing and to prevent the formation of hailstorms."

This prophecy began to be realized in 1946 when Vincent J. Schaefer and Irving Langmuir of the General Electric Research Laboratory started their experimental investigations of supercooled clouds. During the war they had worked on the problem of ice formation on airplanes. In their experiments, carried out on Mount Washington in New Hampshire, they had been struck by the rarity with which ice crystals formed in supercooled clouds in the atmosphere. Schaefer, following up this observation with experiments in a home food-freezer after the war, found that he could produce supercooled clouds very similar to those formed in the atmosphere by merely blowing his breath into the freezer. When he whirled the small propeller of a model airplane in such a cloud at a temperature of zero Fahrenheit, the propeller iced up on its leading edges. But only rarely did an ice crystal appear in the cloud itself, as Schaefer found when he lined the interior of the cold box with black velvet to give a dark background and observed the cloud in a light beam.

Scientists had proposed that smoke and dust particles of various kinds, such as silica, carbon, graphite, and so on, might serve as nuclei for ice-crystal formation. Schaefer tried all of these substances and many others by dusting them into the supercooled cloud. But none of them caused ice crystals to form.

One warm day in July, 1946, the cold box was slow in cooling down. To speed its cooling Schaefer put a piece of dry ice in the box. To his great surprise and delight the entire mass of supercooled cloud rapidly changed to a shimmering mass of hundreds of millions of tiny ice crystals. Looking at them under the microscope, he found that the crystals were miniature six-sided snowflakes. In perfect accord with Bergeron's theory, when Schaefer blew his breath into this cloud of crystals, the moisture formed a supercooled cloud as before, but now the liquid droplets evaporated and con-



PERSISTENCE of ice crystals due to dry ice (*circles*) and silver iodide (*squares*) is shown by plot of icebox experiments. Number of crystals is given as a logarithm of those falling on a square millimeter per minute.

densed on the ice crystals in a matter of seconds.

Why did the dry ice produce ice crystals? Schaefer found that it was solely the dry ice's low temperature. Anything at a temperature of minus 38 degrees F. or below caused ice crystals to form in enormous numbers in a supercooled cloud without the need of dust or other foreign particles. In other words, a supercooled cloud cannot exist below this temperature.

Calculations showed that a single gram of dry ice dropped into a supercooled cloud could produce 10^{16} (10 million billion) ice crystals. This is more than enough ice crystals to seed many cubic miles of cloud, and Langmuir and Schaefer made plans to try the experiment of dropping dry ice from an airplane into one of nature's clouds.

On November 13, 1946, Schaefer took off for the first cloud-seeding experiment in a plane piloted by Curtis Talbot, with Langmuir observing from the ground at Schenectady. At 14,000 feet over Mount Greylock in western Massachusetts they found a supercooled cloud which was a few thousand feet thick and about four miles long. As they flew over it, Schaefer dropped dry ice into it at the rate of about one pound per mile. By the time they had finished the run and looked back, the entire cloud had begun to change greatly in appearance. It quickly condensed into long streamers of falling snow, which were visible to Langmuir some 40 miles away in Schenectady. Although all of the snow from this little cloud evaporated before it reached the ground, the experiment was an unqualified triumph. It showed on a small scale that by relatively simple and inexpensive means it was possible for man to alter the normal course of the weather.

AT JUST about the same time the author was investigating another technique for causing supercooled clouds to turn to snow. It had occurred to him that it might be possible to find some crystal which was very similar to the ice crystal, and that this substance might prove to be a good ice-forming nucleus. He examined the crystal-structure data in a handbook listing 1,900 known crystals, and found a substance that bore a remarkable resemblance to ice. This crystal was silver iodide. The arrangement of its atoms was nearly identical with that in the ice crystal, and the spacing of the atoms was within about one per cent the same. Particles of silver iodide were thereupon introduced into a supercooled cloud in a cold box. The experiment succeeded: the silver iodide caused enormous numbers of ice crystals to form in the cloud.

Although silver iodide is an excellent nucleus for ice formation, it is not quite as good a nucleus as ice itself, because it requires lower temperatures. The tiny ice crystals produced by the use of dry ice can grow, once they are formed, at any temperature up to the freezing point of water, whereas silver-iodide particles are active as a seeding agent only when the temperature of the cloud is 26 degrees F. or lower.

Silver iodide is an effective seeding agent even when it is dispersed as a smoke consisting of particles as small as one-millionth of a centimeter in diameter. One gram of silver iodide, costing about two cents, is sufficient to make 10^{16} snowflakes when the temperature of the supercooled cloud is zero F. When the smoke is introduced into a supercooled cloud, not all of the particles react immediately to produce ice crystals. The reaction is somewhat like the decay of radioactive material. One cannot say which particle will form an ice crystal next, any more than one can say which atom of a radioactive substance will explode next. But within a certain time one half of all the silver-iodide particles will have formed ice crystals, and this period, by analogy with radioactivity, is called the half-life of the smoke. The half-life of silver-iodide smoke in a supercooled cloud depends somewhat on the size of the smoke particles and a great deal on the temperature. At zero F. silver-iodide particles have a half-life in a supercooled cloud of a few seconds, while at 14 degrees the half-life is about a week.

Because silver iodide, unlike ice, does not melt or evaporate under atmospheric conditions, it need not be introduced directly into the clouds. Laboratory experiments, which showed that one gram of silver iodide in the form of smoke should provide enough nuclei to seed from 100 to 1,000 cubic miles of supercooled cloud, suggested that silver-iodide smoke-generators operated on the ground could inoculate enormous volumes of the atmosphere with ice-forming nuclei, which would sooner or later find their way into supercooled clouds.

LANGMUIR'S and Schaefer's exciting experiment in cloud-seeding marked the beginning of a new field in meteorology in which man was no longer merely an observer but an active participant. In the spring of 1947 the U. S. Army Signal Corps and the Office of Naval Research set up a joint project to make a detailed study of the physics and meteorology of cloud-seeding. This program, known as Project Cirrus, had the cooperation of the U. S. Air Force, which supplied airplanes and crews. The General Electric research workers who had originated cloud-seeding were called upon to continue their fundamental studies and to serve as consultants. So far Project Cirrus has carried out more than 200 operations from airplanes, and the results of the cloud-seeding and laboratory researches have been published in more than 40 reports and technical papers.

The flight operations of Project Cirrus soon showed that seeding with dry ice could dissipate and clear large sections of cloud and could produce rain from cumulus clouds. Under certain circumstances, when the atmosphere was unsaturated with respect to supercooled water but supersaturated with respect to ice, seeding could even cause the formation of ice-crystal clouds in clear air.

Schaefer showed that the supercooled fogs that often hug the ground in wintertime, particularly at night and very early in the morning, can be converted into ice crystals and cleared over a considerable area merely by swinging a piece of dry ice on the end of a string.

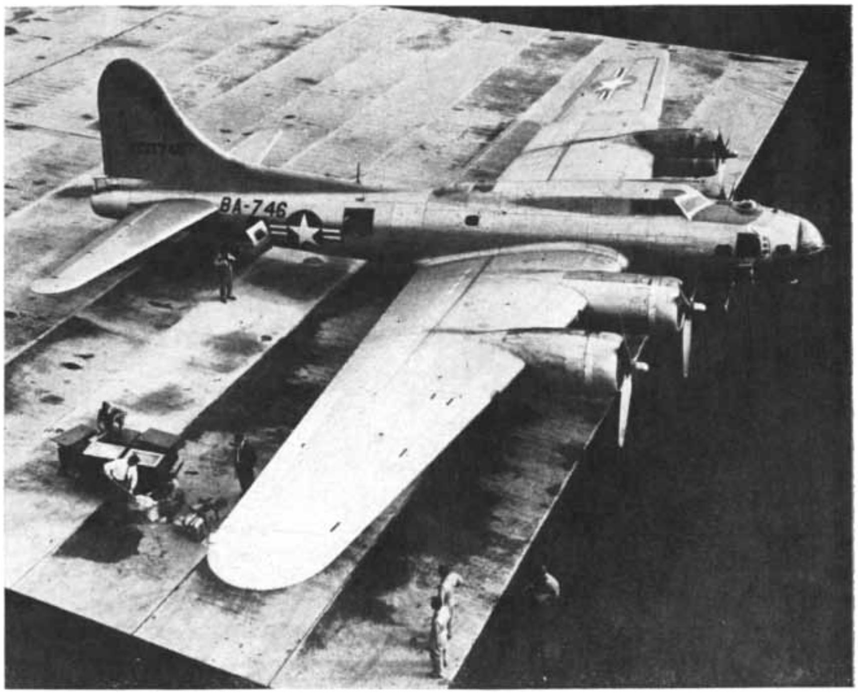
Searching for other substances that might serve as ice-forming nuclei, Schaefer discovered certain soils and dusts which could produce this effect at temperatures up to 10 degrees F. These nuclei, which occur in nature, may greatly influence the weather.

Meanwhile Langmuir developed a chain-reaction theory to explain how rain can form in comparatively warm clouds. His theory suggests that a sizable water drop suspended in the updraft of a cumulus cloud will grow by collision with fine cloud droplets. Eventually this drop becomes so large that it is unstable and breaks into two or more large drops. These drops in turn grow and divide by the same mechanism until the chain reaction fills the cloud with large drops. The drops then fall as rain when the updraft ceases. The theory predicts that certain cumulus clouds can be caused to give rain by introducing into them a few large drops to initiate a chain reaction. Experiments using this method have been carried out with apparent success in Hawaii, Honduras and Australia.

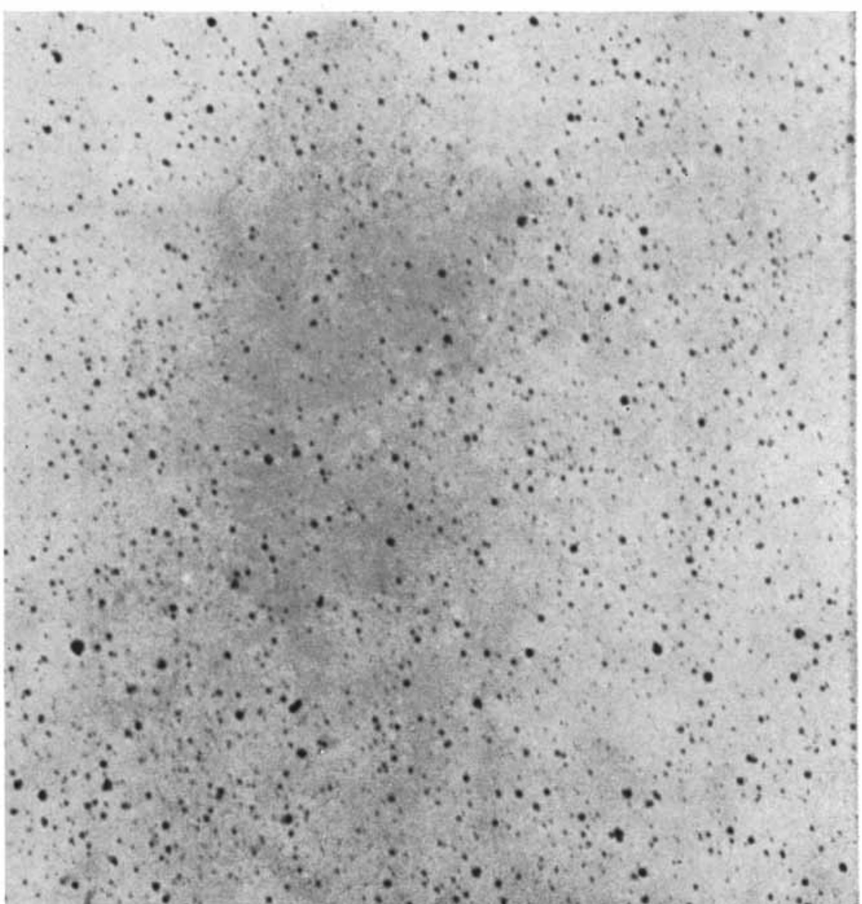
THE practical application of cloud-seeding began in 1947, when several groups started seeding with dry ice in the Western states. Before the silver-iodide technique could be employed on a large scale, it was necessary first to develop suitable smoke generators and to learn how to use them. By the middle of 1947 two simple types of silver-iodide smoke-generators had been perfected for use in seeding, either from the ground or from an airplane.

The first of these generators produces a smoke of fine silver-iodide particles by burning a solid fuel, such as charcoal, impregnated with a few per cent by weight of silver iodide. The heat of combustion of the fuel vaporizes the silver iodide; upon mixing with the atmosphere the vapor is cooled and condenses as submicroscopic ice-forming nuclei. In a ground-based generator of this type the impregnated charcoal is burned in a small furnace with air supplied by a small blower. For seeding from an airplane, pieces of impregnated charcoal about the size of a pea are first brought to red heat in a small heater and then dropped out of the airplane. The particles burn brightly as they fall, leaving behind trails of silver-iodide nuclei. By the time the charcoal has fallen about 1,000 feet it is completely consumed.

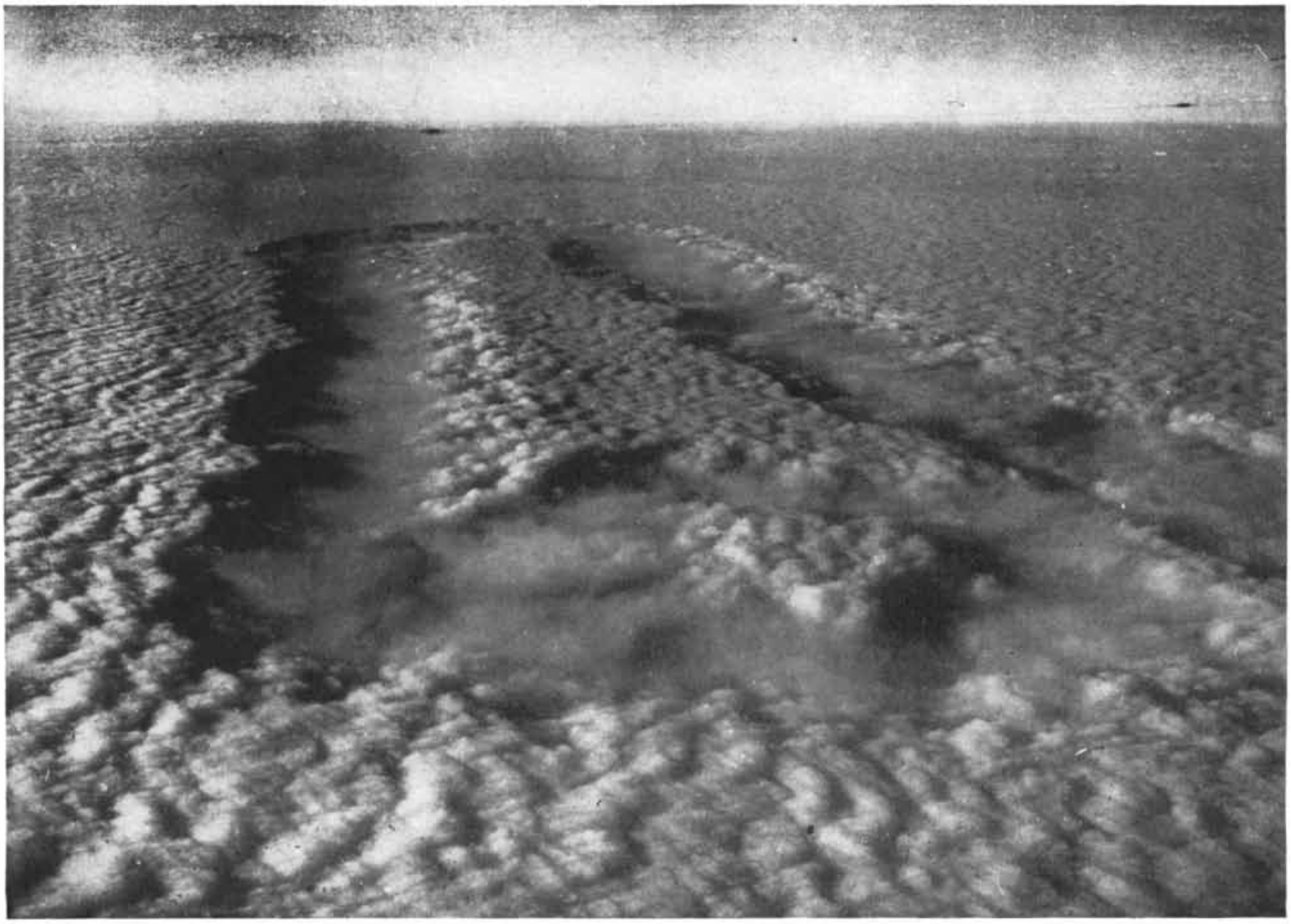
In the second type of smoke generator



AIRCRAFT of Project Cirrus, the Signal Corps and Office of Naval Research study of cloud-seeding, is prepared for an experimental mission. At the lower left dry ice is loaded from an ice chest into small containers for the flight.



PARTICLES in a silver-iodide smoke are shown by an electron micrograph. The size of the particles, which were made by a generator of the spray-nozzle type, may be judged by the fact that they are enlarged 30,000 diameters.



DRY-ICE SEEDING by an aircraft of Project Cirrus made this racetrack-shaped opening in a dense layer of cloud. Such seeding has been proposed not only to make rain but also to improve visibility for cloud-bound pilots.

a solution of silver iodide is fed into a small atomizing spray nozzle operated with compressed hydrogen or bottled gas. The spray of silver-iodide solution and combustible gas is ignited as it leaves the nozzle and burns like a blowtorch. The silver iodide vaporizes and then condenses into large numbers of very small particles as it leaves the flame. This type of generator can be used for seeding either from the ground or from an airplane.

In an hour either of these generators produces enough nuclei to seed about 30,000 cubic miles of atmosphere, at a cost of about two dollars for silver iodide and fuel.

The silver-iodide particles are so tiny that usually the smoke is completely invisible, although in bright sunlight one can occasionally see a bluish haze where the smoke leaves the generator. The particles are so small that their rate of fall under gravity is negligible, and one can assume that they mix with the atmosphere in about the same way that gas molecules do.

Obviously in experiments in which the smoke is released from a ground generator it is very difficult to judge the results of the experiment, because one has no accurate way of knowing when and where the nuclei released on the ground will cause effects in the sky. But in the summer of 1949 a series of tests yielded fairly conclusive evidence of the effects of ground-released silver iodide on natural clouds. The tests were made in the vicinity of Albuquerque by Project Cirrus with the cooperation of the New Mexico School of Mines. In one experiment a spray-nozzle generator in a valley between mountains seeded the air continuously from a little after dawn until dusk. On the days when this was done cumulus clouds over the mountains gave rain far sooner than was normally the case. A detailed analysis of the precipitation throughout the state on these days was made by Langmuir, and his results indicated very strongly that there was a close relation between the precipitation pattern and the seeding pattern. Most of the rain that fell was confined to areas downwind from the point of seeding. The rains began quite near to the point of seeding, and with time the area of rain increased in size at a rate closely corresponding to the average velocity of the wind that carried the silver iodide. The analysis indicated that concentrations of silver iodide as small as one milligram per cubic mile were effective in producing rain, and that the effects of the single generator extended for several hundred miles.

It was decided to set up a regular seeding schedule in New Mexico to determine whether seedings carried out at regular intervals would result in corresponding periodicities in rainfall downwind from the generator. The generator was operated on Tuesday, Wednesday and Thursday of each week. Checking with data on precipitation from the U. S. Weather Bureau, Langmuir soon began to observe a marked weekly rhythm in the rainfall, not only in the region near the seeding but in a broad band through most of the Midwest and into the Eastern states. The records of the Weather Bureau showed no previous instance of a similar periodicity. Langmuir also found an even more striking rhythm of changes in temperature and barometric pressure in the region. His careful statistical analysis indicated that this single silver-iodide smoke-generator produced a large effect on the weather over about one third of the U. S.

In recent months the remarkable weekly periodicity that Langmuir observed has begun to disappear. This is not surprising, in view of the very extensive seeding operations with silver iodide that are now being carried out,

SILVER-IODIDE SEEDING made this circular pattern in relatively clear air. The experimental aircraft flew in a circle five miles in diameter at an altitude of 26,000 feet while it released a trail of silver-iodide smoke.

particularly in the Western states. In this part of the country many ranchers, farmers and power companies have employed private cloud-seeding operators in the hope of increasing their rainfall. At the present time about half of the entire West is under contract with these "rain-makers," who work at rates ranging from about one cent to ten cents an acre. The amount of silver iodide now being released in these operations probably corresponds to the output of 50 or 100 of the generators employed in the weekly Project Cirrus seeding experiment, so that they must certainly blanket the effects of periodic seedings carried out with a single generator. It seems reasonable to expect that the present random operation of all these generators may produce large-scale changes in our national weather patterns. It will be interesting to examine the results in terms of rainfall over a period of years.

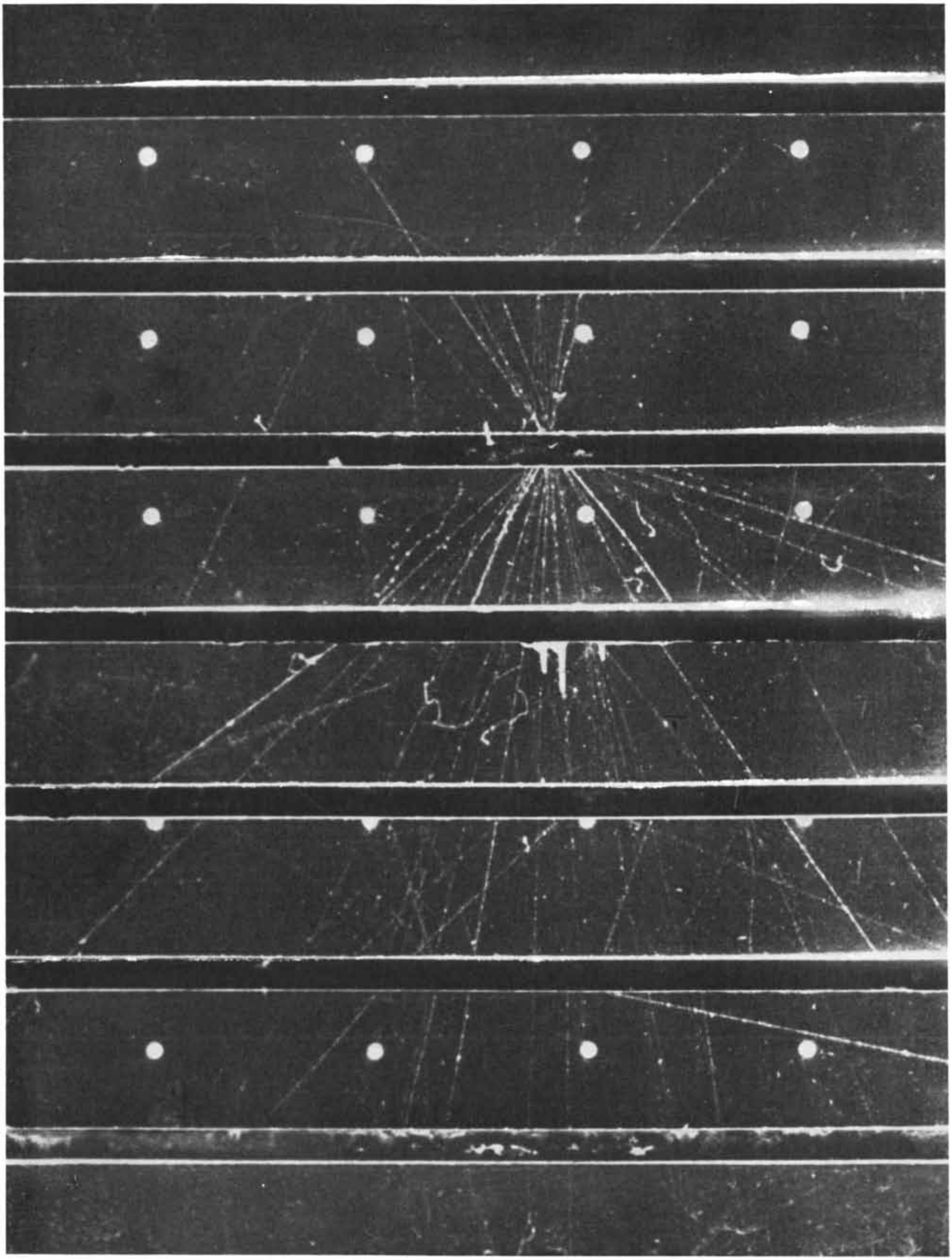
One of the big unknowns involved in predicting the possible large-scale effects of silver-iodide seeding is the variable length of time that silver iodide remains active in the atmosphere. Laboratory experiments have shown that traces of certain organic vapors, such as alcohol, reduce the activity of the nuclei, and traces of ammonia gas enhance it. Impurities in the atmosphere might have a similar effect. In some tests exposure to ultraviolet light or sunlight has been found to deactivate the smoke rapidly; in others the effect of light has been negligible. The reasons for this difference in results are not yet understood. Whatever the answer, it is reasonable to suppose that in any case the activity of the silver iodide could persist for long periods under the protection of clouds.

Practically all the cloud-seeding now being carried out has the primary objective of increasing precipitation. The accumulating data are giving strong evidence that seeding does in many cases increase rainfall. But rain-making is only one of the many possible benefits to be derived from cloud-seeding. Seeding can be used to make large holes in supercooled clouds through which airplanes can fly with good visibility and with freedom from the hazards of icing. There is good reason to believe that seeding may reduce the incidence of hail and lightning. By overseeding, it may be possible to prevent rain and to transport moisture over high mountain ranges into arid areas.

New seeding techniques may be developed in the future. The investigations of Alfred Hitchcock at the Woods Hole Oceanographic Institution, and of others, give promise that seeding with a dust of ordinary salt particles may increase rain from certain clouds, especially in the tropics.

THE implications and possible benefits of cloud-seeding are far broader than mere rain-making. Precipitation may be one of the main driving forces producing the complex motions of the atmosphere. The fall of an inch of rain over a given area releases as much thermal energy, in the form of the latent heat of evaporation, as several days of sunlight over the same area. If, as appears to be the case, man is able to produce rainfall over large areas by cloud-seeding, it means that he is beginning to control energy on a scale that makes his present energy resources seem trivial by comparison. Wisely used, cloud-seeding may some day enable us not only to make rain but to initiate and direct storms and to exercise a considerable control over the atmospheric circulation on our planet.

Bernard Vonnegut is a physical chemist in the Research Laboratory of the General Electric Company.



SHOWER OF PARTICLES is shown in a cloud-chamber photograph made by W. B. Fretter of the University of California. The bars across the photograph are the edges of lead plates within the chamber. The shower, which is composed of protons, electrons and mesons, was precipitated when a high-energy cosmic-ray proton collided with a nucleus in the third plate from the top. The tracks extending through several plates are those of mesons.

THE MULTIPLICITY OF PARTICLES

When the neutron was discovered in 1932, there were five basic units of matter and energy. Now there are perhaps 19, and physics needs a great theory that will unify them

by Robert E. Marshak

IN THE YEAR 1932, when James Chadwick discovered the neutron, physics had a sunlit moment during which nature seemed to take on a beautiful simplicity. It appeared that the physical universe could be explained in terms of just three elementary particles—the electron, the proton and the neutron. All the multitude of substances of which the universe is composed could be reduced to these three basic building materials, variously combined in 92 kinds of atoms. An atom consisted of a tight nucleus, built of protons and neutrons, and a swarm of electrons revolving around the nucleus like planets around a sun. The number and arrangement of electrons in an atom could explain its chemical properties, and the two nuclear particles, proton and neutron, could account in a very simple manner for other properties of the atom—its weight, its nuclear charge, the isotopes, and so on. From atoms it was possible to arrive at molecules and finally at the macroscopic objects of our workaday world.

Strictly speaking, under the quantum-mechanics theory that energy, like matter, also was made up of tiny discrete units, there were two additional elementary "particles"—the photon, the unit of electromagnetic radiation, and the graviton, the unit of gravitational energy. But the photon and graviton acquire existence only as a result of some rearrangement of electrons, protons and neutrons, and it seemed that the latter three particles could be considered the basis of all physical phenomena. They appeared to be the irreducible units of matter for which scientists had been searching ever since Democritus. The electron was an almost infinitesimal corpuscle with a negative charge, the smallest negative charge ever observed; the proton (the nucleus of the smallest atom, hydrogen) was 1,837 times as heavy as an electron but had only a single positive charge, just balancing the electron's negative one; and the neutron, neutral in charge and with about the same mass as the proton (just two and a half electron masses heavier) appeared to be equally fundamental.

Such was the simple, satisfying picture after Chadwick identified the neutron in 1932. But the period of rejoicing was all too brief. Before the year was out Carl D. Anderson at the California Institute of Technology discovered a fourth elementary particle. In the atomic havoc created in a Wilson cloud chamber by the energetic cosmic rays he found a particle with the same mass as the electron but with a positive charge. It was named, of course, the positron. Soon experimenters were proving the existence of positrons by creating them in the laboratory with high-energy photons, *i.e.*, gamma rays. By interaction with atomic nuclei photons are converted into pairs of electrons and positrons. The materialization of a gamma ray into an electron-positron pair is a fine demonstration of Einstein's principle of the equivalence of mass and energy.

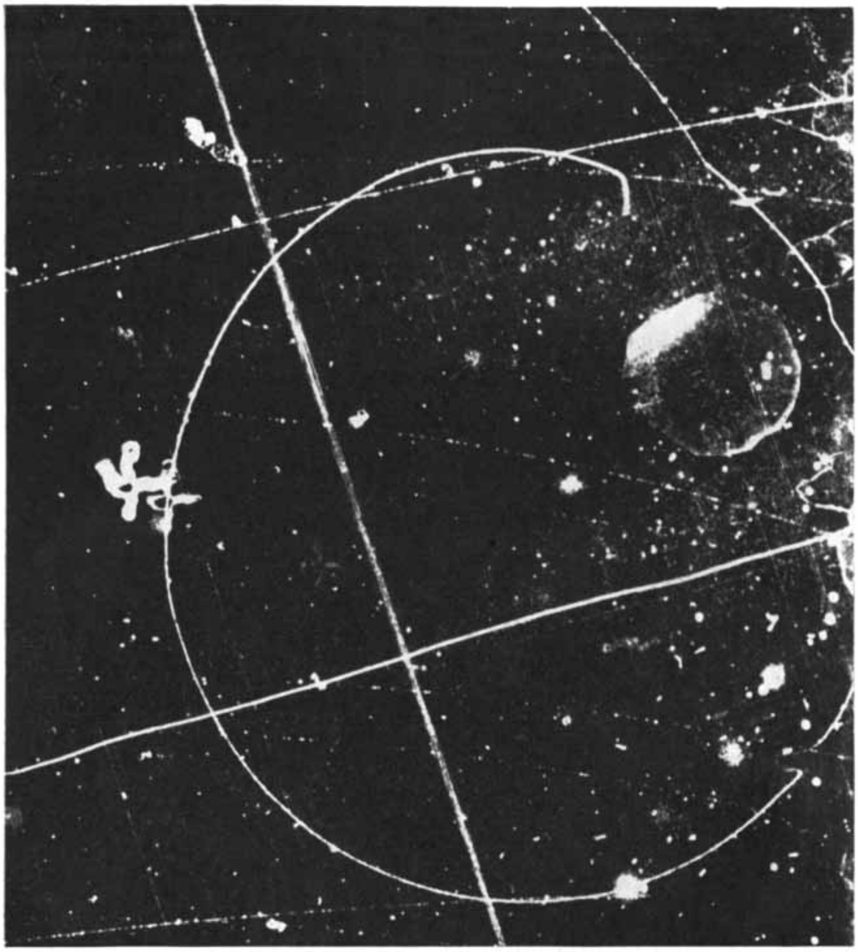
So physicists now had a fourth particle to confuse the picture. But this was only the beginning.

AFTER the positron was discovered, experimenters began to pay closer attention to the beta particles (electrons) emitted by radioactive nuclei. They were not surprised to find that the beta particles from some of the artificially made radioactive atoms were positrons rather than electrons. But in measuring the energies of beta particles they made a discovery that was very surprising indeed. According to the laws of quantum mechanics, the nucleus can occupy only certain discrete energy states, and when it drops from one energy level to another, emitting a particle in the process, it can impart to the particle only the discrete difference in energy—no more and no less. Consequently all beta particles, whether electrons or positrons, should be discharged from nuclei only with certain well-defined energies, just as a properly operating elevator will let you out at one floor or another but not in-between. When the investigators actually measured the energies of beta particles, however, they found that the energies ranged over the whole continuous spectrum from zero to the maximum possible value.

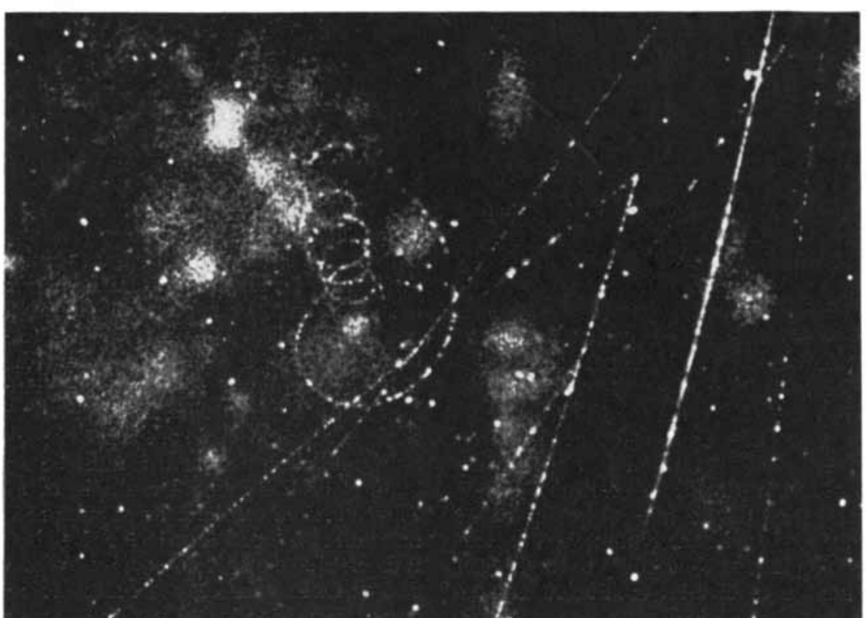
This was indeed a strange phenomenon. If the quantum theory was correct, it seemed to violate one of the fundamental laws of physics—the principle of the conservation of energy. If a nucleus, in dropping from one energy state to another, could emit a beta particle with some in-between energy value, what happened to the rest of the energy representing the difference between the two states?

Furthermore, the emission of beta particles from nuclei appeared to violate another basic physical principle—the conservation of angular momentum, or spin.

Like the earth and other bodies in space, each atomic body—electron, nucleus and the particles that make up the nucleus—spins like a top around its own axis. The spin, or angular momentum, can be measured. The unit of spin in the atomic domain is Planck's constant divided by 2 *pi;* let us call the unit h. The laws of quantum mechanics require that the spin of any particle or system of particles must be quantized: it must be an integral or half-integral multiple of h. Thus a system can have an angular momentum of $\frac{1}{2}h$ or $1h$ or $1\frac{1}{2}h$ or $2h$, but it cannot have a spin of, say, $\frac{3}{4}h$. When two or more particles are combined in one system, the total spin of the system must lie in the range between the difference and the sum of the spins of the particles composing it. Thus if one system has a spin of J_1h and another J_2h, the combined angular momentum of the



POSITIVE PI MESON decays in a cloud-chamber photograph made by Wilson Powell of the University of California. The track of the meson enters the photograph from the top toward the right. The first slight kink in the track of the particle indicates that it has decayed into a positive *mu* meson.



NEUTRAL V-PARTICLE causes a track shaped like an inverted V in a cloud-chamber photograph made by Robert B. Leighton of the California Institute of Technology. The V-particle is invisible; it entered the photograph from the top and gave rise to the twin tracks that begin at upper right.

two together can take on only one of the following series of definite values: $(J_1-J_2)h$, $(J_1-J_2+1)h \ldots (J_1+J_2-1)h$ or $(J_1+J_2)h$. In other words, the angular momentum of the combined system must be some integral multiple of h in the range from the minimum value $(J_1-J_2)h$—when the two spins are in opposite directions—to the maximum value $(J_1+J_2)h$—when they are in the same direction.

Now the spins of various particles have been measured, and it turns out that they do indeed follow these rules. The electron, the positron, the proton and the neutron each has a spin of ½ h. The deuteron (nucleus of heavy hydrogen), which consists of one proton and one neutron, has a combined spin of 1 h, indicating that the proton and neutron spins are in the same direction. In general all nuclei consisting of an even number of nuclear particles possess integral spin, and all those consisting of an odd number have half-integral spin.

But when we come to the case of the beta particle issuing from a radioactive nucleus, the rule apparently breaks down. The birth of a negative beta particle (electron), for example, evidently is due to the transformation of a neutron into a proton according to this scheme: neutron → proton + electron. Here we have a neutron with a spin of ½ h giving rise to two particles, proton and electron, each with a spin of ½ h. Where did the extra spin come from, or to put it another way: assuming there was a balancing of opposite spins in the neutron, what happened to the lost spin of half a unit?

SOMEHOW, then, physicists had to save the laws of conservation of energy and conservation of angular momentum. There was only one way to do it: a new particle had to be invented. The man who suggested this solution for the dilemma was Wolfgang Pauli of Zurich. He proposed that when a beta-emitting nucleus erupts, it creates not only a beta particle but another particle which he named the neutrino. The neutrino hypothesis saved all the conservation principles at one fell swoop. The neutrino would carry the energy representing the difference between that of the beta particle and the total energy lost by the nucleus in changing from one discrete energy state to another. The neutrino, assuming it had a spin of ½ h, would also restore the lost angular momentum, for the neutron with half-integral spin could transform into three particles the sum of whose spins would also be half-integral.

The neutrino as such has never been detected directly, but by now its properties have been fairly well established by indirect experiments. It is an extremely light particle with a mass less than one two-thousandth that of the electron. A free neutron, which as we have seen is heavier than a proton and electron combined, has been found to decay radioactively with a half-life of about 12 minutes into a proton, an electron and a neutrino. A proton, being lighter than a neutron, can transform into a neutron, a positron and a neutrino only inside the nucleus.

Pauli's hypothesis of the neutrino in 1933 raised the number of elementary particles to five. More were soon to come. Some of the new particles were predicted by theory before they were actually discovered. Physicists were seeking an explanation of the extremely powerful forces that hold together the protons and neutrons in an atomic nucleus. In 1935 the Japanese physicist Hideki Yukawa suggested that a new kind of field, consisting of quanta of energy which might take the form of particles of a certain mass, might account for these forces. He pointed out that electrical forces and gravitational forces, the two chief forces previously known, could be explained in terms of the emission and reabsorption of light quanta and gravitational quanta respectively. Since the nuclear forces were of a completely different type—not only much more powerful but acting over much smaller distances than electrical or gravitational forces—it seemed reasonable to Yukawa to introduce a new type of field which would be responsible for the nuclear forces. There is a formula whereby it is possible to calculate the mass of the field quantum exchanged between two particles if the distance over which the force acts is known. On the basis of the extremely short distance (about 10^{-13} centimeters) over which the nuclear force acts, Yukawa estimated that the mass of the field quanta exchanged between two nucleons would be about 200 to 300 times that of the electron. He called these field quanta mesons. The mesons were thought of as the nuclear glue binding together the neutrons and protons in the nucleus. Since there were three types of equally strong bonds in the nucleus (neutron-proton, proton-proton and neutron-neutron) it was assumed that there would be three kinds of mesons, namely, positive, negative and neutral.

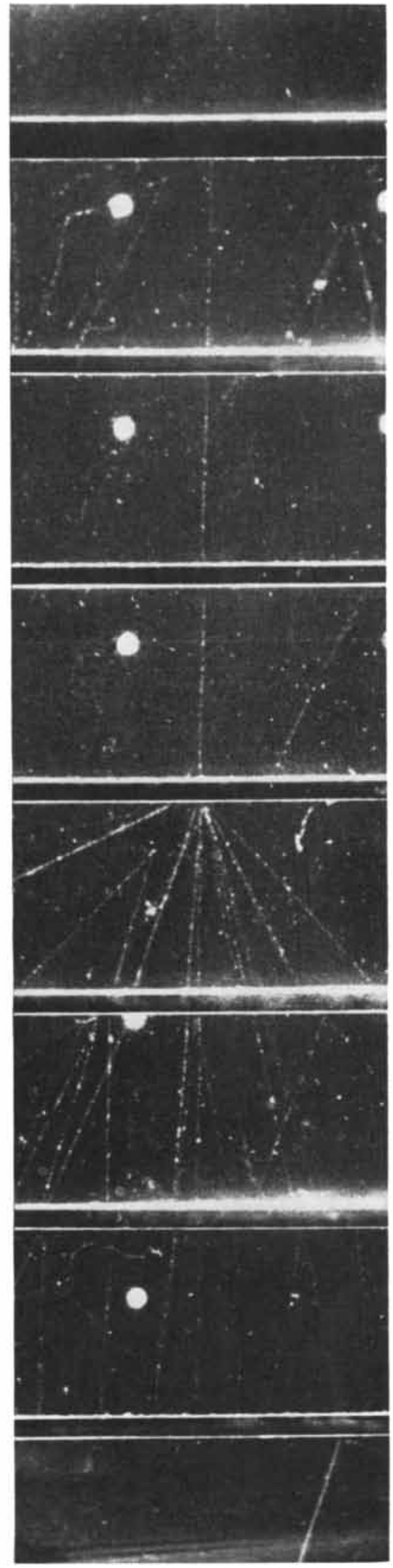
Within two years after Yukawa made his proposal investigators in the U. S. actually discovered mesons with masses about 200 times the mass of the electron. The discoverers, Carl Anderson and Seth Neddermeyer at Caltech and J. C. Street and E. C. Stevenson at Harvard, found the particles in the atomic debris produced by cosmic rays.

THERE followed a great number of experiments to determine the properties of mesons. The net result of 10 years of experimentation, however, was the emergence of a very serious discrepancy: namely, mesons were produced with ease and in great numbers by the incoming cosmic radiation in the upper atmosphere, but only rarely were they later absorbed by the nuclei of atoms. The probability of production was 10^{14} times the probability of absorption. This discrepancy contradicted not only Yukawa's meson theory of nuclear forces but also a general principle of physics—the principle of the reversibility of microscopic processes.

In view of the glaring difference between meson production and capture, the author suggested in 1947 that there were really two types of mesons: 1) a heavier variety which possessed the properties Yukawa had postulated and which was responsible for the forces holding atomic nuclei together, and 2) a lighter variety into which the heavier one decayed. It was the latter type, he proposed, that cosmic-ray experimentalists had been observing for 10 years. According to the author's two-meson theory, the heavy mesons are produced by the primary cosmic radiation in the upper atmosphere and decay into the lighter variety in about 10^{-8} seconds—too short a time for them to penetrate very far into the atmosphere. On the other hand, the light mesons into which they decay, and which are the ones chiefly observed at sea level, can be absorbed by atomic nuclei only with great difficulty. Thus one could explain the paradox of the strong production but subsequent weak absorption and interaction of mesons.

Before the two-meson theory was many weeks old, C. F. Powell and his collaborators in England sent to the U. S. actual photographs of the heavier mesons, caught at high altitudes in the Bolivian Andes. Since then many experiments, especially with the high-energy accelerators, have confirmed the idea that the heavier mesons interact strongly with protons and neutrons whereas the lighter ones do not. The heavy particles are called *pi* mesons and the lighter variety are called *mu* mesons.

We now know that the *pi* meson exists in three forms—positive, negative and neutral. Only two forms of the *mu* meson—positive and negative—have been found, but a neutral *mu* would be very difficult to detect in any case; it would possess many of the same properties as the elusive neutrino. The charged varieties of the *pi* meson have a mass 276 times that of the electron, and the charged *mu* mesons are 210 times as heavy as the electron. The neutral *pi* meson is a little lighter (about 11 electron masses) than the charged *pi;* this contrasts with the case of the nucleons, where the neutron is somewhat heavier than the proton. The spin of the *pi*



MESONS AND V-PARTICLE are shown in photograph by W. B. Fretter. The tracks caused by the V-particle are below fourth plate from top.

mesons is zero, while that of the *mu* mesons is ½ *h*.

A VERY gratifying aspect of the properties of *pi* mesons is that they obey the right kind of statistics. By the statistics of a particle is meant that property which determines the behavior of an ensemble of particles of a specified kind when they interact or are in close physical proximity. If more than one particle in an ensemble of identical particles can occupy the same energy level, the particle is said to obey Bose-Einstein statistics. On the other hand, if no more than one particle in the group can occupy the same energy level, the particle is said to obey Fermi-Dirac statistics. Particles that obey Bose-Einstein statistics are called bosons; those that obey Fermi-Dirac statistics are called fermions. The electron is an illustration of a particle obeying Fermi-Dirac statistics, whereas the photon is an illustration of a particle obeying Bose-Einstein statistics. Pauli has proved a general relation between spin and statistics: namely, that all particles possessing half-integral spin must obey Fermi-Dirac statistics, whereas all particles possessing integral spin must obey Bose-Einstein statistics. The electron's Fermi-Dirac statistics is responsible for the periodic system of elements and for the separation of solids into the three classes of conductors, insulators and semi-conductors. On the other hand, the photon, possessing a spin of 1 *h*, obeys Bose-Einstein statistics, and the Planck radiation law is an immediate consequence of this fact.

Now the *pi* mesons all obey Bose-Einstein statistics. This is gratifying because the field quanta on which electrical and gravitational forces are based also obey Bose-Einstein statistics. Here, then, is a very suggestive kinship between the field quanta (*pi* mesons) connected with forces in the nucleus of the atom and the field quanta of the other two types of forces. As a matter of fact, there even seems to be a certain symmetry in nature: the strongest forces, those in the nucleus, are due to field quanta with finite mass and zero spin; the next strongest, the electrical forces, are due to field quanta (photons) with zero mass and one unit of spin, and the weakest, the gravitational forces, are due to field quanta (gravitons) with zero mass and two units of spin. This would seem to represent progress, even though three new particles (the three *pi* mesons) are added to the list of elementary particles.

But we are thrown into confusion by the entrance of the *mu* mesons. They appear to have no connection whatsoever with nuclear forces. What, then, is their function? Even more confusing is the fact that all the mesons, *pi* and *mu*, undergo spontaneous disintegration. When left alone in free space, a positive or negative *pi* meson decays into a positive or negative *mu* meson and a neutrino within about one 250-millionths of a second. Then the positive or negative *mu* meson decays into a positive or negative electron plus two neutrinos within about two-millionths of a second. The neutral *pi* meson also is unstable and decays into two gamma rays in a very short time indeed—about a hundred-millionth of a millionth of a second.

WHAT is the significance of all these instabilities, and why is the neutrino such a conspicuous partner in many of them? We do not know the answer to these questions. We can assume that the rapid decay of the neutral *pi* meson into two photons probably implies the existence of a negative proton, sometimes called an antiproton. This follows from the fact that the neutral *pi* meson should, by virtue of its strong interaction with nucleons, create a "virtual" proton-antiproton pair, which subsequently annihilate each other as a result of their "virtual" interaction with the electromagnetic field and produce two photons. Consequently, when sufficiently powerful accelerators are constructed (*e.g.*, the new Bevatron being built at the University of California Radiation Laboratory), it should be possible to produce antiprotons. But if antiprotons exist, antineutrons also must exist, and this adds two more elementary particles to our list.

To add to the confusion, there has been increasing evidence in the last year or two for the existence of other types of elementary particles. Of the new particles described by various investigators some are reported to decay in flight while others are supposed to decay in rest; in some cases the decay products appear to be two particles and in other cases three particles. Some of the new particles appear to be absorbed by atomic nuclei and to lead to nuclear explosions, others to be emitted by atomic nuclei.

The best-established of the new particles seem to be the so-called V-particles, first observed in a cloud chamber by G. D. Rochester and C. C. Butler of England in 1948. They exist in charged and neutral varieties. The neutral V-particle appears to decay in the gas of a cloud chamber into a pair of positive and negative particles, and the charged variety seems to decay into a pair of charged and neutral particles in about one 10-billionth of a second. The V-particles appear to be somewhat more massive than a proton or neutron, because in some instances a proton is a decay product. In other instances one of the decay particles has been identified as a *pi* meson. If it is assumed that the decay products of a V-particle are a neutron or proton and a *pi* meson, the V-particle must possess a mass about 2,200 times that of the electron.

PARTICLE	SYMBOL
NEUTRINO	ν
ELECTRON	e
POSITRON	p
POSITIVE MU MESON	μ^+
NEGATIVE MU MESON	μ^-
KAPPA MESON	κ
PROTON	P
ANTIPROTON ?	$\bar{P}$
NEUTRON	N
ANTINEUTRON ?	$\bar{N}$
POSITIVE V-PARTICLE	V^+
NEGATIVE V-PARTICLE	V^-
NEUTRAL V-PARTICLE	V^0
PHOTON	γ
GRAVITON	G
POSITIVE PI MESON	π^+
NEGATIVE PI MESON	π^-
NEUTRAL PI MESON	π^0
TAU MESON	τ

ALL THE PARTICLES known as of December, 1951, are shown in this

Be that as it may, the situation is obscure at the present time. It is not clear how many new particles will have to be added to our list of elementary particles. The known and probable particles, with their properties, are listed in the table above. At least 12 have been definitely established. Seven of these (neutron, proton, electron, positron, neutrino and positive and negative *mu* mesons) are fermions. The remaining five (photon, graviton and positive, negative and neutral *pi* mesons) are bosons. Of the nine probable particles, seven (antiproton and antineutron, three V-particles

CHARGE	MASS	SPIN	STATISTICS	DECAY SCHEME	LIFETIME (SECONDS)
0	0	1/2	FERMI-DIRAC	STABLE	
–	1	1/2	FERMI-DIRAC	STABLE	
+	1	1/2	FERMI-DIRAC	STABLE	
+	210	1/2	FERMI-DIRAC	$\mu^+ \longrightarrow p + 2\nu$	2.1×10^{-6}
–	210	1/2	FERMI-DIRAC	$\mu^- \longrightarrow e + 2\nu$	2.1×10^{-6}
+	1200 ?	1/2 ?	FERMI-DIRAC ?	$\kappa \longrightarrow \mu^+ + (?)\, 2\nu$	10^{-10} ?
+	1836	1/2	FERMI-DIRAC	STABLE	
–	1836	1/2	FERMI-DIRAC	STABLE	
0	1838.5	1/2	FERMI-DIRAC	$N \longrightarrow P + e + \nu$	750
0	1838.5	1/2	FERMI-DIRAC	$\overline{N} \longrightarrow \overline{P} + p + \nu$	750
+	2600 ?	?	FERMI-DIRAC ?	$V^+ \longrightarrow N + \pi^+ + (?)\, \pi^0$	10^{-10} ?
–	2600 ?	?	FERMI-DIRAC ?	$V^- \longrightarrow N + \pi^- + (?)\, \pi^0$	10^{-10} ?
0	2600 ?	?	FERMI-DIRAC ?	$V^0 \longrightarrow N + \pi^+ + \pi^-$? $V^0 \longrightarrow P + \pi^- + (?)\, \pi^0$	3×10^{-10}
0	0	1	BOSE-EINSTEIN	STABLE	
0	0	2	BOSE-EINSTEIN	STABLE	
+	276	0	BOSE-EINSTEIN	$\pi^+ \longrightarrow \mu^+ + \nu$	2.6×10^{-8}
–	276	0	BOSE-EINSTEIN	$\pi^- \longrightarrow \mu^- + \nu$	2.6×10^{-8}
0	265	0	BOSE-EINSTEIN	$\pi^0 \longrightarrow 2\gamma$	10^{-14}
+ or –	966	0 ?	BOSE-EINSTEIN	$\tau \longrightarrow 3\pi$	10^{-9} ?

table. The unit of mass is the mass of the electron; the unit of spin is h (*see text*). The particles adhering to Fermi-Dirac statistics are above the double line; those adhering to Bose-Einstein statistics are below it.

and two *kappa* mesons) are probably fermions, and two (*tau* mesons) are probably bosons. Already, then, we have a total of 21 elementary particles. And if 21 elementary particles really exist, why not many more?

This is a far cry from the simple picture of the physical universe involving only five elementary particles which seemed possible after the discovery of the neutron in 1932. Apart from the plethora of elementary particles, the fact that so many change from one type to another is extremely disconcerting.

It is difficult to believe that nature is really so complex. To explain the large number of particles of different mass, physicists have looked for some unifying principle, such as, for example, mass quantization. It is also natural to try to regard some of the elementary particles as combinations of others. Attempts in this direction were made directly after the discovery of the neutrino; it was suggested that under suitable conditions two neutrinos might combine to give a quantum of light. More recently Enrico Fermi and C. N. Yang of the University of Chicago attempted to show that *pi* mesons can be regarded as combinations of nucleons and antinucleons. On the other hand, Gregor Wentzel of Chicago has developed a theory in which the *pi* mesons are regarded as compounded out of *mu* mesons. Thus far none of these theories has had any spectacular success, and the field is wide open for a deep-going theory which would elucidate the nature and role of the elementary particles of physics.

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Molds and Men

Both harmful and useful, the ubiquitous fungi have had such diverse effects on our civilization as the decline of infectious disease and the increase in the number of Irishmen in the U. S.

by Ralph Emerson

WHAT, you may ask, do molds have to do with men? The answer is: a great deal indeed, far more than might be suggested by our occasional encounter with them on a rotten orange or a jar of bad jelly. Many of them live intimately with us as parasites, from the persistent pest that causes the irritating condition known as athlete's foot to more dangerous types that can cause death. And molds affect us in literally hundreds of less obvious ways, sometimes even influencing the broad course of history. Nor should it be supposed that their activities are always detrimental to man's welfare. They are involved in the production of many foods, are important in fundamental industrial processes and provide us with essential vitamins and life-saving drugs.

Mycology, the science of molds, covers the group of organisms known as the fungi. Along with algae and lichens, fungi make up the assemblage of primitive plants which the botanist classifies in the great subdivision Thallophyta. They are spore-forming plants that lack flowers, seeds or any differentiation into true root, stem or leaves. The fungi, a diverse array, include the mushrooms, puffballs, yeasts, blights, smuts, rusts, rots and creeping molds. They differ from nearly all other plants in a very important respect—their mode of nutrition. Unlike most plants, the fungi form no chlorophyll, cannot make their own food, and hence are dependent upon an outside source of nutrient, as animals are. They are forced to adopt one of two possible ways of life: 1) they may grow on dead plant or animal material, in which case we call them saprophytes (meaning plants that cause decay), or 2) they may live as parasites on living things, thus causing disease.

The fungi live everywhere—on land, in fresh water and in the sea—and their varieties are legion. Some 50,000 species are known, and many thousands more remain to be discovered. They have prodigious powers of reproduction. A large mushroom discharges a million spores per minute throughout the two or three days of its existence, and certain of the giant bracket fungi dust the branches below them with five trillion spores annually, sometimes for years. Each of these spores is potentially capable of producing a new fungus growth. It is not surprising, therefore, that the ways of men and molds meet frequently, often in conflict but also not seldom in friendly fashion. The smut or the esculent truffle, the athlete's foot or the aromatic wine, the rotten fruit or the delicious cheese—many and wonderful are the ways of fungi. From the bizarre, the tragic, the economically beneficent and the perniciously destructive let us select and examine a fair and just sample, considering the good with the bad.

MOLDS have attacked man's crops since he first started to farm. Crop losses from fungus diseases run into billions of dollars annually and require the vigilance and constant efforts of many highly skilled plant pathologists to keep them in check. One of the most alarming diseases is the stem rust of wheat. Pliny in A.D. 100 described wheat rust as "the greatest pest of the crops." In a single modern year (1916) rust destroyed over 300 million bushels of wheat in North America, and as late as the 1930s, when herculean efforts were already being made to control rusts, wheat losses in the U. S. ranged as high as 23 per cent.

Stem rust has a complex life cycle involving four spore stages. One of these stages can develop only on the common barberry. Long before the nature of the disease was understood, observant farmers recognized the possibility of achieving some control by eradicating the barberry. As early as 1660 officials in Rouen, France, issued an edict calling for barberry eradication. In this country the crown colony of Massachusetts passed a law in 1755 demanding that "whoever . . . hath any barberry bushes growing in his or their land . . . shall cause the same to be extirpated or destroyed on or before the thirteenth day of June, A.D. 1760."

In the present century geneticists seemed to have defeated the rust mold by breeding wheat varieties that appeared immune to it. Periodically, however, these supposedly resistant wheats succumbed suddenly, and new waves of rust devastated the Wheat Belt. The reason for this is that the rust mold reproduces sexually and is continuously creating new genetic races. Some 200 such races are now known. Every few years a new race of rust appears that can attack the previously resistant races of wheat. Starting in some obscure region of northern Mexico or the southern U. S. where barberry plants have not been cleaned out, the summer spores are carried for miles on the prevailing south winds to drop upon lush fields of young wheat to the north. Just such a wave of disease is now endangering wheat production in the U. S. and Canada. Its agent, the most virulent race of rust ever found in North America, has multiplied spectacularly since 1949.

Over the years a highly efficient system of spotting and forecasting has been set up by the U. S. Department of Agriculture to combat this ever-present threat. When a new race of rust is discovered, the Department tries to breed resistant races of wheat and distribute them to growers before the new evil reaches the main Wheat Belt states.

ANOTHER mold that has written a fascinating and tragic page in world history is the downy mildew of potatoes. This mold produces a devastating disease known as late blight. On August 23, 1845, the *Gardener's Chronicle and Agricultural Gazette* of England announced: "A fatal malady has broken out amongst the potato crop. On all sides we hear of the destruction. In Belgium the fields are said to have been completely desolated. There is hardly a sound sample in Covent Garden." Within a matter of months the disease spread to all parts of northern Europe. On September 13 the *Gardener's Chronicle* cried out again: "We stop the press, with very great regret, to announce that the potato murrain has unequivocally declared itself in Ireland. The crops around Dublin are suddenly perishing. Where will *Ireland* be in the event of a universal potato rot?" These were the hungry '40s in Europe, and the people of Ireland, already in extreme poverty, depended on potatoes as almost their sole source of food. In seven days of the following summer the blight almost completely destroyed the potato crop, setting the stage, as a chronicler wrote, "for one of the most appalling famines which that country has ever known—a famine which cost the inhabitants tens of thousands of lives and brought misery and privation to millions more."

The effects of the Irish potato famine were far-reaching and long-lasting. Between 1845 and 1851 almost a million people died of famine in Ireland, and a million and a half emigrated to America to make a lasting impression on the complexion and politics of this country. In England Robert Peel used the famine as an excuse for repeal of the so-called corn laws, which prohibited the importation of cheap grain. Thus a mold was responsible, at least in part, for initiating the British policy of free trade.

About 30 years after the Irish famines a close relative of the potato murrain threatened the wine industry of France. This was the mold that causes the downy mildew of grapes. It was well known in America as a mild pest. In 1876 the great American mycologist William Gilson Farlow had warned that if the mold ever reached Europe, it might be disastrous, because the climate there was more favorable to growth of the fungus. His prediction was soon fulfilled. Within two years the first diseased vines were found in France, and by 1882 the mold was rampaging through most of the vine-growing districts.

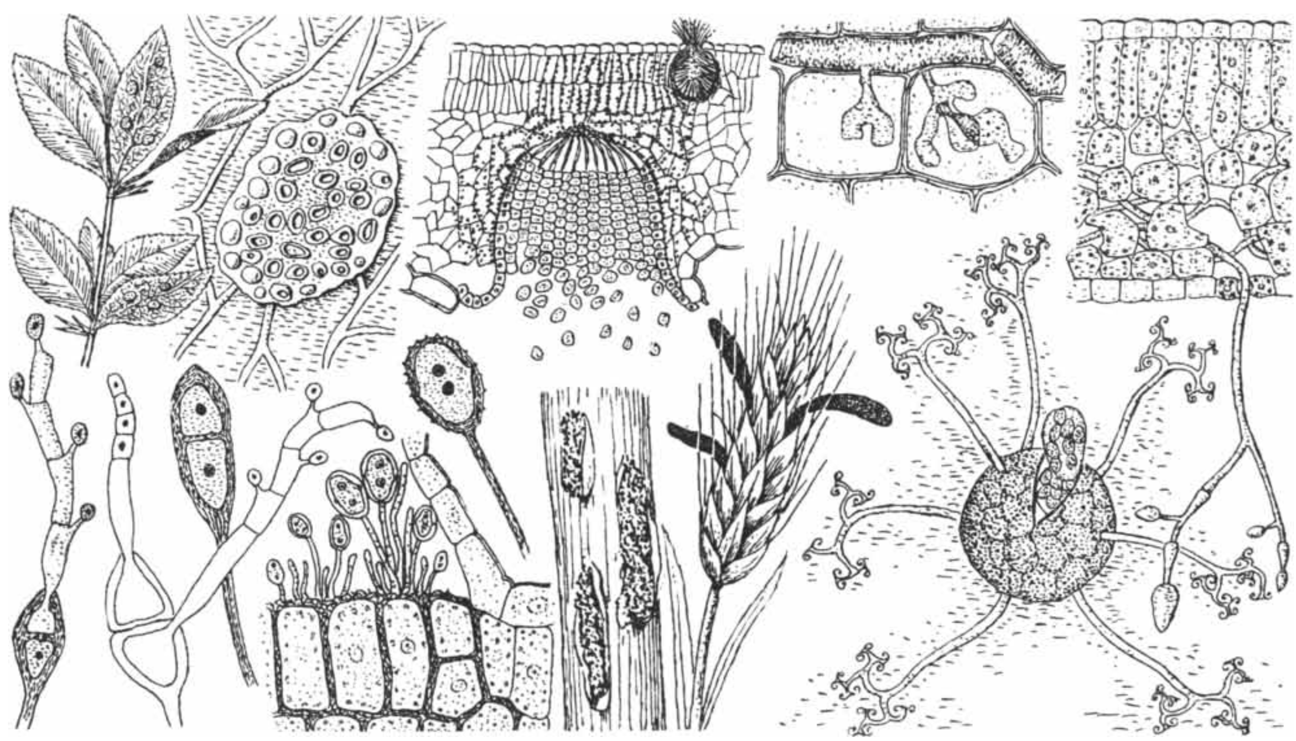
By that time microorganisms were much better understood than they had been in the days of the potato blight and the grape mildew was studied earnestly and scientifically. By a rare combination of chance and keen observation Pierre Millardet, a mycologist and professor of botany at Bordeaux who had labored ceaselessly on the problem, discovered a remedy for the mildew. E. C. Large tells the tale in his fascinating book entitled *The Advance of the Fungi*:

"Towards the end of October in the year 1882, Professor Millardet was strolling through one of the vineyards of Saint-Julien in Médoc. There had been much mildew in the locality that year, and he was surprised to notice that the vines beside the path were still in leaf, while elsewhere they were bare. He paused to examine these leaves which had escaped the common fate, and he found traces on them of a bluish-white deposit, as though they had received some chemical treatment. This was interesting, and he made inquiries about it of Mr. Ernest David, who was the manager of the vineyards at the Château Beaucaillon. He learned that it was a custom of the vinegrowers of Médoc to bespatter the vines beside the paths with a conspicuous and poisonous-looking substance, to discourage the passers-by from pilfering the grapes. For this they used either verdigris or a mixture of copper sulfate and lime."

After two or three years of experimentation with various copper salts, Millardet and others achieved spectacular control of the vine mildew with a preparation of copper sulfate and lime. Thus was discovered the now famous Bordeaux mixture. Today it is still one of the most widely useful sprays against fungi on plants.

By now such molds as the wheat rust, the potato murrain and the mildew of the vine are old, well-understood enemies. But there are still many obscure fungi that grow in out-of-the-way places until the opportunity arises to spread in epidemic proportions and leave their mark upon the world. Such a one was the tiny parasitic fungus named *Labyrinthula*, which 20 years ago mysteriously wiped out the eelgrass in the coastal waters of both sides of the Atlantic Ocean, with profound consequences for marine life, the fishing industries and the topography of the shore line ("The Eelgrass Catastrophe," by Lorus J. and Margery J. Milne; SCIENTIFIC AMERICAN, January, 1951). To this day no fully satisfactory answer has been found to explain why this little organism descended on the eelgrass so suddenly and with such widespread fury.

As THE human population of the world continues to increase at a prodigious rate, control of the hundreds of parasitic fungi that cause diseases of our crop plants becomes an ever more pressing problem. In terms of total human survival the destruction of crops is undoubtedly the major evil that molds inflict upon mankind. In terms of the individual man, however, a direct infection of his own body may bring a much more acute personal awareness of the activities of fungi. Athlete's foot is one of the common and troublesome fungus infections; ringworm is another. Ringworm appears not infrequently on the faces and hands of little children, who are prone to petting stray cats of dubious



Left: macroscopic and microscopic details in the life cycle of a wheat rust. Bottom right center: ergots on grain. Top right center and top right: detail of late potato blight. Bottom right: detail of lilac mildew.

background and unclean associations. The fungus, growing on the skin and fur of the cat, produces great numbers of spores capable of causing infection in the child.

During the last 20 years intensive research has greatlv increased our knowledge of the fungus diseases of man. Fungus infections of the skin are extremely common, probably equaling in prevalence the most widespread of the bacterial or virus diseases. Fortunately they are rarely fatal. There are, however, some more deep-seated mycoses which, while much less prevalent, can cause really serious illness. They accounted for about three out of every thousand deaths due to infections and parasitic diseases in the U. S. in 1945.

Two of these serious diseases, histoplasmosis and coccidioidomycosis, have been selected for intensive research at the Institutes of Public Health of the U. S. Public Health Service. Both diseases are highly fatal in their acute forms, and both have thus far defied prevention or cure.

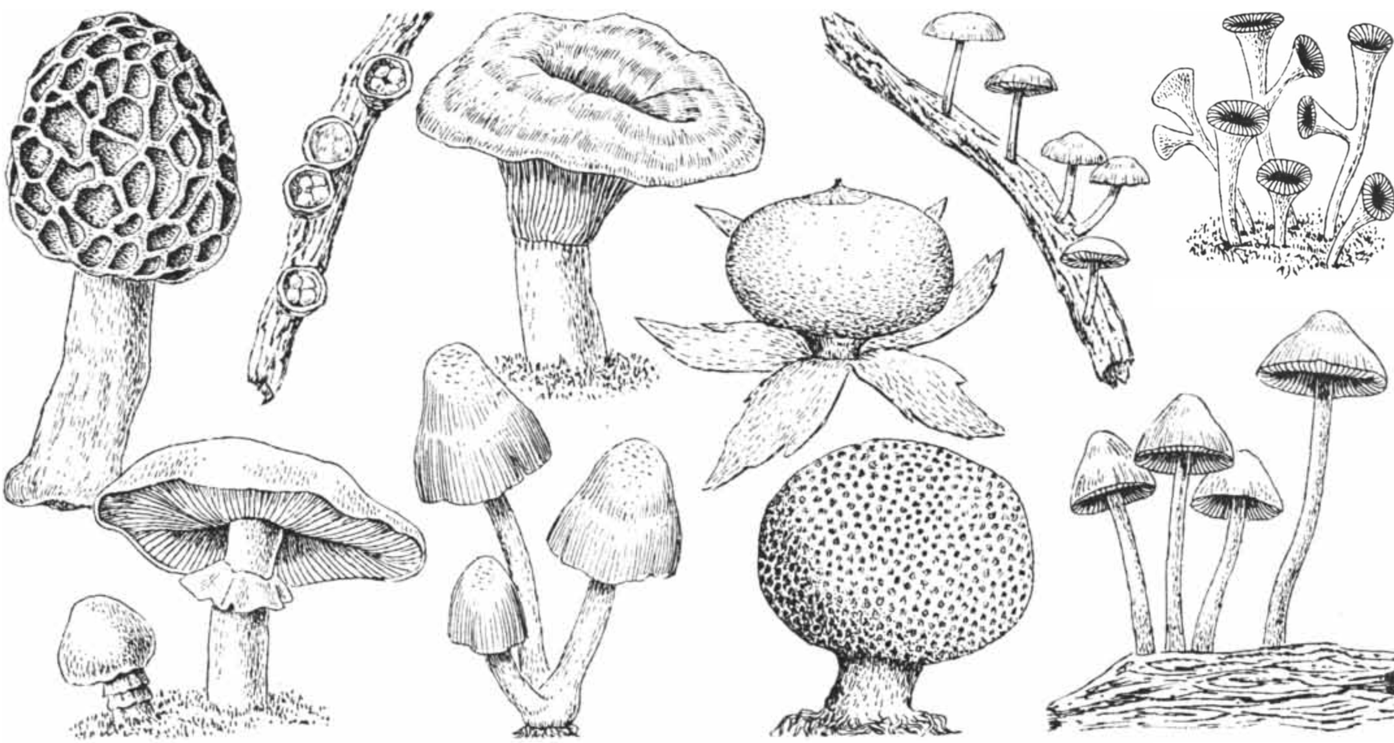
The main endemic area of coccidioidomycosis in the U. S. is the arid Southwest. Spores of the fungus that causes the disease (*Coccidioides immitis*) are harbored in the soil, and human beings are infected by breathing in the spores with dust. The infection has been variously known as "Valley Fever," "California Disease" and "Desert Rheumatism." It was first discovered in North America in a Portuguese dairy worker who lived in the San Joaquin Valley of California. The mycologists and medical men who devoted themselves to intensive laboratory and field studies of this disease were made painfully aware of its exceptionally infectious nature, for a high proportion of them contracted the disease themselves. During World War II the infection got special research attention because so many military personnel were stationed at training fields in the Southwest.

Two forms of coccidioidomycosis are recognized: a primary or benign type which is never fatal, and a secondary type which causes death in 50 per cent of the cases. A mild pulmonary form of the disease is common among residents of the dusty, dry areas of the Southwestern states. The wartime studies showed that rain, field irrigation, the planting of lawns around barracks and the paving or oiling of air fields all lowered the incidence of the disease.

UP TO this point we have dealt entirely with parasitic members of the fungi. The saprophytic forms that cause decay have also interfered with man's endeavors since the dawn of history. Many molds are equipped with a powerful arsenal of enzymes which bring about the rapid decomposition of woody plant materials. We must never forget that fungi play an immensely significant role in nature by rotting the leaves, dead branches and tree trunks of the forest floor. In so doing, they build up the humus layer and enrich the soil for the growth of future generations of trees. Unfortunately, however, they are just as likely to attack a railroad tie, a telegraph pole or a damp timber in a building as they are a moist log in the woods. All too familiar to those who have lived in wooden houses is the threat of fungus rot. The modern builder combats it by creosoting foundation beams, by proper cement construction, by basement ventilation and by various other measures that make life unpleasant for the fungi.

Wood-rotting molds were the scourge of the British Royal Navy for nearly 400 years, from the time of Henry VIII to the building of the first ironclads in the 1860s. The ribs and planking of English ships in those days were of oak, preferably English oak. It is reported that "nine years after the civil establishment of the navy, Henry VIII found it necessary to have the state of his ships examined; out of the 13 not one was in proper condition for service." And so it went, century after century, while English forests were stripped of the great oaks to build new and larger vessels and replace the rotted timbers of the older ones. Between wars the dry rot worked away below decks in the damp deserted holds until the lines of moored warships became known as "Rotten Row."

In an astonishing treatise entitled *Dry Rot in Ships* one of Britain's foremost living mycologists, J. R. Ramsbottom, writes that during the American War of Independence it was found many of His Majesty's ships "had so succumbed to dry rot that it was necessary to shovel away the toadstools and filth from the rotting planks and timbers." Sixty-six ships of the Royal Navy foundered during the war. The best known foundering was "that of the *Royal George* of 100 guns, which sank with Admiral Kempenfelt and several hundred of her crew at



Top row across these two pages, left to right: a morel, "birds' nests" (Crucibulum vulgare), the delicious Lactarius, Marasmius ramealis, Cladonia, yellowish wood rot, parasol mushroom, fairy-ring mushroom. Middle

Portsmouth in 1782. William Cowper, in the poem which familiarized the event to most of us in our schooldays, says, 'Her timbers yet are sound and she may float again.' The court-martial minutes show, however, that her bottom fell out when she was being 'heeled over' for a slight repair just below the water-line."

Again in 1825 the staid London *Times* sounded an alarm: "A disease . . . appears to have made, within 30 years, the most unparalleled and frightful ravages among the King's vessels of war. Ships . . . brought in for repair have, from the virulence of the distemper which afflicted them, decayed almost under the carpenters' hands, and been pronounced incurable. . . . At this moment not a few of the finest-looking vessels in the British Navy have actually perished in their respective harbors, and the hundreds of thousands of pounds which have been expended on them might as well have been cast into the ocean. The fact has not been denied. It is terrifying."

Saprophytic fungi grow on many other things besides wood. A more recent and particularly vivid example of the destructive action of molds was provided in the tropical battle theaters during the Second World War. In the moist heat of the tropics molds grow so rapidly that they cover shoes with a green felt overnight. Besides rotting cloth, cartons, wood and so forth, fungi showed a predilection for Bakelite in radio panels, for the resinous materials employed as waterproofing in clothing and canvas, for roofing tar, paints and varnishes, for the insulation of cables and wires in intricate electronic equipment and for the emulsion of photographic films. They even grew on the lenses of optical equipment, sometimes etching and blurring them beyond use in a matter of months. It was estimated that less than 50 per cent of the military supplies sent to tropical areas reached their destination in usable condition.

Early in the war the U. S. Army Quartermaster Corps set up a Tropical Deterioration Administrative Committee, and an extensive program of research was undertaken in close cooperation with Britain, Canada and Australia. Scores of mycologists, chemists and engineers set about designing complex testing chambers and devising methods to hinder the destructive action of molds. Thousands of cultures of fungi from materiel all over the world were isolated, identified and studied intensively. Many basic as well as practical results were obtained, but the problem still remains, and the Tropical Deterioration Laboratories of the Quartermaster Corps will probably continue to operate in war and peace for a long time to come.

I CERTAINLY do not wish to leave you with an overwhelming impression of the molds' evil aspects. It is high time we took a look at the other side of the ledger. Consider the fungus *Claviceps purpurea,* better known as ergot. This mold grows as a parasite on the heads of rye and produces conspicuous purplish spikes like cockspurs. They are called ergots, from the old French word for spur. The ergots contain a complex of alkaloid drugs, and when they are eaten by animals these drugs cause a contraction of smooth muscles and also affect the central nervous system. They can produce gangrene, abortion and even death. During the Middle Ages and as recently as the 19th century plagues of ergotism devastated the people and domestic animals of certain regions of Europe whenever infected grain was used directly or in flour.

Modern farming and flour-milling practices have virtually eliminated this disease in all civilized areas of the world. In the meantime modern medicine has turned the drug to good advantage. Its principal use is to prevent hemorrhage following childbirth, by promoting contraction of the relaxed uterus. For a time the raising of artificially infected rye was a lucrative business, because the ergot was worth far more than the grain itself. But *Claviceps* can now be grown in culture on laboratory media, and a few months ago scientists in Florida discovered that some of the ergot alkaloids can be obtained from a certain mushroom. Cultures of this saprophytic fungus are being tested by one of the major drug companies for large-scale manufacture.

Many fungi synthesize vitamins and can serve as a good source of these essential nutrient substances. During the war this knowledge was put to a remarkable and dramatic use by prisoners in the Japanese prison camps on Java and the Moluccas. The prisoners, fed a very restricted diet, had developed serious symptoms of pellagra and other vitamin-deficiency diseases. Fortunately among them were several British and Dutch scientists, and they conceived the idea of growing yeast, which is rich in

row: "earth star" (Geaster fimbriatus), jack-o'-lantern. Bottom row: common mushroom, glistening Coprinus, common Scleroderma, Mycena, Panus, "destroying angel" (Amanita verna), Boletus, shaggy-mane mushroom.

vitamins, as a supplement to their prison fare.

First they had to assemble somehow the necessary culturing equipment. In an article reporting this experience, entitled "Biology Behind Barbed Wire," L. J. Audus wrote: "We raked the rubbish tips for bottles and saucepans . . . a bunsen burner was constructed out of scrap metal. An old hot-water cylinder . . . was converted into a steam sterilizer." Next they needed a small supply of yeast to start with. This they obtained by smuggling into the camp a little ragi, a yeast-containing preparation that has long been used in the Orient in fermented foods and beverages. Now they needed a medium on which to grow the yeast. Yeasts require sugar. They had rice, and they knew that rice-starch could be converted to sugar by molds. There was no problem about finding molds; they were in the very soil of the campgrounds. So the prisoners exposed steamed rice to the dust of the camp, cultured the molds that developed and selected the one that was most active in converting starch to sugar. Soon their yeast factory, using only a small fraction of their daily rice ration, was producing enough fermented yeast juice to provide a few ounces daily for each prisoner. Audus reported that "pellagra, which had been serious and widespread at the beginning, cleared up completely in the first three months of the yeast distribution, although the quality of the food tended to deteriorate rather than improve over that period."

There are fungi which are very important in industry. One is the black mold *Aspergillus*, which when grown under very acid conditions produces large amounts of citric acid. Citric acid is used in medicinal products, soft drinks, candies, inks and dyeing and engraving processes. Thirty years ago 90 per cent of the world's citric acid came from citrus fruits in Italy. But by 1930 this source had been almost entirely supplanted by industrial production of citric acid from mold fermentation. Such factories, cultivating fungus mycelium continuously in shallow aluminum pans, now produce more than 10,000 tons of citric acid a year.

I HAVE reserved for the end of this account what is unquestionably the most dramatic and significant chapter in man's use of the molds. It is the romantic story of penicillin—the drug that has become a household word throughout most of the civilized world. Nearly everyone knows how that story began in 1928, when Alexander Fleming noticed that a chance mold contaminant had inhibited the growth of bacteria in a culture he was studying; how Howard Florey and his associates at Oxford 10 years later purified the drug, tried it on human patients and later came to America and interested this country in developing large-scale production of penicillin; and how the drug has revolutionized medicine. Not so well known is the story of the development and evolution of the fungus itself—*Penicillium*, the large genus of molds from which the drug is extracted. One investigator tried adding to the culture medium in which the fungus was grown the waste water from steeped corn, and penicillin yields made their first rise. A girl from the Northern Regional Laboratories of the Department of Agriculture in Peoria, Ill., made daily rounds of the fruit and vegetable stands in town searching for new strains of *Penicillium*. Out of thousands of collections made by "Moldy Mary," as she was affectionately dubbed, one from a spoiled melon showed great promise. After repeated selections and special treatments this strain finally gave yields 500 times as high as those Florey had been obtaining. It has since been distributed all over the world. The production of penicillin rose from a few million units per month in 1942 to more than 700 billion in 1945.

The spectacular successes of penicillin stimulated a world-wide search for other antibiotics. Streptomycin was discovered, and aureomycin and chloromycetin and terramycin and others. The molds and their relatives are the source of most of the antibiotics so far discovered. And the search continues in one of the great advances of modern medicine.

In the 20th century scientific research has tipped the scales strongly in favor of the molds; the good they do is beginning to outweigh the harm. By penetrating ever more deeply into the biology and chemistry of fungi man is learning to control the molds that interfere with his activities and to foster those that are beneficial.

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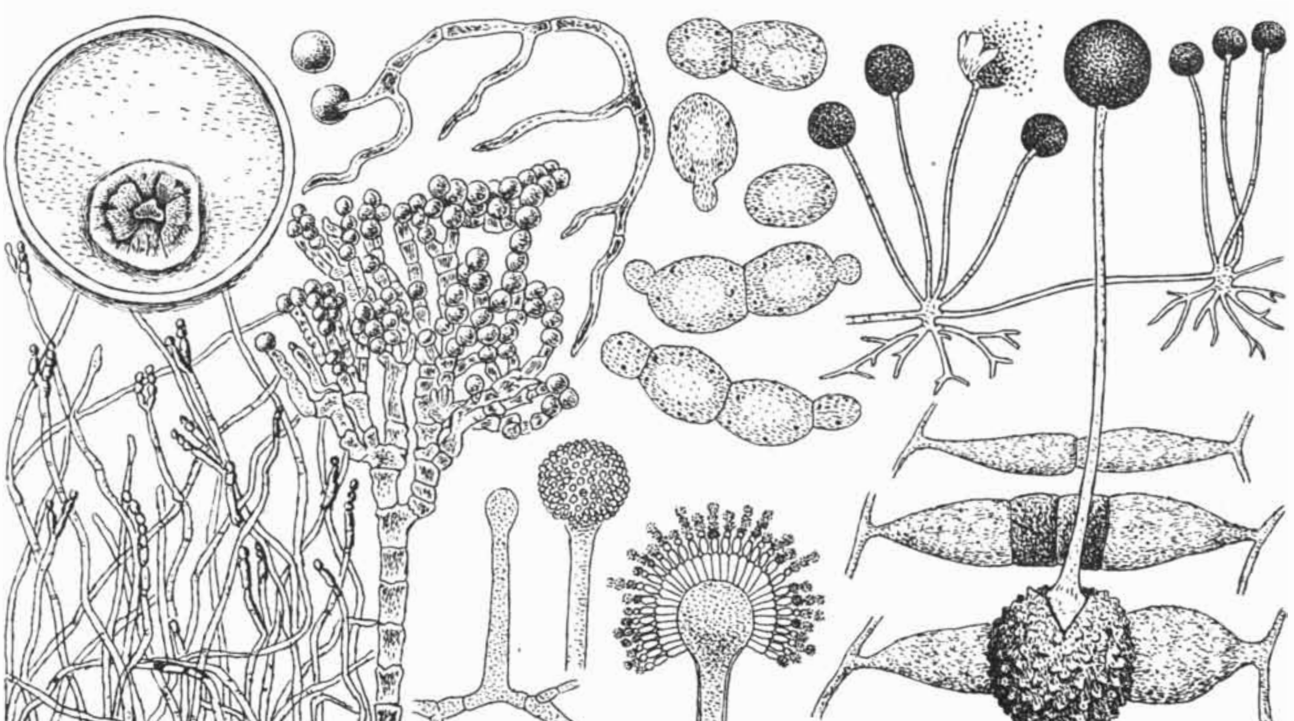
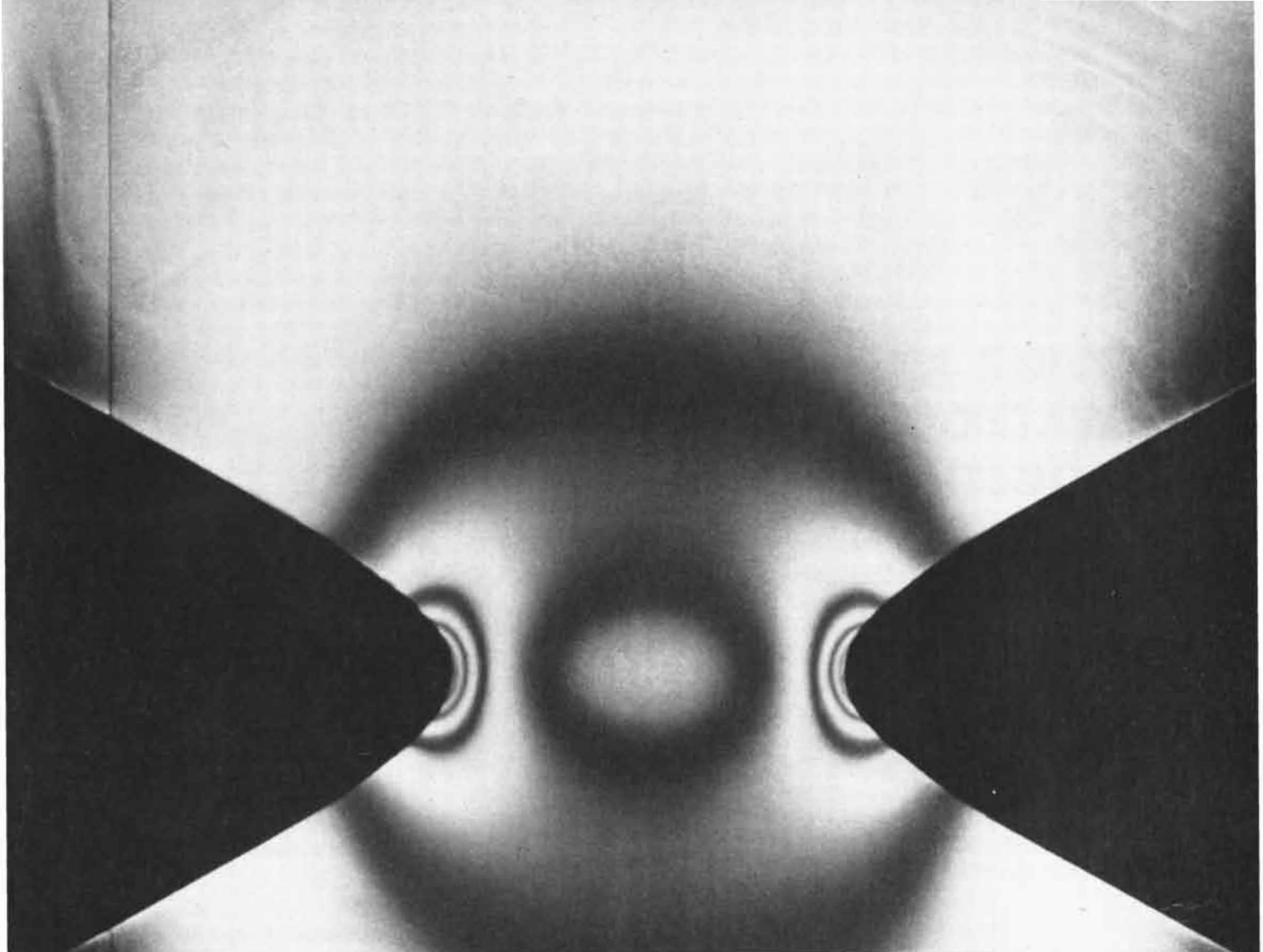


Left: culture and microscopic detail of Penicillium notatum. Top right center: yeast cells. Bottom right center: microscopic detail of Aspergillus niger. Right: detail showing stages of development in a bread mold.



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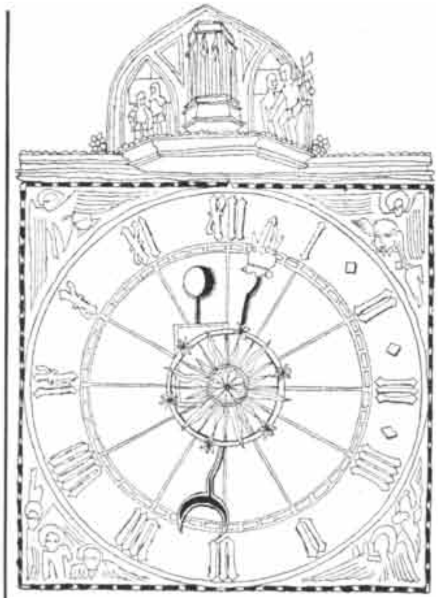


A Dash of Humus

FOR gardeners, farmers and others who have anything to do with the soil, one of the most interesting developments in years was announced at the annual meeting of the American Association for the Advancement of Science last week. Chemists of the Monsanto Chemical Company reported that they had synthesized a new kind of substance for improving the structure of soil. Not a fertilizer, it performs the same function as humus, but in applications measured in pounds rather than tons. A sprinkling of the stuff in powdered form, worked into a crusty soil, quickly gives the soil the friability and good tilth that gardeners prize. The Monsanto researchers said that pound for pound the synthetic conditioner is 200 to 1,000 times as effective for this purpose as natural humus or manure, will be several times cheaper and will be longer-lasting in its effects. They also reported that the substance prevents soil erosion and improves the surface of ball fields, tennis courts and the like.

The announcement was presented before the A.A.A.S. by Charles Allen Thomas, president of Monsanto, and was discussed at a technical symposium by a group of workers headed by C. A. Hochwalt, vice president in charge of research and development for the company. Monsanto and some 80 cooperating groups in various parts of the country have been testing the new chemical extensively and will continue the tests during the coming year. The product is not expected to be on the market in substantial quantities until 1953.

The structure of a soil depends on how its primary particles (sand, silt and clay) are lumped in aggregates. If the aggregates are of the proper size, ranging from that of a pinhead to that of a pea, the soil is easy to work and relatively stable. It keeps its porous, spongy structure, holds moisture well and lets air get to the roots of plants. In a soil of poor structure, on the other hand, the aggregates break down after a rain, and the soil cakes, shrinks and cracks. Seeds may fail to germinate or, if they germinate, to emerge through the hard surface-crust. Rain does not readily penetrate the crust and runs off on the surface. Water in the soil evaporates through the cracks. The sealing crust prevents the soil from "breathing," and lack of oxygen reduces the ability of plant roots to use the soil nutrients. The soil is hard to work and forms clods.

Organic matter, as every farmer and gardener knows, helps to give soil a good structure. In recent years soil scientists have worked out the chemical process by which organic material produces this result. They have found that decaying organic material yields certain natural gums, known as polyuronides, which act as a kind of glue in the soil, cementing together the particles in water-stable aggregates. It struck the Monsanto workers that this natural process was a remarkably inefficient way to condition the soil. In the first place, the polyuronides are only a minor by-product of organic decomposition; it takes many tons of decaying material to produce one ton of polyuronides. In the second place, bacteria rapidly decompose the polyuronides themselves, so the supply has to be constantly replenished by adding large quantities of organic material to the soil.

The Monsanto chemists decided to try to find chemicals that would act directly to cement soil aggregates and would resist bacterial decomposition. After testing many hundreds of compounds, they developed a synthetic polyelectrolyte that seems to fill the bill. One pound of this product, trade-named Krilium, is equivalent to 200 pounds of peat moss or 500 pounds of commercial compost. It is disked into the soil in concentrations ranging from one part in 1,000 to one part in 5,000 of the soil by weight, depending on the type of soil and the degree of improvement needed. When the object is to control erosion, the powder is merely spread evenly on the surface.

The new conditioner of course does not improve a soil that already has a good structure. But the Monsanto workers reported that in tests comparing treated and untreated poor soils their product increased the infiltration of water into the soil two- to three-fold, improved the soil's water-holding ability by 30 per cent, reduced the evaporation rate to one-half, made the soil much easier to work and was 50 times as re-

THE CITIZEN

sistant to bacterial decomposition as the polyuronides. Treated soil can be plowed earlier in the spring, because it is less sticky and does not puddle even when relatively wet. In a few preliminary tests the Krilium treatment has increased the yield of crops such as carrots and corn by 30 to 100 per cent. (The treatment has a drawback, however: it also increases the crop of weeds!) Much more extensive tests of crop yields are to be made in the coming year. Methods of applying Krilium also will be studied further.

The substance controls rain erosion by forming a water-permeable film on the surface of the soil. It holds the soil and seeds in place while a cover crop establishes itself. The conditioner is not inflammable and does not readily blow away.

Tested on a baseball diamond, the Krilium treatment made it playable more quickly after a rain and greatly improved the "workability and ball-bounce characteristics" of the field. It also helped clay tennis courts to dry out faster.

The Monsanto workers believe that Krilium will be especially useful for home gardens, greenhouses and truck farms, particularly where the bulky organic composts and manures are not readily available, and for erosion control. Whether its use will be economically feasible in large-scale agriculture is still to be determined.

Schaefer Method Supplanted

THE controversial Schaefer method of artificial respiration, for many years the standard, officially preferred system in the U. S., has been given up. It will be replaced by the Holger Nielsen method, invented by a physical training instructor in the Danish army and used in Europe since 1932. This announcement was made last month by the American Red Cross, the Department of Defense, the National Research Council and the U. S. Public Health Service.

In the Schaefer method the victim lies face down and the operator presses rhythmically on his lower ribs. In the Holger Nielsen method the operator first pushes down on the back and then lifts the victim's arms. The essential difference between the two techniques is that the Schaefer operation merely pushes air out of the chest, relying on elastic recoil to draw air into the lungs again, while the Holger Nielsen arm-lift operation helps to pull air in. It not only brings twice as much air into the lungs but also is closer to the natural breathing process ("Artificial Respiration," by Stefan Jellinek; SCIENTIFIC AMERICAN, July, 1951).

The change in policy was made on the strength of three years of research sponsored by the Red Cross, which proved that the Holger Nielsen procedure is better. The new method has now been approved by the U. S. Armed Forces, the Civil Defense Administration, the P.H.S., the American Medical Association, the Bureau of Mines, the Boy Scouts and Girl Scouts, the American Telephone and Telegraph Company and other groups. It will supplant the Schaefer method as soon as these agencies can instruct teachers and operators in it. In cases in which the victim's arms are injured, the recommended procedure is to lift the hips instead of the arms. When the victim cannot be placed face down, operators are to use the Sylvester method, pressing the abdomen and then raising the arms.

Intravenous Oxygen

WHEN a patient cannot eat, doctors can feed him by injecting nourishment into his veins. B. G. Lary of the University of Illinois College of Medicine is experimenting with a similar stratagem for providing the body with oxygen when the lungs are disabled. He has successfully tested on dogs a method of "intravenous breathing."

Lary anesthetizes the animal, injects heparin to prevent blood-clotting, opens an artery and a vein in its leg, passes the blood from the artery through tubes and a porcelain filter, where it picks up oxygen, and then lets the blood flow back into the vein. In this way he has kept dogs alive for 50 minutes in an atmosphere entirely lacking in oxygen. The animals survived the experiment without apparent damage.

The main obstacle to the administration of oxygen or any other gas through the blood is the danger of forming bubbles, which can be fatal. Lary prevents this by use of the filter and a wetting agent, which lowers the surface tension of the blood so that "the size of the bubbles is tremendously decreased."

He reported recently to the American College of Surgeons: "The device is not yet as efficient as the lungs and does not provide the normal amount of oxygen, but it may be adequate for use in a crisis, to tide the patient over until his lungs can resume their functions." Such crises may occur in heart attacks, severe asthma and accidents in which the lungs have been badly burned.

Aspiration Pneumonia

"PRIMARY atypical pneumonia" and "virus pneumonia," which have been diagnosed in many thousands of patients in the last 15 years, are meaningless labels for a nonexistent condition, according to two British researchers. Philip W. Robertson, a Royal Air Force physician, and K. D. Forgan Morle, a radiologist at the University of Liverpool, declare that in most cases of this kind that they have examined the real cause of the pneumonia is a blocking of one segment of the lungs by fluids from the nose or throat.

Ordinary pneumonia is caused by bacteria. When no bacteria can be found, physicians are apt to call it atypical or virus pneumonia. Robertson and Morle argue that this is not sufficient reason to blame it on a virus. They studied 500 cases among recruits in RAF training camps. In every instance the pneumonia was preceded by some infection of the nose or throat, and X-rays showed that lesions of the lung were confined to certain segments. Since it is known that breathing in of mucus, blood or pus can cause such lesions, and since there is no explanation of why a virus would limit itself to one segment of the lungs, they conclude that the aspirated fluids are responsible for most cases of atypical pneumonia.

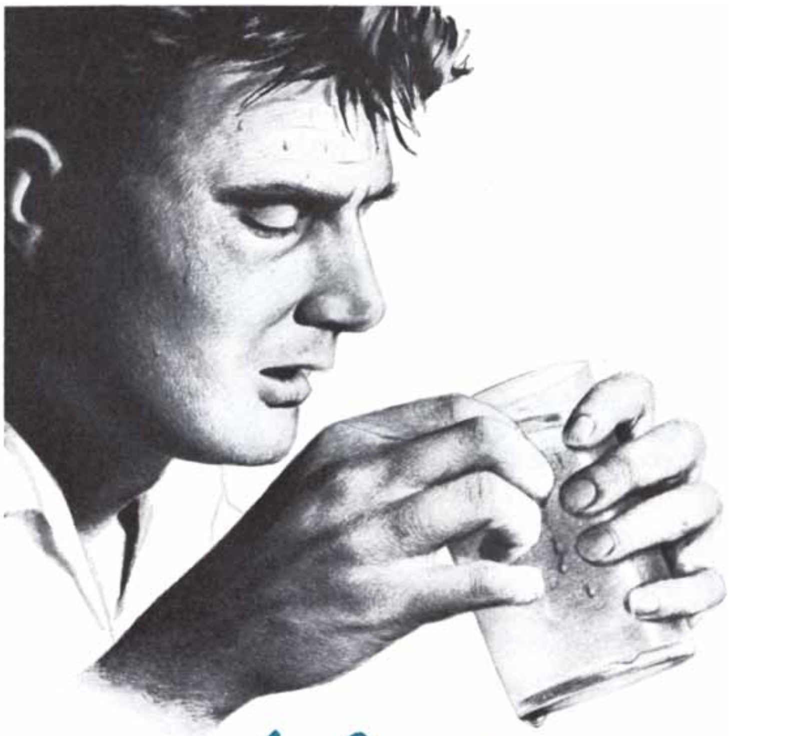
As additional evidence, they note that "symptoms often first arose when severe physical exercise had been undertaken in the presence of an upper respiratory infection." These are the conditions under which mucus or pus are most readily aspirated. The aspiration theory would explain why sulfa drugs and antibiotics produce highly variable responses, for the fluid drawn into the lungs sometimes has infectious organisms and sometimes does not.

Robertson and Morle, writing in the *British Medical Journal*, advise draining, steam inhalations and diathermy as the most rational treatment for atypical pneumonia. They conclude: "The acceptance of an aspiration basis for 'primary atypical pneumonia' greatly simplifies the understanding of the condition. It provides an explanation for its apparently obscure epidemiology, showing that its infectivity and method of spread are merely those of the upper respiratory infection."

Cross Section of a Virus

BIOLOGISTS have been photographing viruses through the electron microscope for years, but these pictures always showed a side view of the tiny particles. The tobacco-mosaic virus, for instance, was always seen as a long, rod-shaped object; its cross section was unknown. Now Robley Williams, University of California biophysicist, has obtained the first cross-sectional photograph of a virus. He finds that the cross section of the tobacco-mosaic virus is a hexagon, a shape characteristic of crystals.

Williams irradiated a solution of virus with high-frequency sound waves. When he dried the solution and photographed



the result, he found that the ultrasound had broken the viruses into little bits, and some of the pieces were standing on end. Pictures taken at the very high magnification of 200,000 times then showed that the cross section is hexagonal. His photographs indicate that individual virus particles, like aggregations of them, have a crystal-like structure.

Poisonous Poultry?

ANTIBIOTICS speed the growth of chicks and turkeys, and U. S. raisers are now feeding them to poultry on a large scale. Mortimer P. Starr and Donald M. Reynolds, bacteriologists at the University of California, warn that this practice may have dangerous results. Chicks raised on antibiotics, they suggest, may develop resistant bacteria and poison people who eat them.

Examining the intestines of turkeys grown on a diet supplemented with streptomycin, the two investigators found that the birds had developed large numbers of streptomycin-resistant bacteria. It took only three days for a bacteria population completely resistant to the drug to appear in such birds.

Starr and Reynolds point out that poultry commonly carry a parasite, *Salmonella,* which can cause food poisoning, enteritis and typhoidal infections in man. If the feeding of antibiotics produces resistant varieties of the parasite, the organism may not only poison human consumers but be immune to treatment with drugs.

Nobel Prizes

THE 1951 Nobel prizes in chemistry and physics were awarded to four nuclear scientists.

Edwin M. McMillan and Glen T. Seaborg of the University of California shared the chemistry prize for the creation of six new elements heavier than uranium. In 1940 McMillan first identified element 93, neptunium, among the products of a nuclear reaction. Seaborg and co-workers followed this up by synthesizing plutonium, americium, curium, berkelium and californium. McMillan also developed the principle of the synchrotron, which has made possible the building of much more powerful accelerators than the cyclotron.

The Nobel prize in physics went to Sir John D. Cockcroft and Ernest T. S. Walton of England "for their pioneer work on the transmutation of atomic nuclei by artificially accelerated particles." Cockcroft and Walton in 1930 built one of the first high-energy accelerators.

The National Science Board

CHESTER I. BARNARD, president of the Rockefeller Foundation, is the new chairman of the 24-member Board

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of the National Science Foundation. He succeeds James B. Conant, president of Harvard University, whose term expired last month. Barnard will retire from his post at the Rockefeller Foundation on June 30, when he will have passed the Foundation's age limit of 65. Dean Rusk, now Assistant Secretary of State for Far Eastern Affairs, will take his place.

The NSF Board re-elected its vice-chairman, Edwin B. Fred, president of the University of Wisconsin, and several members of its executive committee.

The Foundation will award 400 fellowships to graduate students of science in the academic year beginning next September. Stipends will range from $1,400 for first-year graduate students to $3,000 for post-doctoral fellows. From the second year on, fellows will also receive family allowances. In addition to the stipends the Foundation pays the fellows' tuition and laboratory fees.

The Case of Dr. Ivy

DR. ANDREW C. IVY, head of the medical school at the University of Illinois and one of the nation's leading physiologists, has been suspended from the Chicago Medical Society for three months "for the methods he employed in promoting a substance known as krebiozen in the treatment of cancer."

The controversy that led to this unusual public rebuke began last March, when Ivy told a private conference of physicians at the Drake Hotel in Chicago about a drug sent to him by Dr. Stevan Durovic, a Yugoslav physician who came to the U. S. from Argentina. Durovic, who kept the ingredients secret, saying only that krebiozen was extracted from the serum of a horse, claimed that it was effective in treating cancer. Ivy, after testing it clinically, believed it merited study. News of the conference leaked to the Chicago daily newspapers, and the drug was widely publicized as a "cancer cure." After the conference a Krebiozen Research Foundation was set up in Chicago. It sent free samples to hospitals and research institutions.

Because of a great demand for information by physicians, the Council on Pharmacy and Chemistry of the American Medical Association studied the results of trials of krebiozen by clinicians who had received samples. Of 100 unselected cancer patients who had been given the drug, only two showed any objective evidence of improvement; 44 had died. The A.M.A. group concluded that "these findings fail to confirm the beneficial effects reported by Ivy and associates."

The Chicago Medical Society said it suspended Ivy because of his role in promoting a secret drug. Ivy himself has never seen krebiozen except in solution. His defense was that the free distribution of the drug to all who wanted to

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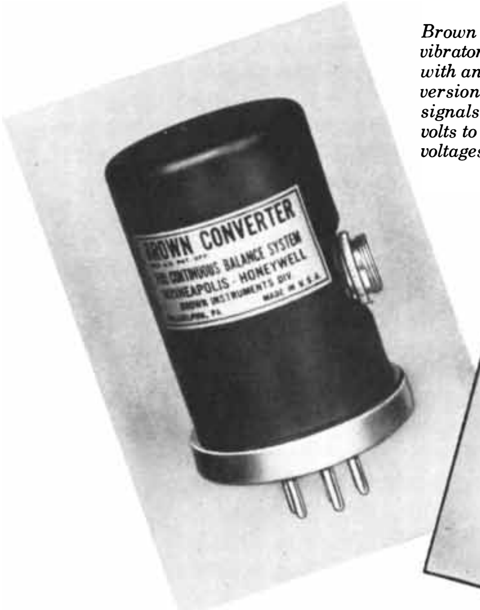

Brown Converters are precision, vibrator-type converters for use with any system requiring the conversion of low power direct voltage signals of the order of 100 microvolts to 60 or 400 cycle alternating voltages.

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investigate it proved that no ulterior motive was involved. He said he would continue to investigate krebiozen. The University of Illinois announced that he would be retained in all his posts there.

Atomic Central Heating

THE world's first atomic heating system is now in successful operation at Britain's nuclear research center in Harwell. Bepo, the big Harwell reactor, is providing all the heat for an adjacent building of 80 offices. A spokesman of the Ministry of Supply, which operates Britain's atomic research, said the system works perfectly and maintains an even temperature of about 65 degrees.

The hot air from Bepo's air-cooling system heats water in pipes to 130 degrees Fahrenheit. The water, untainted by radioactivity, is piped to radiators in the office building. The installation cost about $42,000 and will save $7,420 worth of coal a year.

Workers at Harwell had been studying the possibilities of atomic heating for more than three years. One important function of the new installation will be to supply engineers with data on operating characteristics and costs of atomic heating.

The Screw-Worm Fly

THE screw-worm fly is a major pest of U. S. agriculture. It attacks livestock and causes annual losses of millions of dollars. A single fly lays 300 eggs. But the female screw-worm fly mates only once in her lifetime. On the strength of this knowledge the U. S. Bureau of Entomology and Plant Quarantine has just conceived a scheme for a subtle attack on the pest.

It occurred to the Bureau's entomologists that if enough female screw-worm flies were forced to mate with sterile males, the insect might be stopped at the source: the females' eggs would not hatch. The Bureau has therefore started to raise millions of screw-worm flies in its laboratories. They will all be sterilized with X-rays or other radiation and then be strewn from airplanes throughout Florida, where screw-worm flies of the Eastern U. S. winter. The Bureau figures that it may be possible to concentrate enough sterile male flies so they outnumber the wild ones 5 or 10 to one. The sterile males will pre-empt most of the females at large. Far fewer screw-worm flies will be born. Within two seasons, the Bureau calculates, the screw-worm fly should be entirely eradicated from the whole section east of the Mississippi. It seems useless to try to wipe them out by this means in the West, because they are too well entrenched there.

The Bureau is now preparing to make a pilot-plant test of the idea on an island off the west coast of Florida.

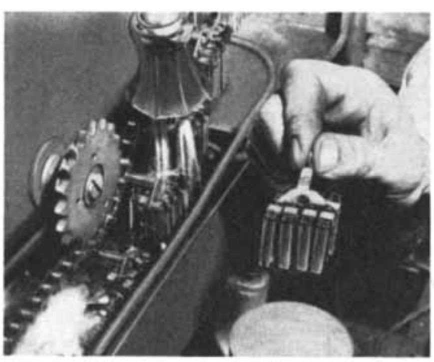
DEVELOPMENT BRIEFS

From Special Instrument Headquarters

Announcement by AEC of available fission products has accelerated the use of radioisotopes by industrial firms. Radioactive cobalt is a prime example. Proper instrumentation for specialized procedures is available from General Electric. See descriptive bulletin GEA-5735.*

The new G-E Width Gage now being field tested provides accurate measure of hot strip steel. Mounted 15 feet above the moving strip, this non-contacting electronic device is actuated by the light of the strip itself. Increased production of critical steel and savings of hundreds of thousands of dollars annually are predicted by the steel industry. See bulletin GEC-783*.

Chemical analysis by x-ray absorption is now successful on a commercial scale with the G-E X-Ray Photometer, saving hours of valuable laboratory time, and freeing the chemist from routine work. Petroleum refiners slash time and cost determining tetraethyl lead in gasoline, and sulphur in oils. Many other industrial uses are possible since it measures the absorption coefficient of matter. See GEC-412A*.



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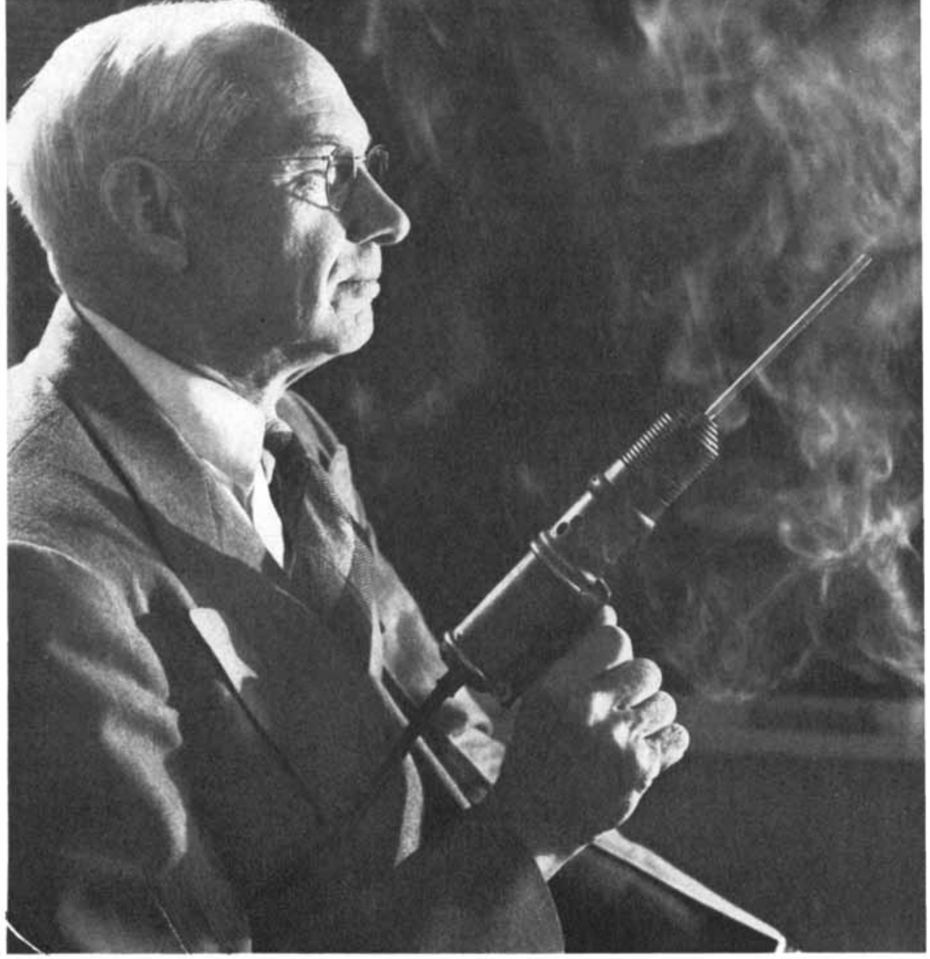
when cleaned with 500-kc vibration in trichlorethylene. G-E Ultrasonic Generator beams high-frequency sound through any liquid solvent greatly accelerating the cleaning action. Small metal parts are quickly cleaned of oil, grease, lapping compound and metal chips. See bulletin GEA-5669* describing how an electric shaver manufacturer cut cleaning costs 58%.

**Write for bulletins to: General Electric Co., Sect. 687-84, Schenectady 5, N. Y.*



W. C. White, co-inventor of . . .

Leak Detector: New Tool for Fast Production Testing

Basic research at General Electric produced the Leak Detector—so sensitive it finds leaks of one ounce per century in tanks, pipes, valves, and even footballs.

It works like this: A halogen tracer is introduced in the closed system and air pressure applied. The detector nozzle "sniffs" for leaks in suspected areas.

Air drawn in the nozzle passes hot, electrically charged platinum surfaces. Vapors containing compounds of chlorine, fluorine, bromine, and iodine dissociate on the hot surfaces releasing positive ions. Resulting current registers on meter, light, or buzzer.

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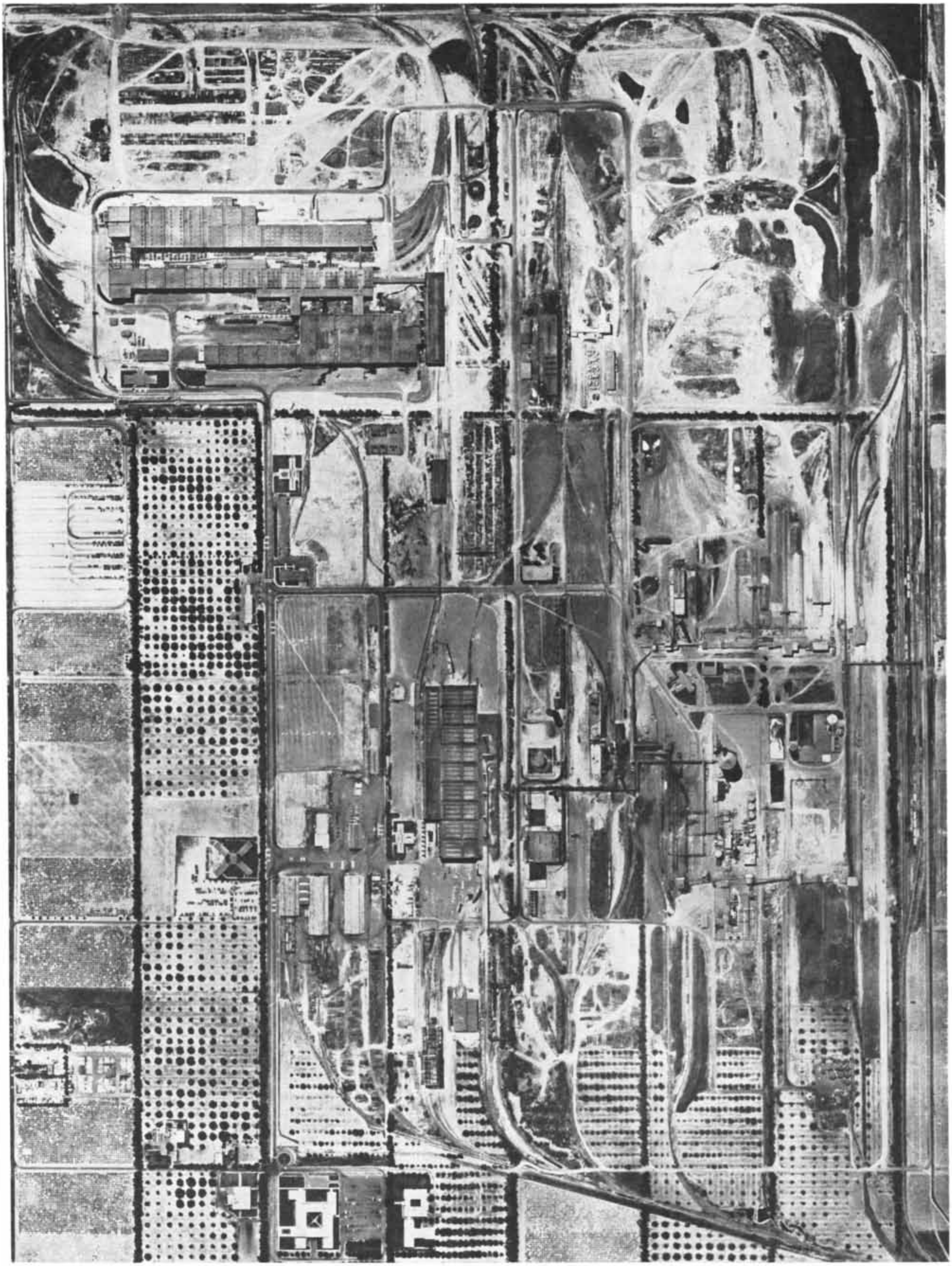


AERIAL PHOTOGRAPH shows the Kaiser Steel plant at Fontana, Calif. The diagram on the opposite page locates the principal organs of the plant and shows how materials flow through them. Coal is stored at 1; iron ore at 2. At 3 are the coking ovens; at 4, the blast furnace. The open hearth furnaces are at 5; the rolling mill at

THE GEOGRAPHY OF STEEL

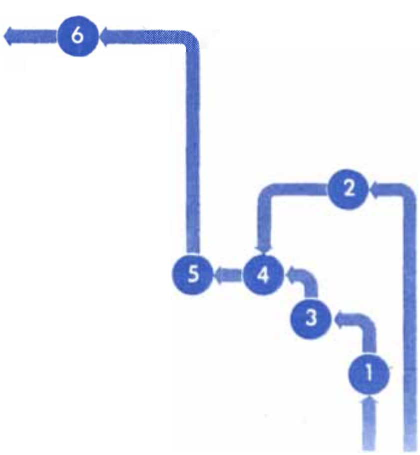
As our need for the metal increases, more of its raw materials are imported from other parts of the world. A general account of this situation at present, against a background of how steel is made

by George H. T. Kimble

A HUNDRED YEARS AGO a hunk of steel was something of a curio. Few people had ever seen the metal; fewer still knew anything of its properties—or its technological possibilities.

In the year just ended (1951) the world production of steel is estimated to have exceeded 200 million tons, for use in 10,000 different ways by a billion different people. In the U. S. alone the steel industry provides a livelihood for nearly one million people, has capital assets in excess of six billion dollars (a figure that no doubt would have impressed even Andrew Carnegie) and during 1951 turned out a record production of some 106 million tons. And there is every prospect that this figure will be exceeded by a handsome margin before the decade is out.

The demand for the things made of steel—ships, skyscrapers, tanks, tractors, household appliances, toys and trinkets—seemingly is insatiable. Everybody knows that ships and skyscrapers devour immense quantities of steel: the *Queen Mary* alone has some 55,000 tons of the metal in her, the Empire State Building about the same and the Golden Gate Bridge over 100,000 tons. But the consumption of steel for purely domestic purposes is scarcely less spectacular when compounded at the national level. It has been calculated, for instance, that the average American home has between two and three tons of steel equipment—about 220 pounds in the cooking stove, about the same in the refrigerator, 150 to 200 pounds in the washing machine and well over a ton in the automobile. If every other country follows suit and comes to regard refrigerators, washing machines and automobiles as part of the necessary paraphernalia of 20th-century life, the world output may well rise to a round billion tons a year before leveling off—always supposing, that is, that the supply of raw materials does not run out beforehand.



6. Since this photograph was made the Fontana plant has been considerably enlarged and also modernized.

On what materials does the modern technology of steel depend? The array is impressive. The first step—production of pig iron—requires iron ore, fuel and fluxing stone (limestone or dolomite). The second—smelting of the iron to make steel—calls for metal scrap, limestone (and sometimes burnt lime), fluorspar, ferro-alloys and spiegel (a mixture of iron, carbon and manganese). In addition both operations require large amounts of water and air.

How Steel is Made

The first operation takes place in the familiar blast furnace—a cylindrical steel structure as high as a 10-story building and lined throughout with heat-resisting brick. The ore, coke and limestone are fed in at the top in mathematically determined amounts; the air, dried and heated to about 1,250 degrees Fahrenheit in massive stoves alongside the furnace, is blown in near the base. The burning of the coke in the air generates gases (mostly carbon monoxide and carbon dioxide) which melt the charge, decreasing its volume and inducing chemical reactions. Close to the top of the furnace some of the oxygen is removed from the ore. Further down still more of the oxygen is removed through the agency of the coke, and the limestone crumbles and melts. In so doing it mops up the nonmetallic minerals and coke residue, forming slag. Toward the bottom most of the charge becomes a pasty mass, and at the very bottom, where the heat is of the order of 3,500 degrees, the iron and slag acquire the consistency of molten lava. At the right moment, which is determined with the aid of smoked glasses and a device known as a pyrometer, the slag, floating on the surface of the molten iron, is drawn off. Every four or five hours the product iron itself is tapped from the furnace, as much as 300 tons being drawn off into buckets at a single time.

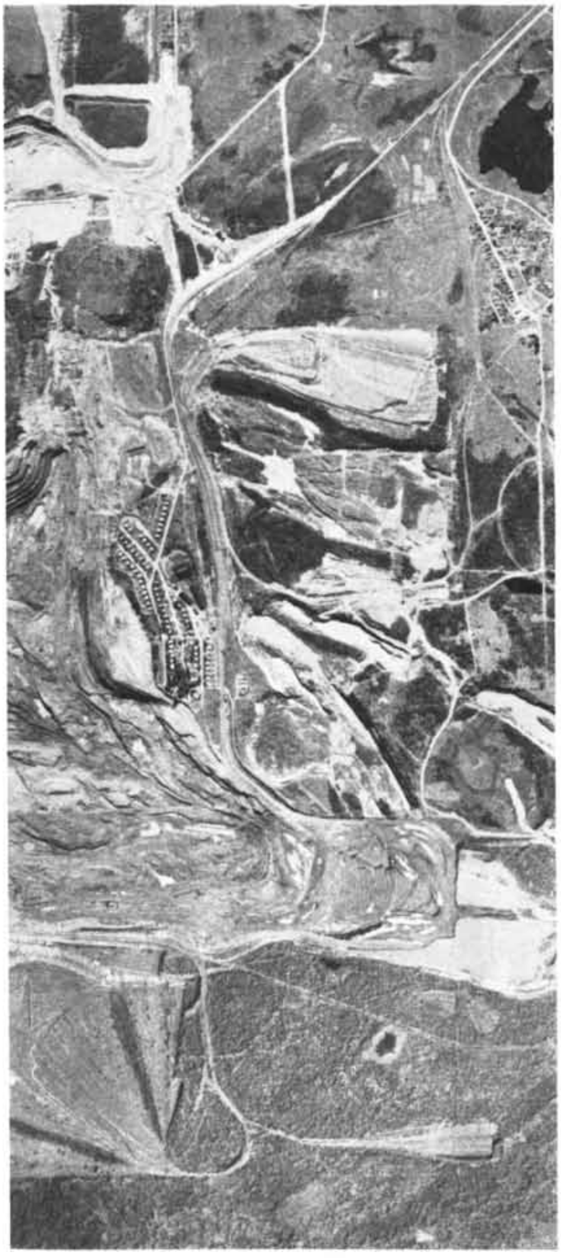
The second operation is by far the more complicated of the two. It may be carried out in several different ways. In this country fully 90 per cent of the steel is made by the open-hearth method, so-called because the floor (or hearth) of the furnace in which the charge is fired is exposed to the sweep of the flames. The typical furnace consists of a battery of rectangular hearths whose walls and chambers are lined with bricks, some chosen for their ability to retain heat, some for their anti-erosive properties. The bricks used in the open-hearth furnaces of this country during the course of a year would build a city capable of housing between 30,000 and 40,000 souls! Each hearth can hold a pool of molten steel some 40 feet long, 20 feet wide and 2 feet deep. Beneath the hearth are two chambers fitted with a checkerboard latticework of firebrick. A mixture of air and gaseous or powdered fuel is preheated in one of these chambers and fed into the furnace proper, where it burns. Fierce exhaust gases then escape from the opposite end of the furnace and sweep through the second checker chamber, heating the brickwork. Every 15 minutes or so the flow of air and fuel is reversed so the hot chamber can give off its heat to the incoming mixture while the exhaust gases are reheating the chamber just cooled. This "regeneration," as it is called, not only utilizes waste heat but raises the open hearth to temperatures of 3,000 degrees and above, which would otherwise be unattainable without an enormous consumption of fuel.

When the appropriate temperatures have been reached, the "heat" of steel begins. The "melter," or supervisor, first charges the furnace with a combination of scrap steel and limestone; this operation is carried out by means of a mechanical arm which picks up long steel containers of these raw materials, pushes them through the furnace door and flips them over onto the hearth. In the presence of the searing heat the mixture soon begins to melt, the lighter limestone forming a slag above the molten scrap steel. After three hours or so the "heat" is ready to receive its next ingredient—cast-iron scrap. An hour later the melter and his assistants begin to feed in molten pig iron delivered direct from the blast furnace. At the end of a further 50 to 60 minutes the charge, now consisting roughly of 70 per cent steel scrap and 30 per cent iron, starts to "work," that is, to turn into a uniform mass of molten steel. The unwanted silicon and some of the phosphorus, sulfur and carbon in the mixture either escape as gases or are absorbed by the slag—a process that can be accelerated by adding a little fluorspar. By the time the heat has been on 10 hours or more, the steel

HULL-RUST-MAHONING MINE of the Mesabi Range, largest iron mine in the world, is shown in a mosaic of aerial photographs made by the Aero Service Corporation. The open pit of the mine stretches three and a quarter miles from left to right and a mile from top to bottom. The maximum depth of the pit is 475 feet. The fan-shaped areas around the mine are piles of waste material. At the top is the town of Hibbing, Minn. At the is ready to be examined for its carbon content. This an expert melter can judge merely by looking at the structure of a cooled solid sample. Should the sample be reckoned to contain too much carbon, the melter will then add a small charge of iron ore. On entering the molten bath the ore releases its oxygen, which takes some of the carbon out of the steel by combining with it to form carbon monoxide.

When further samples show that the carbon content is right, one such sample goes to a nearby laboratory for a quantitative chemical analysis. From this analysis a determination is made of approximately what quantities of ferro-alloys (*e.g.*, manganese) and other ingredients need to be mixed with the steel to give it the prescribed chemical composition. When these amounts have been added, and a further sample shows that the carbon, alloy, sulfur and phosphorus contents are "within range," the heat is ready for tapping. But even this may not be the last act in the operation; if the sample does not measure up to the specified percentages of ingredients, which sometimes have to be accurate to three decimal places, the melter may have to add a few pounds of ferro-manganese or other metal to the steel after it has been poured into the ladle.

This done, the ladle is moved to a pouring platform. Here the steel is poured into ingot molds. As soon as each ingot has solidified, which may take upwards of an hour, it is stripped of its mold by an overhead crane and placed in a soaking pit. This is a gas-fired furnace which brings the still red-hot ingot to the uniform temperature required in the "blooming" mill where the raw steel is to undergo its final grooming. There ponderous rollers, acting like wringers, flatten and stretch the hot metal as it is passed back and forth and turned from side to side—a process as casual, seemingly, as the baker's kneading of a lump of dough. From then on it is anybody's steel, ready to serve as railroad tracks, bridge girders, pipes, coaxial cable, electricity pylons and, less spectacularly but no whit less essentially, as "tin" cans, hypodermic needles and shoe grips.



edge of the mine is North Hibbing, which will shortly be evacuated. From 1895 through 1950 the mine produced 496,558,000 tons of ore.

Bessemer and Electric Furnaces

To the dominant open-hearth process two other processes for steelmaking play important supporting roles. They are the Bessemer and electric-furnace methods.

The Bessemer furnace turns pig iron into steel merely by blowing air through it at high pressure. No fuel is needed, because the chemical reaction between the oxygen in the air and the iron's impurities is so violent that the temperature of the metal is actually raised during the process. The transformation takes place in a brick-lined, pear-shaped container with a narrow mouth and a double bottom, the inner surface of which is perforated with half-inch air holes. To receive its charge this converter, as it is called, is tipped sideways. As soon as the molten iron is in, the air blast is turned on and the converter is swung back to the vertical position. What ensues is the kind of pyrotechnic display Americans pay good money to see every July 4th. The cascading sparks (evidence that the impurities are being burned away) are more dazzling than Chinese fire, and the reddish-brown flames emerge from the converter with the roar of a subway train. In 10 to 15 minutes the show is over: the flames die down, the blast sputters out, the converter is tilted on its side again and the charge is unloaded.

Because the Bessemer process does not lend itself readily to the production of alloy steels, it is used mainly for the manufacture of free-cutting steels and steel wires. Almost each year sees a diminution of its relative importance in the U. S. metallurgical economy. In the period up to 1940 Bessemer steel accounted for almost a fourth of all the steel produced in this country, but in 1948 it contributed only five per cent of the total U. S. output.

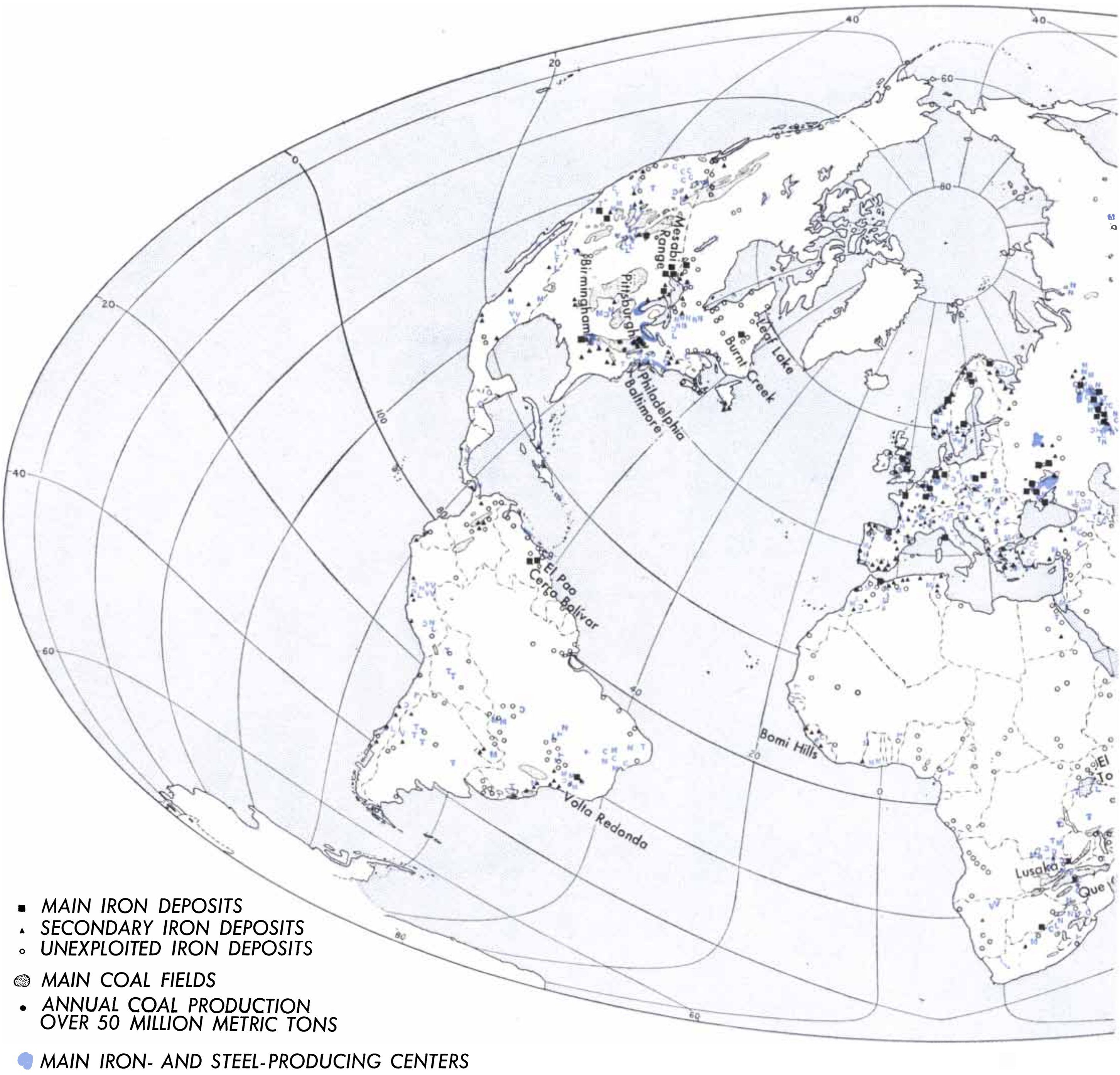
With electric-furnace steel the situation is different. From a mere four tons in 1906, when the first electric furnace was installed in this country, the production had grown by 1948 to more than five million tons, shooting ahead of Bessemer steel. And it is still growing. The reasons are not far to seek. In the first place electric furnaces are much more susceptible of temperature control than either Bessemer or open-hearth furnaces. This is an important factor where stainless and other high-quality alloy steels are concerned. Secondly, electric furnaces are not tethered to coal fields or congested water-fronts and railroad sidings. They can be located wherever low-cost electricity is available. They are in particular favor, therefore, in those countries which have abundant hydroelectric power and little or no coking coal, such as Sweden, Norway, Italy and Switzerland. Thirdly, the capital outlay involved is less than in open-hearth installations. Fourthly, they can consume cheap, light steel scrap for which no ready market is normally available.

The Raw Materials

To keep all of America's open-hearth, electric and Bessemer furnaces going at full capacity, along with the now almost extinct crucible furnaces, poses the biggest problem in industrial logistics that any nation has ever had to face. Furthermore the problem is getting tougher every year, first because the curve of U. S. steel production is still rising steeply, and second because raw materials and fuels are no longer as easy to come by as they used to be.

The amounts of raw materials and fuels already involved in U. S. steel production are prodigious. To produce 100 million tons of steel our furnaces require approximately 135 million tons of iron ore, 110 million tons of coal, more than 50 million tons of scrap, more than 30 million tons of limestone, 1.7 million tons of manganese ore, 650,000 tons of chrome ore, 42,000 tons of metallic nickel, 60 million barrels of fuel oil and 275 billion cubic feet of gas—not to mention half a billion tons of hot air and more than seven billion tons of water.

How do we stand with respect to reserves of these essential materials? Fuels present little or no problem. Though it

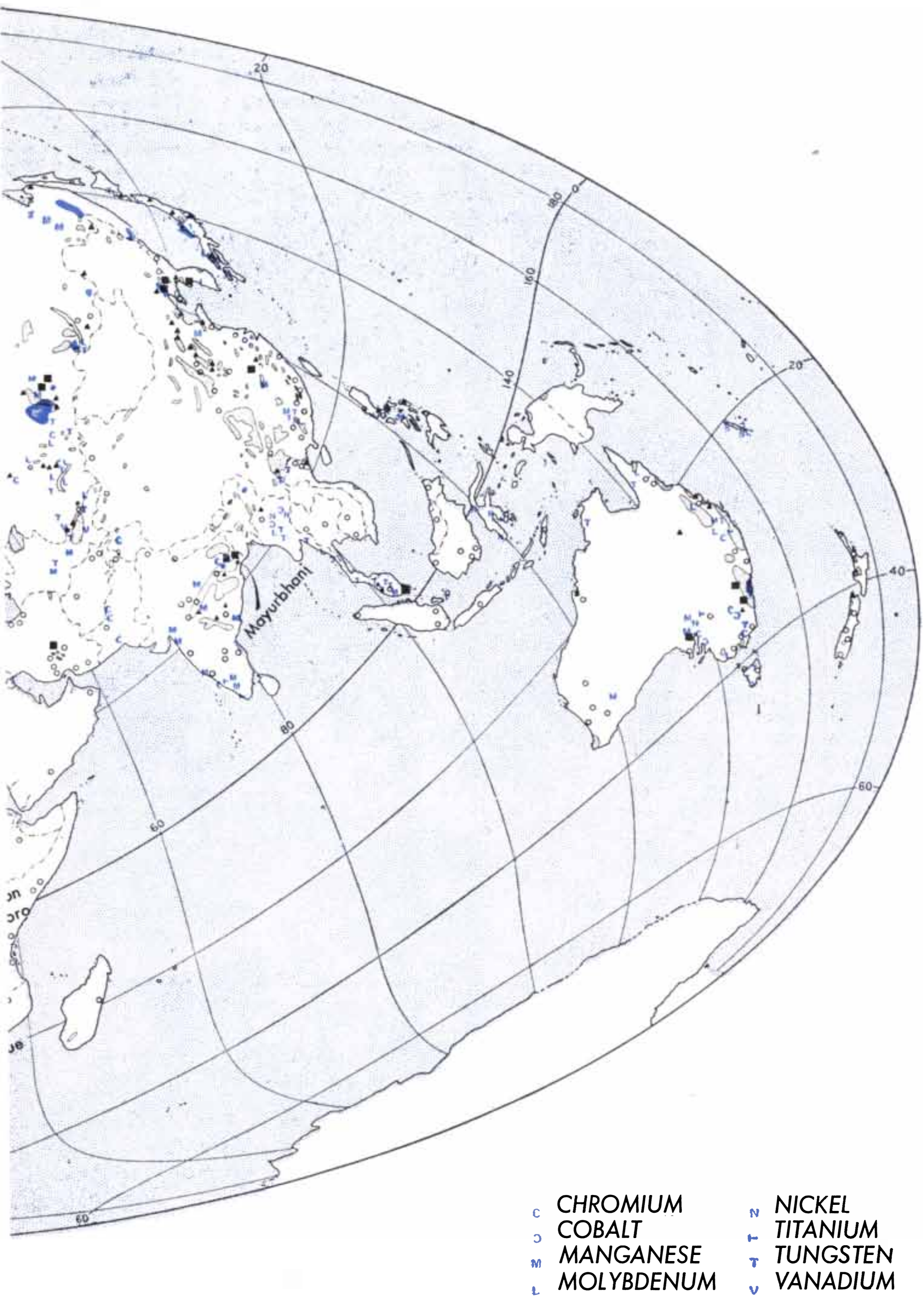


WORLD MAP shows the distribution of the resources needed to make steel. Given on the map are the names of several iron-ore areas discussed in this article. Baltimore appears because it is near the Sparrows Point

would not be difficult to find an abandoned coal mine, and rusting derricks are a common sight in many of our oil fields, nobody seriously questions the ability of this country to go on raising power for its still burgeoning industries. The proved accessible reserves of good-quality coal are of the order of 2,000 billion tons, which gives them, even at twice the present rate of consumption, a life expectancy of over 3,000 years! The fuel-oil situation is not quite so rosy, but if we may venture to include the newly revealed Canadian petroleum fields in our estimates, along with the continent's oil-shale and tar-sand deposits, even the pessimists would give us a 100-year supply at the present rate of consumption. As for hydroelectric energy, which, there is good reason to believe, will figure increasingly in the steel-manufacturer's equation, this country still has an undeveloped potential of approximately 14 million horsepower, and all of it available in perpetuity, given reasonable watershed conservation.

The situation with regard to fluxing materials also is satisfactory. While Dame Nature has distributed her best limestones and dolomites with a fine disregard for the economics of steelmaking, calcareous rocks suitable for fluxing underlie at least one tenth of inhabited America and are in no sense a vanishing resource.

The critical materials are iron ore and ferro-alloys. In this country practically all the iron ore used in steel manufacture comes from three main locations: 1) the Lake Superior field, which still contributes almost four fifths of the ore used in the U. S., 2) the Alabama field,



Works of Bethlehem Steel; Philadelphia, because it is near U. S. Steel's Fairless Works. The map was prepared by the American Geographical Society.

contributing about eight per cent, and 3) the Northeastern field, notably the Adirondack region, yielding about four and a half per cent. The rest is made up of shipments from such widely scattered states as Wyoming, Utah, California, Texas, Virginia, Georgia, Minnesota, Nevada and Washington.

Iron-Ore Reserves

The greatest single producing region continues to be the Mesabi Range in northeastern Minnesota. In 1948 nearly two thirds of the total U. S. shipments of 101 million tons of ore came from this region, notwithstanding the fact that the field was then some 60 years old and reportedly past its prime, having in its lifetime yielded up no less than 1,800 million tons of high-grade hematite ore. Just how much longer the Mesabi Range and its near neighbors—the Cuyuna and Vermilion Ranges in Minnesota, the Gogebic Range in Wisconsin and the Marquette and Menominee Ranges in northwestern Michigan—can go on disgorging such riches is a question that is much easier to ask than to answer.

The answers of geologists and mining men vary with the assumptions made as to the probable total reserves and the tonnages needed annually. There is, however, a growing body of belief that at existing rates of removal the high-grade Mesabi ores will be exhausted in a matter of years. In 1946 the Minnesota Tax Commission estimated that the remaining reserves of open-pit ore amounted to 575 million long tons. Even if we doubled this figure (and mineral tax commissioners are, it seems, given to understatement), the Mesabi hematites would have only about 20 years to run. This does not mean to say that the Lake Superior region would then be abandoned. In addition to the high-grade hematites, there are vast reserves of lower-grade hematite and taconites in the region. The aggregate iron content of these ores is almost certainly greater than the total shipments of high-grade hematite to date, but their thin concentration poses some weighty metallurgical problems. On these several steel companies and ore-producing companies are still working; so far the results, while technically encouraging, are not exciting commercially. Notwithstanding this, one reduction plant at Babbitt, Minn., has already begun to produce pig iron from taconite on a substantial scale. Beginning with an output of 300,000 tons in 1951, it expects to reach five million tons a year by 1955. And plans for a second plant are well advanced.

What are the production prospects in the other main ore-bearing areas of this country? The Alabama field, it is estimated, can continue to yield good-grade hematites at the existing rates for many years to come—perhaps 200. There are other localities in the same Appalachian system, stretching as far north as New York State, where sizable ore deposits of similar grade (but different chemical constitution) can be drawn upon to boost the national output. In the past few months aeromagnetic surveys have been carried out by the U. S. Geological Survey in the New Jersey Highlands with distinctly promising results. In the West similar explorations are under way from Texas to Wyoming and from Missouri to California. In addition many fields that had been abandoned are now being cajoled into producing more than ever before, to meet the compelling needs of our defense mobilization program. But the truth of the matter—and it is grievous—is that none of these fields is a Mesabi. They may carry us along at the present rate of exploitation for a generation or longer, but what is an output of five million tons (the total present ore production of the whole region west of the Mississippi) in an economy which already demands 20-fold and will soon demand 30-fold?

What the U. S. needs in the direst

kind of way is another Mesabi. Unfortunately the prospects of finding one within the confines of the 48 states are negligible. The iron-mining geologists have been looking too long.

Northward

However, north of the 49th parallel the prospects are brighter. Indeed, there are two very promising deposits right on Mesabi's doorstep. The open-pit Steep Rock mines located 140 miles west of Port Arthur and the Helen Mine near Michipicoten at the northeastern extremity of Lake Superior are already producing about three million tons a year between them and could comfortably produce 10 times as much, according to the latest reports coming from the Dominion. Cyrus Eaton, chairman of the Steep Rock Board, recently said that the reserves in that area alone exceed a billion tons, or more than "those of any other range, old or new, on the continent."

Of scarcely less promise is the Labrador-northern Quebec region. Here in the sub-Arctic bush are two major deposits. One of them, located at a place called Burnt Creek which as yet is little more than a name on a very empty map, is known to have at least 400 million tons of hematite analyzing at approximately 65 per cent iron. The other, situated at Leaf Lake near the shores of Ungava Bay, may prove to be even larger. A railroad is already under construction from Seven Islands on the north shore of the lower St. Lawrence to Burnt Creek, 360 miles inland. It is expected to be moving ore at the rate of 10 million tons per annum by 1955. The Leaf Lake deposit, though farther north, has a potential advantage over its neighbor in that it is only 80 to 90 miles from a promising dock site on the Koksoak River. Here, so it is said, ocean-going ore freighters could load their cargoes for direct shipment to U. S. blast furnaces, at least during the short navigation season.

And ore prospecting in northern Canada has barely begun. With the Pre-Cambrian shield, in which all these deposits are located, occupying approximately two million square miles, iron-seeking geologists have better reasons than most of their kin for their prevailing cheerfulness. But the shield is not without its problems. Indeed, few parts of the world present the mining company with bigger problems—physical or economic. Northern Canada is forbidding country. For eight months in the year it is covered with snow; it is chilly the other four. Much of the surface is as naked as the day it was delivered from the womb of the retreating icecap. All food will need to be brought in from outside, either by airplane or by a combination of sea, rail and road traffic. Living expenses will therefore be much higher than they are, let us say, in the Mesabi region. Power likewise promises to be expensive. There are, it is true, more rivers, lakes and falls than anybody can count, but they are frozen over for almost two thirds of the year. It is difficult to see how labor can be attracted to so desolate a region (Jacques Cartier called it "the land God gave to Cain") without large monetary inducements. Furthermore, the bulk of the labor force must be migratory, since the open season for mining in northern Quebec promises to be considerably less than six months long, and the winter a period of enforced hibernation.

At the same time it must be remembered that many of the same problems have been faced and solved in the Mackenzie Valley Yellowknife mining region of Northwest Canada, which is still farther north and has an even more rigorous regime. Yet gold mining is a different proposition from iron mining, and so far not even its most ardent boosters have suggested that the Quebec ore is worth its weight in gold! Until the economic feasibility of working these northern ores has been proved, many American steel companies are reserving judgment and concentrating attention instead on the newly discovered fields in more southerly latitudes.

Southward

As long ago as 1915 the Bethlehem Steel Company was mining iron ore in Chile. More recently it has started to develop another source in Cuba. At the moment, however, the greatest interest is concentrated on the iron ranges flanking the southern banks of the Orinoco River in Venezuela. El Pao, some 250 miles upriver from the sea, is the focus of special attention, for its knob of jagged rock, a landmark for miles around, is said to be good for nearly a billion tons of ore. At the end of a nine-year construction job, which included the building of roads, railways, freights and two brand-new ports, ore shipments are now being made regularly from this former wilderness to the Bethlehem Steel works at Sparrows Point, Md., 2,300 miles away. The present rate, 125,000 tons a month, is expected to be stepped up sharply in the course of a year or so.

Meanwhile the United States Steel Corporation has even more ambitious plans for the development of a deposit at Cerro Bolívar, 80 miles upstream from El Pao. This range was discovered in 1948 after one of the most intensive "triphibious" operations ever undertaken, involving land, water and air craft. So far exploration of the range has revealed more than half a billion tons of high-grade ore, and it promises a great deal more. In fact, some geologists are already claiming Cerro Bolívar as the biggest single deposit in the continent, if not in the world. Be that as it may, there can be no denying that this peak, rising 2,000 feet from the surrounding savanna-covered lowlands, is literally an iron mountain. Once U. S. Steel has settled the development terms and royalty rates with the Venezuelan Government (which is much more iron-conscious today than it was in 1933 when Bethlehem started negotiations), it will not be long before the first boatloads of ore start moving northward toward the Fairless Steel plant now going up along the shore of the Delaware River 15 miles northeast of Philadelphia. By 1960 annual shipments of Venezuelan ore to this site are expected to exceed 25 million tons.

Where two steel corporations are gathered together, there is a good chance that more are in the offing. And so it is in Venezuela: pretty well the entire southeastern part of the country is currently being scoured for iron. The Republic Steel Corporation and the M. A. Hanna Corporation have already taken up joint options on an area near El Pao and Cerro Bolívar. Nor is the search limited to Venezuela; it is being diligently pursued in other South American republics, notably in Brazil, vast areas of which are underlain by most promising iron-bearing formations. Near the headwaters of the Rio Doce in eastern Brazil the Volta Redonda field is already producing ore beyond the local smelting capacity. A growing surplus is being shipped down to the coast port of Vitória for overseas shipment.

These rich tropical finds are not without drawbacks. Admittedly it is no more expensive to ship ore from El Pao to Sparrows Point than it is from the Mesabi to Pittsburgh, for transportation by ocean-going boat is approximately 10 times as cheap as it is by rail. The chief problem is the same as it is in northern Quebec—climate. In South America it is a matter of too much rather than too little. There is too much heat, too much humidity and too much monotony for the good of the worker's health and temper. The prevailing mood in the Venezuelan fields is that "it's slow death, but we survive."

That things will be made more tolerable nobody doubts. The Bethlehem Company has already done a mighty work in the land, the significance of which is certainly not lost on the native Venezuelan, whose children now eat regularly and well, enjoy excellent free medical care and play "beisbol." Imported U. S. workers, habituated to such cultural perquisites, are less impressed and long for the lights of Broadway. Then again, labor costs, food costs and living costs generally are very high—as high as they are in northern Canada, and for some not dissimilar reasons. Apart from bananas and a few other tropical foods, almost all supplies have to be brought in from outside, many of them from the U. S. The same is true of housing materials, clothing and the other paraphernalia of modern American life.

All the key positions in the Venezuelan fields, and many of the lesser ones, are occupied by Americans and Europeans. Their salary scales are higher than those prevailing in temperate regions. Even so, the "casualty" rate is serious, with boredom taking a higher toll than ill-health. It is true that Venezuela, unlike northern Canada, has an ample reservoir of unskilled labor available at rates seemingly favorable to low-cost operations, but when considered from the standpoint of man-hour output, these rates begin to look high enough.

The Old World

Where else may America look for supplementary supplies of iron ore? Clearly little or none will be forthcoming from Europe. The main producing fields of France, Luxembourg, Sweden, Great Britain and Spain, though together capable of impressive production figures, have their work cut out at the present time to meet the demands put upon them by civil and military contractors. As it is, Great Britain has to import between six and seven million tons of ore to maintain an annual steel production of roughly 16 million tons. For very different reasons the massive deposits of the U.S.S.R., said by many competent geologists to be of the same order of magnitude as those of the U. S., lie outside our present reckoning. So, too, do the deposits of India, whose per capita consumption of steel (12 pounds) is one of the world's lowest—an invidious distinction which India's industrialists are striving manfully to remove. Nor is any other country in free Asia likely to be able to feed American blast furnaces within the discernible future. Significant deposits of high-grade ore are scarce in that part of the world. Indonesia, Malaya and the Philippines appear to be better off than their neighbors, but so far none has turned up a Burnt Creek or Cerro Bolívar. Australia has two major fields, but these barely take care of the rapidly growing domestic market.

We are left, then, with Africa—a continent whose iron-bearing possibilities are only now coming fully to light. It is true that the iron-ore deposits of the Barbary States (Morocco, Algeria and Tunisia) have been worked for many years, mainly for export to Great Britain, and it is equally true that the end of their accessible supplies is not yet in sight. However, it is Africa south of the Sahara that is now attracting most attention. In tropical Africa the latest estimates of iron-ore potential are equaled only by the optimism that they have inspired. Piecing together the still far from

BARGES carrying iron ore from Bethlehem Steel's Venezuela workings are unloaded at Puerto de Hierro. The ore is moved to ocean-going carriers.

ORE CARRIER of the Republic Steel Corporation which has brought a cargo from the Bomi Hills of Liberia is unloaded by conveyor at Baltimore.

complete reports, it is clear that in four small areas alone there is enough good-quality ore not only to take care of all conceivable needs of Africa for generations to come but also to provide a handsome export surplus.

These areas are located near Lusaka in Northern Rhodesia, near Que Que in Southern Rhodesia, in the Bomi Hills of Liberia and in the Elgon-Tororo district of Kenya. The most significant of these from the U. S. standpoint is the Liberian field. The Bomi Hills ore, with an iron content averaging almost 70 per cent (compared with 50 to 55 per cent for Mesabi ore), is said to be second to none in the world in quality. To transport this ore from the Hills to the newly improved port of Monrovia, 45 miles away, a railroad has been built through high tropical bush which until 1950 was penetrated only by narrow native trails. To ship the ore to the East Coast ports of the U. S. the Liberia Mining Company has built a fleet of four carriers, each capable of hauling 22,000 tons of ore and speedy enough to make the 9,000-mile round trip within a couple of weeks. The first shipments of Liberian ore reached this country during the past summer; before long the company expects to be exporting something more than two million tons annually.

The development of the Rhodesian ores is likewise under way. Here the initiative is in British hands, but the deposits are so large that they could well become of international importance. Nobody has yet put a ceiling on their size; even if we cast aside the more astronomical estimates, there is no "peanuts nonsense" about it. If there were, it is difficult to see why the British should currently be allocating millions of pounds from their very tight budget for the building of blast furnaces in Southern Rhodesia capable of processing more than a million tons of iron ore annually. Already there is talk of shipping surplus ore to this country by way of the Port of Beira in Mozambique.

The Alloying Metals

As we saw earlier, the manufacture of steel calls for ferro-alloys as well as iron ore. Those most commonly employed are manganese, vanadium, nickel, molybdenum, cobalt, chromium, tungsten and titanium. Without these the production of high-speed tools, engine parts, guns and other equipment subject to intense heat would be impossible. The same is true of automobiles, which commonly contain no fewer than 80 different alloy steels. So important are these alloys nowadays that their supply has become a matter of almost as much concern to the steelmaker as the supply of iron ore. Yet because the quantities involved in a given metallurgical operation are small, their importance is frequently overlooked by the layman. Cobalt steel, for instance, commonly contains only about one half of one per cent of cobalt.

While the U. S. has always had more than enough iron ore, it is not as well-placed for ferro-alloys. Molybdenum, titanium and vanadium offer no great difficulty; in recent years the U. S. has been producing about 90 per cent of the world's output of the first, and half of the second and third. But the cases of tungsten, chromium, manganese, cobalt and nickel are very different.

Our imports of tungsten currently exceed our domestic output by two to one, and our reserves of high-grade tungsten ore are unlikely to last more than a generation at the existing rate of depletion. The chromium situation is still worse. Even during World War II, when every effort was made to exploit domestic supplies, our production of chromite failed to reach even 20 per cent of our consumption. The rest of the ore came from the U.S.S.R., the world's largest producer at that time (its present standing is unknown), Cuba, the Union of South Africa, Turkey, Southern Rhodesia and a number of other countries. Since the war the U. S. output has declined sharply. In 1948, the last year for which full statistics are available, more than 99 per cent of our chromite consumption was imported, with the U.S.S.R. still the largest supplier.

The position in regard to manganese is little or no better. In recent years the U. S. production of manganese ore has amounted to 120,000 tons, about four per cent of the world total. Our annual imports over the same period have averaged more than 1.5 million tons. Even so, in 1948 the total supply of metallurgical ore available to us was inadequate to meet our industrial demands. The fact that 34 per cent of the imports in that year came from the U.S.S.R. is not calculated to allay the anxieties of those in charge of the fast-diminishing national stockpile. Brazil, Mexico and Cuba can supply some manganese, but their aggregate output is only 220,000 tons.

As for cobalt, in good years we produce rather more than 10 per cent of our needs; in poor years—and they are mostly poor—not more than five to six per cent. Mitigating the strategic weakness of this particular situation is the fact that our northern neighbor, Canada, is the second largest producer of cobalt in the world, and her known reserves are sufficient to maintain the present annual rate of 700 tons for at least half a century. The leader by a big margin is the Belgian Congo, with an average annual output of roughly 4,000 tons.

Without question the weakest link in our metallurgical chain is nickel—a fact that may surprise those of us who think of nickel as something as common and of as little worth as a five-cent piece. The truth is that this country has long had difficulty in raising even one per cent of its nickel requirements. But the position is not quite as parlous as this figure suggests, for Canada produces about 80 per cent of the world supply of the metal. The nickel-copper deposits of the Sudbury region of northern Ontario have been worked continuously for some 70 years and are probably good for as many more. Other significant producers are the U.S.S.R., which undoubtedly ranks second (though precise figures are unavailable), and New Caledonia.

Yet by and large the steel industry in this country has more cause for congratulation than concern. It probably stands in less jeopardy of domestic decay or external blockade than any other major industry. It can call upon a coal supply that is good for many hundreds of years, and upon virtually inexhaustible stores of fluxing stone and water. Its high-grade ore reserves are by no means exhausted, and its low-grade ores, such as the taconites of the Mesabi Range, are only now being put to productive use. The same is true of the new iron fields opening up in the American lands to the north and south of us. The industry may have to look beyond the Americas for supplies of scarce ferro-alloys, but without exception its deficiencies in such commodities can be made good by friends in the free world.

Geographical Readjustments

All this is not to say that some of the older steel manufacturing centers in the country will not eventually succumb in the fight for survival. Already there are indications that the Pittsburgh-Cleveland-Buffalo triangle is in process of losing its long pre-eminence in metallurgical matters. The massive plants mushrooming along the Eastern Seaboard—at Morrisville, Pa., at Paulsboro, N. J., and at New London, Conn.—are more than a shadow of things to come. No less than 40 per cent of the steelmaking facilities now being constructed are located in this area. At the same time there is nothing in the present situation to suggest that the days of America's metallurgical dominance are numbered. On the contrary, if we take the country as a whole, and keep in mind the vast mineral and fuel supplies to which it is tributary, it is difficult to see how the U. S. steelmaking potential can be matched by any nation or existing association of nations for many years to come. Such a prospect may perhaps be irksome to our less well-placed friends, but it must be downright discomfiting to our enemies!

George H. T. Kimble is Director of the American Geographical Society.

CERRO BOLÍVAR, the Venezuelan mountain of iron ore, here stands behind La Frontiera, another such mountain. U. S. Steel's Orinoco Mining Company plans to build a town in foreground to house mine workers.

SPARROWS POINT PLANT of Bethlehem Steel is already using iron ore from Venezuela. Its blast furnaces are to the left of the buildings in the center. In the foreground are facilities for storing raw materials.

Tree Rings and Sunspots

Concerning the lifework of A. E. Douglass, who applies the regular variation in the growth pattern of conifers to the investigation of solar cycles and human history

by J. H. Rush

THE museum of the University of Arizona at Tucson houses a unique exhibit. Down one side and up the other of a long display case runs a continuous strip photograph. It is a series of pictures of tree cross-sections showing their rings, and every ring is precisely dated with the year it grew. The rings are a continuous record of the annual growth of trees for nearly 2,000 years, from A.D. 11 to the present.

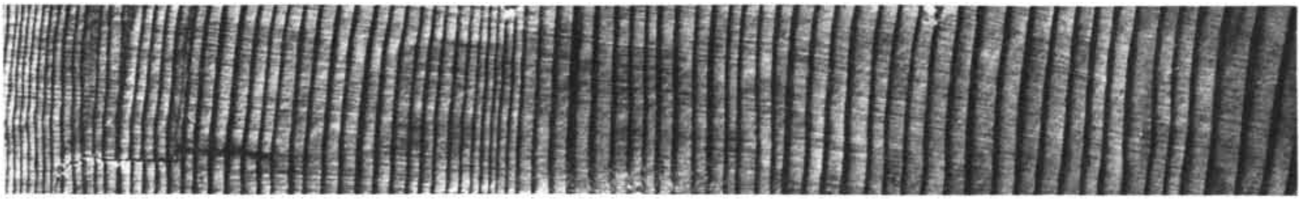
This remarkable exhibit goes back to a day in 1901 when Andrew E. Douglass, then first assistant at the Lowell Observatory in Arizona, was riding through the Arizona pine forest on a buckboard. Astronomer Douglass fell to thinking of the sunspot cycle, of its possible relation to weather and of the great age of the stately trees around him. It occurred to him that in this arid region, where plant growth depends crucially upon rainfall, the sunspot cycle might be reflected systematically in the growth rings of the trees. If so, then cross-sections of old trees might provide an index to solar variations for several centuries past. This idea led Douglass to undertake in 1904 what has become a classic investigation, involving elements of astronomy, meteorology, botany and archaeology.

He began by analyzing cross-sections from 19 selected ponderosa pine trees near Flagstaff. The average age of the trees was 348 years, according to counts of their rings. When Douglass measured the width of the rings, he was able to identify certain sequences, or cycles, of wide and narrow rings. Furthermore, he was elated to find that these sequences matched in different trees; that is, the ring grown in a particular year in one tree could be matched with a ring grown the same year in another tree of the group, so that a period of time could be cross-identified in the two trees. Douglass compared these ring sequences with rainfall records at Flagstaff, and he found that the relative thicknesses of the annual rings faithfully reflected variations in the moisture supply from year to year. A broad white ring of wood laid on in a wet growing season might be followed by a hardly perceptible growth layer in a year of drought. The absolute widths of rings varied widely from tree to tree, and even at various locations in the same tree, but the relative widths of rings in any consecutive short sequence followed the rainfall curve. After analyzing the Flagstaff trees, Douglass got some specimens from Prescott, 70 miles away, and he was able to cross-identify these with the group at Flagstaff. Thus he established the feasibility of constructing a climatic record from tree rings.

In 1906 Douglass was appointed professor of physics and astronomy at the University of Arizona, and he continued his tree-ring studies with improved techniques and facilities there. By 1915 he had analyzed and cross-identified hemlock sections from Vermont, Douglas fir from Oregon, pine and spruce from Britain, Norway, Sweden and Germany. Most of the tree-ring sequences correlated well with sunspot cycles. In these groups of trees the remarkable fact was that the correlation of tree growth with sunspots was strong even though rainfall usually showed no such correlation. Apparently in these areas of abundant moisture, where the annual growth of trees was not so sensitive to variations in rainfall, tree growth still followed the rhythm of the sunspot cycle.

DOUGLASS' task was tedious, slow and riddled with pitfalls. It was fortunate, as he realized later, that he had begun his work on the great ponderosa pines. Not many species of trees, he discovered, put on their annual growth in clear, continuous rings that can be counted and cross-identified consistently. Some trees, such as the ironwood of the Southwest, are wholly impossible to analyze because of the lack of a regular ring structure. Some others, such as the oak, yield good rings, but old specimens are hard to find. After much exploration Douglass came to the conclusion that the conifers were most suitable for his purposes. They are distributed over great regions and endure widely varied climates, and their rings are exceptionally clear and prominent. Most of his work has been done with the yellow (ponderosa) pine, Scotch pine, hemlock, Douglas fir and sequoia.

The location of a tree also has a bearing on its suitability. Trees that grow in river valleys, basins or coastal regions where soil water is abundant cannot be accurately dated or cross-identified because their rings are too nearly uniform. The Coast redwood, which might otherwise have been a most useful tree for chronological purposes, was regretfully abandoned by Douglass for this reason. He had to get his specimens from hillside slopes or porous soils, where tree growth depends mainly on the water immediately available from rain and snow.



"COMPLACENT" RINGS are from a pine that stood in a locality where there was sufficient water for the tree to grow without marked annual variations. Such rings cannot be used for the reliable cross-dating of trees.

Here the thickness of the growth rings faithfully reflects the variations in precipitation from year to year. Douglass found that an Arizona pine growing on a southerly slope sometimes even has thicker rings on the north side than on the south, evidently because the north side of the tree holds snow longer and intercepts more of the water flowing down the slope.

An uneven growing season can create another pitfall for the analyst. When a tree begins growing in the spring, it lays down a fresh layer of soft white sapwood upon the previous year's growth. Ordinarily this layer continues to thicken throughout the summer, and in the fall, when the growth slows down, it is capped by wood that is hard, compact and reddish brown in color. This brown layer normally marks the end of a growing season and the boundary of an annual ring. But a drought that interrupts the growing season may bring the growth of the sapwood to an unseasonable halt and cause the tree to lay down a hard brown layer in late spring or summer. Then later rains may produce another layer of white wood, to be followed by the normal brown layer in the fall. The result is a double ring that may look like two years' growth. This was very troublesome to Douglass at first, but he learned that the outer boundary of the brown ring marking the end of the season is always sharp and clear-cut, whereas the edge of the midseason brown ring is fuzzy.

Other anomalies are occasionally found. A tree may put on two clearly defined rings in one year for no apparent reason, or fire injury may cause the insertion of a false brown ring. Sometimes a tree that grows in too dry a locality may miss a growing season entirely, so that the next ring it puts on covers an interval of two years with little or no clue to the omission. Usually at least the suspicion of a ring appears somewhere on the circumference, but Douglass remarks that occasionally he has "traced a missing ring entirely around a tree without finding it." In most such cases Douglass can deduce the existence of the missing ring by cross-matching with other trees.

To avoid having to handle full cross-sections of large, heavy trees, Douglass developed a technique of sawing out a pie-shaped triangular strip from the end of a log or top of a stump. To obtain specimens from living trees or from logs in old ruins he uses a tubular borer that cuts out a thin cylindrical core through the ring structure. The triangular strips or borings are glued to wood backings, planed and shaved smooth and oiled to bring out the rings in full detail.

Once the specimens have been prepared, the real work of analysis begins. Douglass first measured ring widths with a steel rule, but these readings were good only to about one-tenth millimeter. He now uses a special plotting micrometer. This instrument consists of a reading microscope which travels on a screw and is coupled to a revolving drum in such a way that the travel of the microscope across an individual ring (*i.e.*, the ring's width) is recorded much magnified as a vertical line on the recording paper on the drum. In establishing cross-identifications the thin rings corresponding to drought years are most significant. They stand out in readily discernible patterns. For this reason it has been found that a most useful device for quickly establishing cross-identifications is a "skeleton plot," which records only the conspicuously thin rings.

DOUGLASS had set out on his study of tree rings primarily to extend the record of sunspot activity back to earlier times. It had long been known that the number of spots on the sun grew and waned in a more or less regular cycle, averaging about 11 years from peak to peak. Regular, reliable records of sunspot activity went back less than 100 years. Douglass found that the tree-ring cycles correlated well with the known sunspot maxima and minima during this period. He also found clear evidence of an 11-year cycle appearing at intervals during most of the 500-year period covered by his tree records. The cycle seemed to break down at times, however, and in the period from about 1650 to 1720 it disappeared entirely.

Douglass turned to the ancient sequoia groves of California. He began in 1915 to collect sequoia specimens for detailed laboratory study. Expeditions to Kings River Canyon, General Grant Grove, Calaveras and other localities yielded a fine collection of sections, many of them over 2,000 years old and several over 3,000. Throughout most of this period they clearly showed the 11-year solar cycle. But again the cycle unaccountably disappeared in the late 17th century.

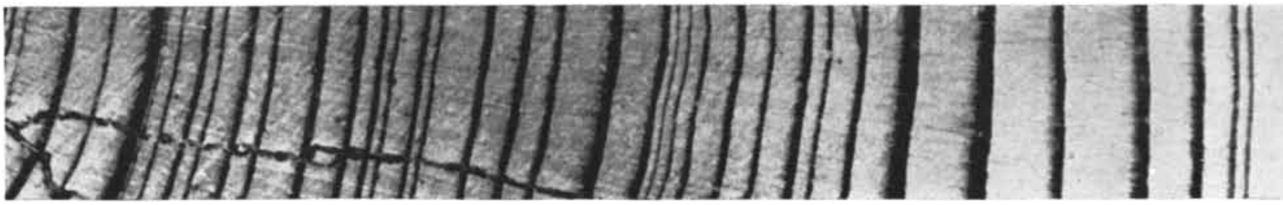
Not until 1922 was the puzzle resolved. In that year Douglass received a remarkable letter from E. W. Maunder, a meteorologist at the Royal Observatory in Greenwich, England. Maunder, who had long been concerned with the problems of solar variation, had looked into the available records and compiled all the known sunspot observations for several centuries back. Knowing nothing of Douglass' difficulty, he wrote to let Douglass know that according to these records there was very little sunspot activity between 1645 and 1715.

The anomalous failure of the 11-year cycle in Douglass' trees during that period was explained! Thus after 18 years of work he could at last feel confident that he had established a reliable correspondence between tree growth and the sunspot cycle.

MEANWHILE Douglass' study of tree rings had led him into a fascinating excursion in archaeology. It began as a result of his search for old specimens. The yellow pine that he was working with in the Southwest was an admirable wood for his purpose, but the living trees did not go back far enough; the oldest was a mere juvenile of 640 years. If the living specimens were too young, why not look among the dead—ancient pine logs or timbers that had somehow been preserved? If such remnants of long-dead trees could be found, their rings might be cross-identified with those of contemporary trees over an overlapping period; still earlier specimens in turn might be cross-identified with them, and so on indefinitely.

In 1916 Douglass had obtained from the American Museum of Natural History several sections of pine logs from prehistoric pueblo ruins near Aztec, N. M., and from Pueblo Bonito, grandest of the ancient pueblos, 50 miles south of Aztec. In 1919 Douglass made a trip to the Aztec ruin and obtained 50 more specimens from house beams with his tubular borer. By 1920 he had developed from this prehistoric material a continuous chronology of about 200 years. He demonstrated that the trees for the Aztec beams had been cut about 50 years later than those from Pueblo Bonito.

Douglass started, therefore, with a "floating" chronology of a 200-year pe-



"SENSITIVE" RINGS are from a Douglas fir that stood in a locality where the water supply varied enough to influence the annual growth of the tree. These rings, which go back to 1084, have been used for cross-dating.

riod of unknown date before A.D. 1300. Soon afterward Neil M. Judd, director of a National Geographic Society expedition that had gone to Pueblo Bonito, sent Douglass 160 more specimens, and these expanded the floating chronology to about 350 years. But Douglass still had to find the missing links that would close the gap between these fragments of early pueblo history and his 600-year-old living trees.

In an effort to find log specimens that would close the time gap, the National Geographic Society in 1923 sent an expedition to some of the most likely Southwestern sites. They visited first the Hopi villages in Arizona. Some of these settlements have been continuously inhabited since before the Spaniards came. But the specimens found there, though useful, did not bridge the gap, and the expedition went on from one to another of those old places of the romantically conglomerate names: to the Black Mesa, to Chinle, Zuñi, Chaco Canyon and the Rio Grande Valley of New Mexico, to the enigmatic cliff dwellings at Mesa Verde, to Wupatki, Canyon de Chelly, Citadel and Solomon. Altogether the expedition brought a hundred new beam specimens to Douglass' laboratory at Tucson.

The work of analyzing and cross-dating proceeded slowly, for Douglass now had many other duties as professor of astronomy and director of the Steward Observatory. But by 1927 the pattern of the pueblo chronology began to take definite shape. Pueblo Bonito, the grandest enigma of them all, was cross-dated with four other ruins besides Aztec. Further, a new "floating" chronology appeared, linking Mesa Verde with several other ruins, but not connected with the chronology of the Pueblo Bonito group. A year later, by means of one good specimen from the great cliff houses of Betátakin which spanned a gap of 40 years, Douglass joined the chronology of the Mesa Verde group to the floating Pueblo Bonito chronology.

That same year, 1928, the National Geographic Society sent a second wood-hunting expedition back to the ancient Hopi town of Oraibi. They collected more than 200 specimens, and these linked up with Douglass' modern pine sequence in the 14th century and extended back to A.D. 1260. In October Douglass dated his first prehistoric ruin. By cross-dating with this extended record he was able to say that the building of the pueblo called Kawaika in Arizona began in the year 1357.

THE floating chronology of the Pueblo Bonito group had now grown to a span of 585 years. Twenty-six large ruins had been cross-dated by means of nearly 500 wood or charcoal specimens from their ancient timbers. But an obstinate gap of unknown duration still lay between this fragment of prehistory and the modern sequence. The modern sequence had been traced back with certainty to 1300. For the preceding 40 years, from 1260 to 1300, Douglass had the single specimen from Betátakin. But no good specimens overlapping the Betátakin period had been found.

Analysis of the Betátakin specimen provided a clue to the reason for the absence of timbers from this period. From 1276 to 1299 one thin ring after another told a terrible story of sustained and unprecedented drought. The effect of such a period upon the pueblo peoples, living always on the edge of disaster, is not hard to imagine. Many villages had to be abandoned, and in the rest further construction of houses was delayed many years.

Before undertaking more field work the National Geographic Society archaeologists studied the pueblo pottery as a means of narrowing the search. Pueblo pottery, they knew, had developed in a distinct sequence, from a black-on-white ware made by the earliest Pueblo Bonito people through several kinds of polychrome to a beautiful cream-colored pottery developed at the Kawaika settlement, whose date was known. The pottery study made it clear that the gap between the floating Pueblo Bonito chronology and the continuous modern sequence was not great, and that it lay in the period of transition from a polychrome pottery to cream. As the result of this study a certain ruin at the little town of Show Low, Ariz., was chosen for the next, and last, expedition.

In 1929 Douglass went with the archaeologists to this site, prepared to make on-the-spot analyses of any material they should find. From several specimens of wood and charcoal they soon succeeded in extending the floating chronology forward a few years into what appeared to be a time of extreme drought. Then the charred end of a timber was uncovered in a dirt pit. It was carefully sawed off and taken to Douglass. He studied it by lamplight that evening with increasing interest and assurance. Finally he remarked: "Well, this looks mighty good. And now I'm going to bed!"

Thus in one climactic evening the gap was closed and the dates of nearly 40 prehistoric communities were fixed. Southwestern archaeology took its place as the most precisely dated archaeology without written records in the world.

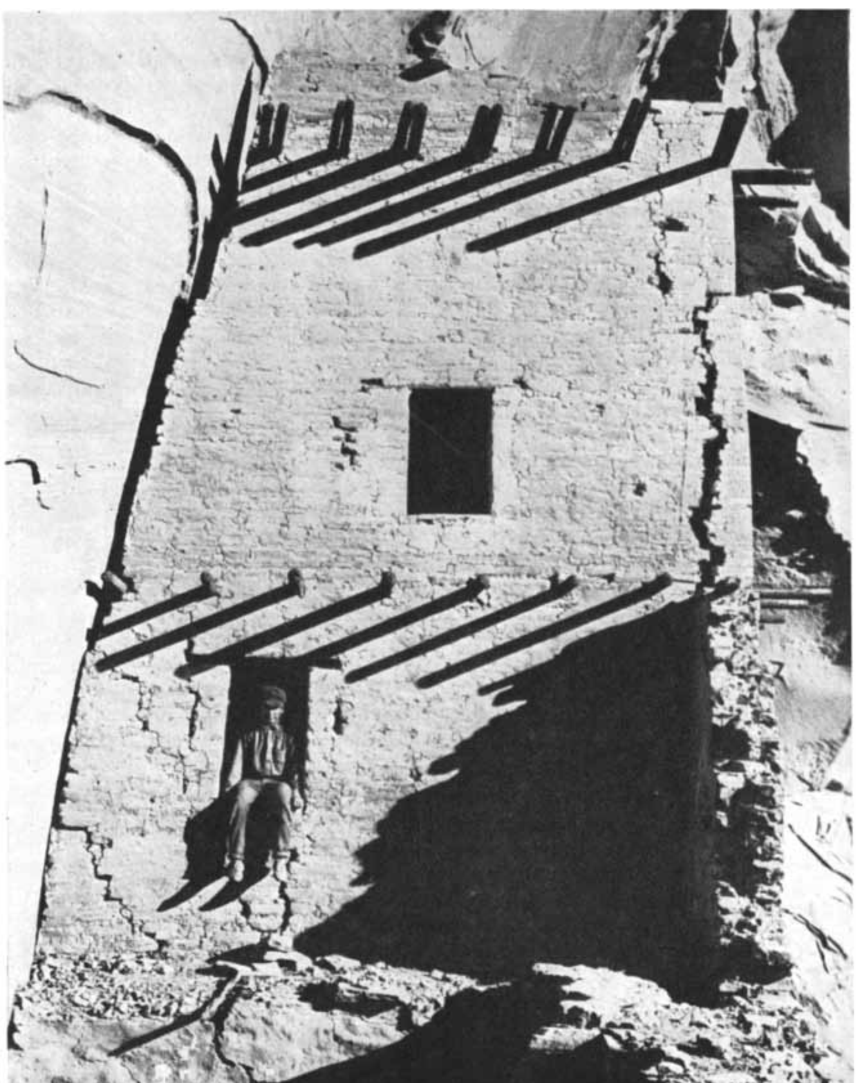
Since that eventful year Douglass has used the same techniques to push the tree-ring calendar of the pueblo region back to A.D. 11. The value of this continuous 1,900-year record is very great. Because in this region the growth response of trees is directly correlated with rainfall, the record gives a rather good picture of the long-run rainfall trends during the period it covers.

Douglass also obtained much older records from a few petrified trees in which the ring structure happened to be preserved. From Yellowstone Park he got 38 specimens of a petrified sequoia of the Tertiary Period, some 50 million years ago. He was able to measure and analyze in them more than 11,000 rings. These very ancient rings gave indications that an 11-year sunspot cycle existed as long ago as 50 million years. Similar results have been obtained on specimens of Pleistocene cypress from a peat bog in Germany.

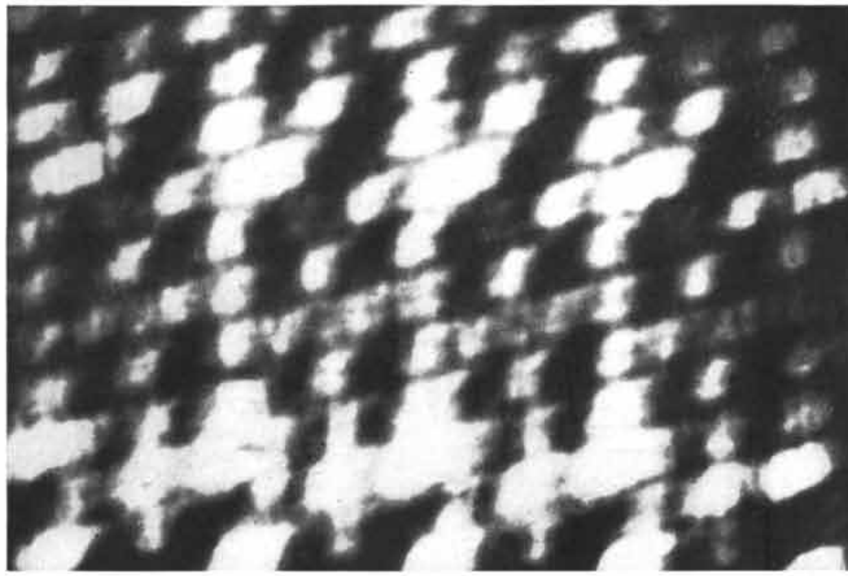
ALTHOUGH his excursion into archaeology was rewarding and intensely interesting, Douglass remained an astronomer, and his prime interest in developing the tree-ring chronology was to extend the sunspot record beyond the history of direct observations. Satisfied that the tree rings truly reflected solar variations, he undertook to analyze these variations in detail.

Douglass distinguishes carefully between indefinitely sustained periodicities, which may be called true cycles, and periodicities that appear only transiently and sporadically, which he calls "cyclics." He had concluded from preliminary studies that the periodic variations in solar activity were cyclics and not persistent cycles; the 11-year sunspot "cycle," for example, was not continuous but disappeared from the record at various periods. To plot the cyclics in a form that would make it possible to analyze them quickly and efficiently Douglass developed a remarkable instrument called the cyclograph. With this instrument he examined the periodicities of sunspot numbers, rainfall, tree growth and the annual clay deposits of glaciers known as varves.

All these phenomena exhibit cyclics of one kind or another, with periods ranging from 5 to 23 years. They are not random statistical effects—they are too persistent for that. But they interrupt and succeed one another unpredictably, and sometimes, particularly in the tree



TOWER IN MUMMY CAVE shows how beams are preserved in some Southwestern ruins. The comparison of beam rings has dated ruins back to A.D. 11.



CYCLOGRAPH is an optical method developed by Douglass to amplify the periodicity of variations in tree rings and similar natural phenomena. The cyclogram above shows two cycles in the rings of the sequoia. The two brighter areas on a vertical line running from the top to the bottom represent two crests in the Hellman cycle (*see text*). The same two areas on a diagonal line running from lower left to upper right represent two crests on a 14-year cycle.

records, two or more may persist simultaneously. Douglass has long recognized the complexity of his task, and has ventured few generalizations. He notes several intimations of order, however. In the records of sunspot numbers, recent trees, historically ancient buried trees and petrified trees of the Tertiary Period, cyclics with periods of about 8, 10, 11.5 and 14 years appear consistently. The 11.5-year cyclic is of course the familiar sunspot "cycle." This cycle has appeared rather regularly since about 1830, but before that date, according to the available records of direct observations, other periodicities were dominant at various times, and for a half-century in the late 1600s, as we have seen, no cyclic maxima were observed at all.

One of the complications, for example, is the so-called "Hellman cycle." Douglass found in trees from northern Europe what he took to be a two-crested sunspot cycle, one crest occurring at sunspot maximum and the next near sunspot minimum. Yet this double-crested cycle tended toward a period of more nearly 12 years than 11, which seemed puzzling. Then the German investigator G. Hellman and others showed that the two-crested cyclic is independent of the sunspot period, although it is stronger when one of its peaks coincides with a sunspot maximum. This cyclic was found in German rainfall records and is common in the Arizona trees since about 1800. Douglass believes that it is fundamentally related to the sunspot periodicity and is preparing a hypothesis attributing both to a common origin.

Douglass emphasizes that he is still far from his goal of predicting climatic cycles. But he finds some evidence that the pattern of cyclic variations and successions repeats itself about every 275 years. The 11.5-year cyclic, in particular, recurs throughout the sequoia records at some such interval, and persists about a hundred years after each recurrence. This latter point can be checked in the next few decades by direct observation, for the 11.5-year cyclic should now be in process of replacement by some other periodicity.

IN ALL his long, tedious research Douglass has been animated by a dual motive. Intellectual curiosity, the natural wonder of man at the world about him, made him a scientist. But his years of living in the arid Southwest, feeling intimately the rhythm of rain and drought, channeled his interest and gave it a practical bent. He once commented on a Hopi Bean Dance he attended at Oraibi: "As I sat watching the dance, I realized that I was one of three terms in a human series: First, the Indians of a neighboring village, who believe that rain is actually controlled by proper magic performed by their powerful priests; then those before me, who were praying to the more powerful spirits that rule the rain; and, lastly, I myself, who was there to study the rainfall history in pine timbers and learn of the great natural laws which govern the coming of rain. We were all doing exactly the same thing according to our lights."

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STATISTICS

The word usually suggests masses of numerical information, but it also describes that department of mathematics which grapples with the complexity of nature by means of samples

by Warren Weaver

Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write.
—H. G. Wells

THERE are two main forms of logical thinking—deduction and induction. For the former we are chiefly indebted to the Greeks, who first saw clearly revealed the great power of announcing general axioms or assumptions and deducing from these a useful array of implied propositions. Inductive thinking, which has been called "the second great stage of intellectual liberation," did not begin to become a systematic tool of man until late in the 18th century. Induction proceeds in the opposite direction from deduction. Starting from the facts of experience, it leads us to infer general conclusions.

Deductive reasoning is definite and absolute. Its specific inferences follow inescapably from the general assumptions. Inductive reasoning, on the other hand, is uncertain inference. The concrete and special facts of experience, from which inductive reasoning begins, generally do not lead inexorably to categorical general conclusions. Rather they lead to judgments concerning the plausibility of various general conclusions.

Francis Bacon was the first properly to emphasize inductive methods as the basis of scientific procedure, but it was not until 1763 that the English clergyman Thomas Bayes gave the first mathematical basis to this branch of logic. To get an idea of what Bayes did, let us look at an admittedly artificial example. Suppose you have a closed box containing a large number of black and white balls. You do not know the proportion of black to white but have reason to think that the odds are two to one that there are about equal numbers of black and white balls. You reach into this box, take out a sample of balls and find that three fourths of the sample are black. Now before taking this sample you tended strongly to think that the unknown mixture was half white, half black. After taking the sample you clearly should change your thinking and begin to lean toward the view that black balls outnumber the white in the box. Bayes worked out a theorem which indicates exactly how opinions held before the experiment should be modified by the evidence of the sample. Though the usefulness of this theorem itself has proved to be very limited, it was the beginning of the whole modern theory of statistics, and thus of a mathematical theory of inductive reasoning.

WHAT'S this, you will say; is statistics something as general and profound as all that? Isn't statistics merely the name for the numerical information with which propagandists try to convince and sometimes even to confuse us?

The word statistics has two somewhat different meanings. In familiar usage, to be sure, statistics does mean simply numerical information, usually arranged in tables or graphs. It is in this sense that we say *The World Almanac* contains a great deal of useful statistics. But more broadly, and more technically, statistics is the name for that science and art which deals with uncertain inference—which uses numbers to find out something about nature and experience.

The importance of inductive reasoning depends on the basic fact that, apart from trivial exceptions, the events and phenomena of nature are too multiform, too numerous, too extensive or too inaccessible to permit complete observation. As the author of *Ecclesiastes* remarked, "No man can find out the work that God maketh from the beginning to the end." We can't measure cosmic rays everywhere and all the time. We can't try a new drug on everybody. We can't test every shell or bomb we manufacture—for one thing, there would then be none to use. So we have to content ourselves with samples. The measurements involved in every scientific experiment constitute a sample of that unlimited set of measurements which would result if one performed the same experiment over and over indefinitely. This total set of potential measurements is referred to as the population. Almost always one is interested in the sample only insofar as it is capable of revealing something about the population from which it came.

The four principal questions to be asked about samples are these: 1) How can one describe the sample usefully and clearly? 2) From the evidence of this sample how does one best infer conclusions concerning the total population? 3) How reliable are these conclusions? 4) How should samples be taken in order that they may be as illuminating and dependable as possible?

Question 1 pretty well covers the subject matter of elementary statistics. Tables, graphs, bar and pie diagrams and the schematic pictorial representations which can be so useful (and sometimes so deceptive) are all ways of summarizing the evidence of a sample. Averages and other related quantities—arithmetical means, medians, modes, geometric means, harmonic means, quartiles, deciles, and so on—are useful for similar purposes; and these also must be used with discretion if they are to be really illuminating. The arithmetical mean income of a certain Princeton class five years after graduation, for example, is not a very useful figure if the class happens to include one man who has an income of half a million dollars.

Descriptive statistics of this sort is concerned with broad and vague questions like "What's going on here?"; and the answers returned are a not unworthy example of "doing one's damndest with one's mind, no holds barred," to use Percy W. Bridgman's phrase. It is only when we pass to Questions 2, 3 and 4, however, that we get to the heart of modern mathematical statistics.

THESE three questions have to do with different aspects of one common problem: namely, how much can one learn, and how reliably, about a population by taking and analyzing a sample from that population? First of all, what sort of knowledge about a population is possible?

Remember that a population, as one

uses the word in statistics, is a collection—usually a large or even infinite collection—of numbers which are measurements of something. It is not possible in the case of an infinite collection, and usually not feasible in other cases, to describe one at a time all the individual measurements that make up the population. So what one does is to lump similar or nearly similar measurements together, describing the population by telling what fraction of all measurements are of this approximate size, what fraction of that size, and so on. This is done by stating in a table, a graph or a formula just what fraction of the whole population of values fall within any stated interval of values. When this is done graphically, the result is a frequency curve, which describes the distribution of measurements in the population in question. The most widely useful population distribution is the so-called normal or Gaussian probability distribution, which takes the form of the familiar bell-shaped curve. A frequency curve can, of course, be described by stating its mathematical equation.

It is frequently useful to give a condensed description of a distribution. If circumstances make it necessary to be content with only two items of information, then one would usually choose the average (which the statistician calls the arithmetical mean) and the variance. The variance is defined as the average of the squares of the differences between all measurements of the population and the mean of the population. It is a very useful measure of the degree of scatter of the measurements, being relatively small when the distribution clusters closely about the mean and relatively large when the distribution is a widely spread-out one. The square root of the variance is called the standard deviation. A small variance always means, of course, a small standard deviation, and *vice versa.*

The statistician's shorthand usually denotes the arithmetical mean by the Greek letter mu, the variance by sigma squared and the standard deviation by sigma. In the special case of normal distributions, a knowledge of the mean, mu, and of the standard deviation, sigma, is sufficient to pick out of all possible normal distributions the specific one in question. Thus the mathematical formula for the normal distribution curve need involve, in addition to the variable, just the two quantities mu and sigma. More complicated distributions may depend upon more than two.

Using the notions just introduced, we can now restate our last three questions:

2) Using the evidence of a sample, what can one say about the population distribution?

3) How can one characterize the reliability of these estimates?

4) How can one select the sample so as to produce the most reliable estimates?

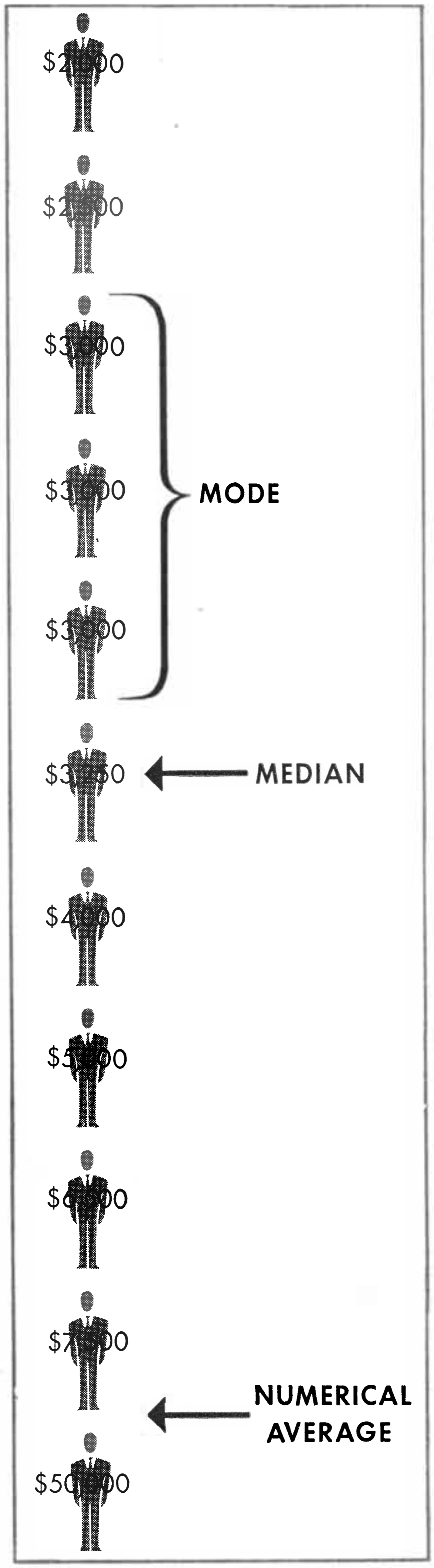
BEFORE going on to indicate the kind of answer modern statistical theory can give to these three questions, it would be well to stop a moment to consider once more, and somewhat more accurately now, the relation between the descriptive statistician who deals only with our original Question 1, and the mathematical statistician who deals with Questions 2, 3 and 4.

In seeking to summarize and describe a sample, the descriptive statistician is in fact trying to shed some light, however dim and indirect, on the nature of the population. Thus he is often trying to give some sort of informal and loose answer to Question 2; and he frequently succeeds in a really useful way. He differs from the mathematical statistician in that he uses only elementary mathematical tools and is therefore unable to give any really precise answers to Question 2 or any answers at all to Questions 3 and 4.

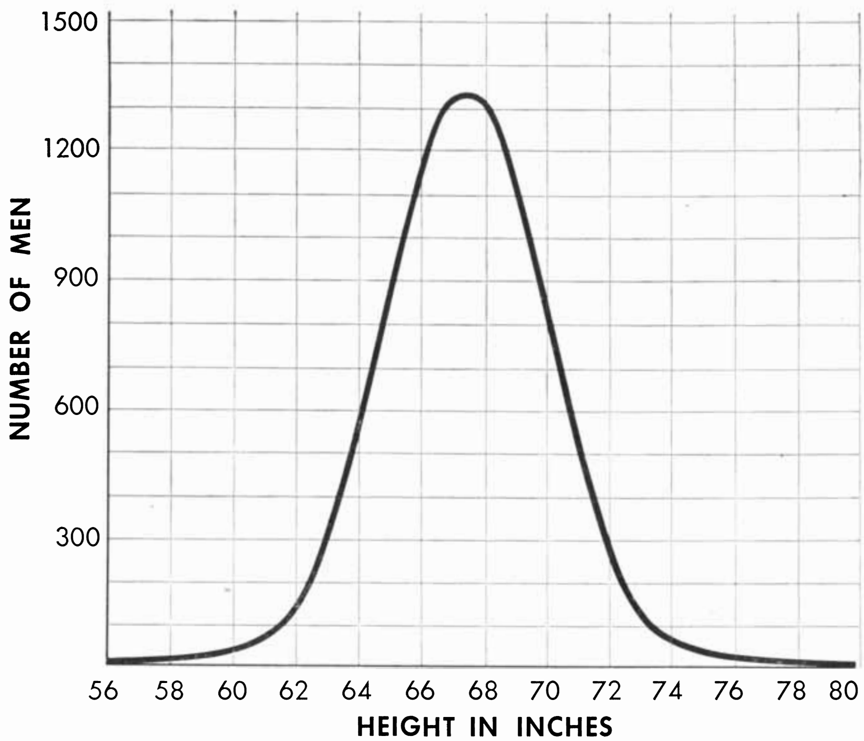
The problem of drawing inferences concerning a population from a sample is a problem in probability. There is an obvious analogy between this procedure and the artificial case of sampling the box of colored balls. It is important to remember that when you take a sample of colored balls out of an unknown mixture, you cannot make simple probability statements about the mixture unless you start out by having some idea about what is in the box. In technical terms, this means that you have to have knowledge, before the drawing of the sample, of the *a priori* probabilities of all possible mixtures that might be in the box. As we have mentioned earlier, Bayes' theorem furnishes a basis for modifying this prior opinion, but it is powerless to originate an opinion.

Bayes' theorem furnishes a sound and simple procedure. But unfortunately it is very seldom applicable to really serious problems of statistical theory, for the good reason that in such situations one seldom has any positive knowledge of the *a priori* probabilities. Consequently it is necessary for statistics to take recourse to more complicated and more subtle theorems.

It is evident that the statistician can never say for certain what the parent population is merely by sampling it, because the samples will vary. If, for example, you draw from a mixture containing 60 per cent white balls and 40 per cent black, you will by no means get this 60-40 ratio of white to black in every sample you take. However, for a given kind of parent population and with suitable methods of sampling it is possible to work out theoretically the pattern of variation for samples. This knowledge of the pattern of sample variability gives the statistician a toe hold. It permits him



ELEVEN SALARIES illustrate how a single number may be used to characterize a set of numbers. The numerical average of the salaries ($8,159) is heavily influenced by one very large salary ($50,000). Hence the average is not as representative of this set of numbers as the median (the salary in the middle) or the mode (the salary that occurs most often).



FREQUENCY DISTRIBUTION OF HEIGHT for 8,585 men is expressed as a normal distribution curve. The actual points from which the curve was derived are not shown, but only a theoretical approximation of them.

to look at samples and draw inferences about the parent population.

The pattern of variation depends not only on the population being sampled; it also depends sensitively upon the method of sampling. If you were interested in family sizes in the U. S. and took your evidence solely from houses with eight rooms or more, obviously the sample pattern would be atypical. When samples are deliberately selected in an atypical way, we call that rigging the evidence. But often samples have quite innocently been taken in an atypical way, as Mr. George Gallup will remember.

It turns out that in general the only good method of sampling is a random method. In a random method the sample is picked in accordance with purely probabilistic criteria, personal choice or prejudice being completely excluded. Suppose television tubes are passing an inspector on a moving belt and it is desired to test on the average one of every six tubes in a random way. The inspector could throw two dice each time a tube passed him and take off the tube for test only when he threw a double number. This, of course, would happen on the average once in six throws of the dice. The tubes thus selected would be a random sample of the whole population of tubes.

NOW we must note an important fact about the pattern of variation of random samples. Suppose you have a parent population which is normally distributed, with a certain mean value and a certain standard deviation. Suppose you take from this population random samples consisting of a certain number of items, n. Compute the mean for each sample. You will find that this new population of means is normally distributed, just as the parent population was. Because an averaging process has entered in, it is more tightly clustered than was the original population. In fact, its standard deviation is found by dividing the standard deviation of the parent population by the square root of n, the number of items in each sample. Thus if the samples each contain 64 items, the standard deviation of the means of these samples will be one eighth of the standard deviation of the parent population.

The fact that samples from a normal population have means which are themselves normally distributed tells us that normally distributed populations have a kind of reproductive character. Their offspring (samples) inherit their most important character (normality). And it is comforting to know further that if large samples are taken from almost any kind of population, their means also have almost normal distributions.

The importance of sample pattern can easily be illustrated by a concrete example in manufacturing. A manufacturer makes large numbers of a part which in one dimension should measure one inch with high accuracy. Random samples of the product are measured. If the samples consistently average more than one inch, he knows there is some systematic error in his manufacturing procedure. But if the mean of the samples is just an inch, and the variations from the mean fall into the pattern of distribution which is theoretically to be expected when the parent population itself is normally distributed about an average of one inch, the manufacturer can conclude that systematic errors have been eliminated, and that his manufacturing process is "under control."

Sampling is not merely convenient; it is often the only possible way to deal with a problem. In the social sciences particularly it opens up fields of inquiry which would otherwise be quite inaccessible. The British Ministry of Labor was able to carry out a most useful study of working-family budgets for the entire nation from detailed figures on the expenditures of only 9,000 families over a period of four weeks. Without sampling such studies would be wholly impracticable.

TO return to our main argument. We are now better prepared to deal with Questions 2 and 3. (We shall omit Question 4, on the design of experiments, because it is a large subject that would make this article far too long.)

Suppose that the mean lifetime of a certain type of electronic tube is known to be 10,000 hours and the standard deviation 800 hours. The engineers now develop a new design of tube. A sample of 64 of the new-type tubes is tested, and the mean life of the 64 tubes in the sample is found to be 10,200 hours—200 hours longer than the mean life of the old population.

Now the new design may actually be no longer-lived than the old. In that case the sample of 64 just happened to be a somewhat better than average sample. Clearly what the engineers want to know is whether the apparent improvement of 200 hours is real or merely due to a chance variation.

The amount of variation one expects from chance can be estimated by comparing the actual deviation with the standard deviation. Since the standard deviation of the means of samples of 64 items is one eighth the standard deviation of the parent population, in this case the standard deviation in the means of such samples would be one eighth of 800, or 100 hours. Hence the apparent improvement of 200 hours in our sample of new-type tubes is twice the standard deviation in the means of such samples.

Probability theory tells the statistician that the odds are 19 to 1 against a difference of this size between the sample and population means occurring merely by chance. He therefore reports: "It seems sensible to conclude that this mildly rare event has not occurred, that on the contrary the sample of 64 in fact came from a new population with a higher mean life. In other words, I conclude that the new design is probably an improvement."

This is one of the common ways of dealing with such a situation. There are various rather complicated and subtle weaknesses in the argument just given, but we need not go into them here. A more satisfactory way of dealing with the same problem would be to apply the modern theory of statistical estimation, which involves the use of so-called confidence intervals and confidence coefficients. Here the statistician proceeds as follows: He says that the sample of 64 tubes comes from a new population which, while assumed normal, has an unknown mean and variance; and he very much wants to know something about the mean of this population, for that information will help him to conclude whether the new design is an improvement.

Now we must remember that statistics deals with uncertain inference. We must not expect the statistician to come to an absolutely firm conclusion. We must expect him always to give a two-part answer to our question. One part of this reply goes: "My best estimate is. . . ." The inescapable other part of his reply is: "The degree of confidence which you are justified in placing in my estimate is. . . ."

Thus we are not surprised that the statistician starts out by choosing a number which he calls a confidence coefficient. He might, for example, choose the confidence coefficient .95. This means that he is about to adopt a course of action which will be right 95 per cent of the time on the average. We therefore know how much confidence we are justified in placing in his results. Having decided on this figure, statistical theory now furnishes him with the width of a so-called confidence interval whose midpoint is the mean of the sample. In our example this interval turns out to be 10,200 plus or minus 195 hours, or from 10,005 to 10,395 hours. The statistician then answers Questions 2 and 3 as follows: "I estimate that the mean of the population of lifetimes of new-design tubes is greater than 10,005 hours and less than 10,395 hours. I can't guarantee that I am correct; but in a long series of such statements I will be right 95 per cent of the time. Since this range is above the mean life of the old tubes, I conclude that the new design is probably an improvement."

If the statistician had originally decided to adopt a procedure that would be correct 99 per cent of the time, his confidence interval would have turned out wider. He could make a less precise statement but make it with greater confidence. Conversely, he could arrange to make a more precise statement with somewhat less confidence.

Finally, let us examine this same question in the still more sophisticated manner that goes under the name "testing of statistical hypotheses." Here one starts by making some sort of guess about the situation, and then goes through a statistical argument to find out whether it is sensible, and how sensible, to discard this guess or retain it.

Thus the statistician might tentatively assume that the new design is equivalent to the old in average tube life. Of course he hopes that this is not true. Although it sounds a little perverse, it is in fact customary to start with a hypothesis that one hopes to disprove.

Here, just as in the previous case, the statistician first picks out a number which is going to tell what confidence we dare have in his statements. Actually he uses something which might be called an "unconfidence coefficient," for it measures the per cent of the time he expects to be wrong, rather than the per cent he expects to be right.

This unconfidence coefficient is technically called the significance level. Let us say that the statistician chooses a significance level of .05, which is exactly equivalent to .95 as a confidence coefficient. Then he calculates the confidence interval for this confidence coefficient. Since we have the same confidence coefficient as before, we already know that this particular confidence interval reaches from 10,005 hours to 10,395 hours. The statistician then reports: "The mean life of the old population (10,000 hours) does not fall within my confidence interval. Therefore theory tells me to discard the assumed hypothesis that the new tube has the same average lifetime as the old. The assumed hypothesis may of course actually be true. But theory further tells me that in cases in which the hypothesis is true, and in which I proceed as I just have done, I will turn out to make mistakes only 5 per cent of the time."

This report, if one thinks it over carefully, is rather incomplete. It says something about the probability of one sort of error—the error of discarding the hypothesis when it is in fact true. But it says nothing about another sort of error—accepting the hypothesis when it is in fact false. In certain situations one of these two mistakes might be very dangerous and costly and the other relatively innocuous. There are available still more refined statistical procedures (called the Neyman-Pearson methods and the theory of decision functions) in which one designs the test so as to make a desirable compromise with respect to the probabilities of the two types of error.

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Animals by Audubon

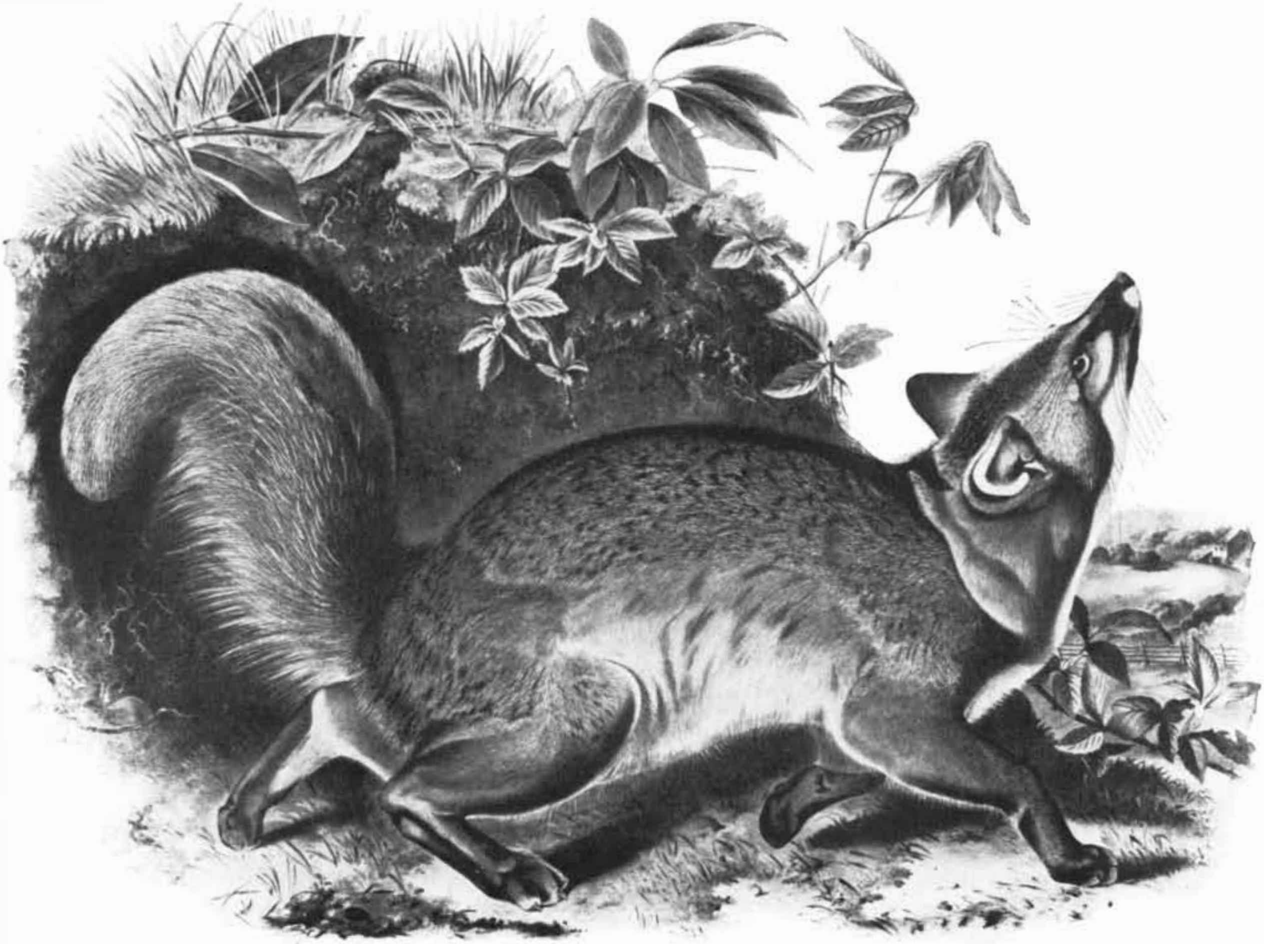
The renowned painter of nature, best remembered for his birds, also drew other animals and published a massive work called "The Viviparous Quadrupeds of North America"

JOHN JAMES AUDUBON, the great 19th-century painter of nature, is remembered for his birds. His monumental work *The Birds of America* first appeared in a full folio edition, then in a smaller edition and has been reprinted in whole or part many times since. But *The Birds of America* was only one of the two principal projects of Audubon's life. He also painted large numbers of animals other than birds, and published a book entitled *The Viviparous Quadrupeds of North America.* Like *The Birds of America* this book was published in several editions in rapid succession. But it was never reprinted until three months ago, when it was brought out as *Audubon's Animals,* edited by Alice Ford and published by Studio Publications, Inc., and the Thomas Y. Crowell Company.

Like his birds, Audubon's animals are painted with a pleasing combination of design and detail. Wherever possible he drew the animal from life. Some animals he kept alive at home; others he obtained from friends or sought on expeditions. His principal excursion for the preparation of *The Viviparous Quadrupeds* was a trip up the Missouri River, on which he was saddened by the plight of the Indians and of the buffalo and revolted when his companions ate raw buffalo brains. Audubon also drew from dead animals that had been shot or trapped. Once he wrote Spencer F. Baird, later secretary of the Smithsonian Institution but then a 15-year-old naturalist: "You have *Bats, Wood Rats, Mice, Weasels,* etc. Could you not save all you come across, place them in *common good rum,* and forward them to me?"

Audubon worked with prodigious speed; it was not unusual for him to do a finished painting in one day of 16 hours. In most of his work on *The Viviparous Quadrupeds* he was assisted by his able sons John Woodhouse and Victor. John Woodhouse painted many of the animals in *The Viviparous Quadrupeds,* and Victor did many of the backgrounds.

Detail of Richardson's Red Squirrel (Tamiasciurus hudsonicus richardsoni)



Gray Fox (Urocyon cinereoargenteus)

Badger (Taxidea taxus)

Father of Aviation Medicine

Paul Bert, a 19th-century physiologist and politician who was a disciple of the great Claude Bernard, laid the foundation for the study of life at high altitudes

by J. M. D. Olmsted

THE branch of science known as aviation medicine, which concerns the human body's behavior at high altitudes, has developed mainly since the arrival of the airplane as a means of transportation after the First World War. But the father of aviation medicine was a 19th-century French physiologist who never saw an airplane. He was Paul Bert, a pupil of the great Claude Bernard. Before and after the Franco-Prussian War of 1870-1871 Bert carried on a number of pioneering investigations of oxygen needs in respiration, and a book he published in 1878, titled *Barometric Pressure,* is still sometimes called the Bible of aviation medicine.

Bert was born October 17, 1833, in Auxerre, the chief city of Burgundy, which lies on the Yonne River some 150 miles south of Paris. His father was a lawyer in good local esteem, and young Paul was trained to follow his father's profession. He was sent to the communal school, then to the *Collège Amyot* and finally to Paris to study law. Paul had no particular urge to be a lawyer, but the family pressure was great and he dutifully finished his law course. From boyhood one of his chief interests had been collecting birds, insects, shells and other biological specimens. While in law school he happened one day to go to a university lecture on zoology by a Professor Gratiolet, who was celebrated for his work on the comparative anatomy of man and the monkey. Bert was fascinated. He promptly registered for Gratiolet's courses and faithfully attended them as well as his law classes.

After he got his law degree in 1857, at the age of 23, Bert continued his study with Gratiolet at the university and received in 1860 the licentiate in natural science. Bernard, the leader of French physiology, happened to be on the committee that examined him for the licentiate. During his examination on respiratory physiology Bert gave so clear and able a defense of his position, even daring to enter into argument with the master himself, that Bernard was greatly impressed. He asked the young man to become his laboratory assistant for the course in experimental medicine he gave at the *Collège de France.* Bert, who had registered in the Faculty of Medicine at the university, first finished that course, obtained his M.D. in 1863 and then joined Bernard in his laboratory, at a stipend of 1,000 francs a year. For two years Bert arrived at the laboratory at eight o'clock each morning and worked with Bernard until midnight.

THE YOUNG physiologist also began some experiments of his own. He started with the grafting of tissues, apparently under the inspiration of reports from India of successful human transplants of skin over lost noses. Bert tried sewing pairs of rats together—side to side, belly to belly, tail to nose, and so on. He even attempted grafts with animals of different species, such as a rat and a guinea pig. It seems that he carried out these experiments in his own bedroom, for he once remarked that the continual cries of guinea pigs made life difficult in a Paris apartment. He tried to graft a rat on a cat, thinking this combination would be less noisy. One of the grafts failed because the kitten lay down on the rat and smothered it. Another was more successful, but the grafted pair unfortunately had to be separated after seven days, because the rat engaged in such contortions that the kitten yowled constantly with discomfort.

In one of his experiments Bert grafted the tip of a rat's tail beneath the skin of its own back, and after the graft had taken root there, he cut off the tail at its base. The tail, now attached by its tip to the middle of the rat's back instead of by its base to the animal's rump, eventually regained its sensitivity to stimulation. Bert thought this proved that sensory nerves could convey sensations in both directions. We now know that he was wrong: although a nerve can convey an impulse in either direction if it is stimulated at some point between its ends, it is impossible to reverse the direction of the whole process of perception of a sensation.

It is said that Bert's studies of grafting helped surgeons to repair the wounds of soldiers mutilated by shells in the War of 1870, and some of his findings and techniques are still in use today. Of particular value for experimental purposes is the method of transplantation called "parabiosis," which he originated. In this type of experiment two individuals, usually of the same species, may be united so that blood circulates from one animal to the other. The two animals can interchange materials, including hormones; when the experimenter removes an endocrine organ from one, the other may supply the missing hormone.

Bert's work on grafts won for him the 1865 prize in experimental physiology of the Paris Academy of Sciences and the doctorate of natural sciences the following year.

He was now 33, and Bernard thought it was about time that his favorite pupil should have a responsible post of his own. He got Bert a professorship of zoology at the University of Bordeaux. The university had no laboratory of its own, but Bert had the use of a nearby marine biological station on the seacoast. Bert began to study the respiration of mollusks and fishes and wrote articles for a medical dictionary on absorption, asphyxia and animal heat. He loved speechmaking, and besides lecturing to his students at the university he often went to give talks to railroad workers on "man as a machine."

IN 1865, at 32, he had married a Scottish girl who was studying French in Auxerre in preparation for teaching. Bernard, whose own marriage turned out unhappily, was present at his pupil's wedding. Bert's marriage was much more successful. No family could have been more sympathetic with the aims of its head than was Bert's. In the eyes of his wife, his two daughters, his aunt and his sisters-in-law Paul Bert was always right. Thanks probably to the fact that he was surrounded by adoring females at home, Bert strongly and actively championed the cause of female education in France. He once wrote:

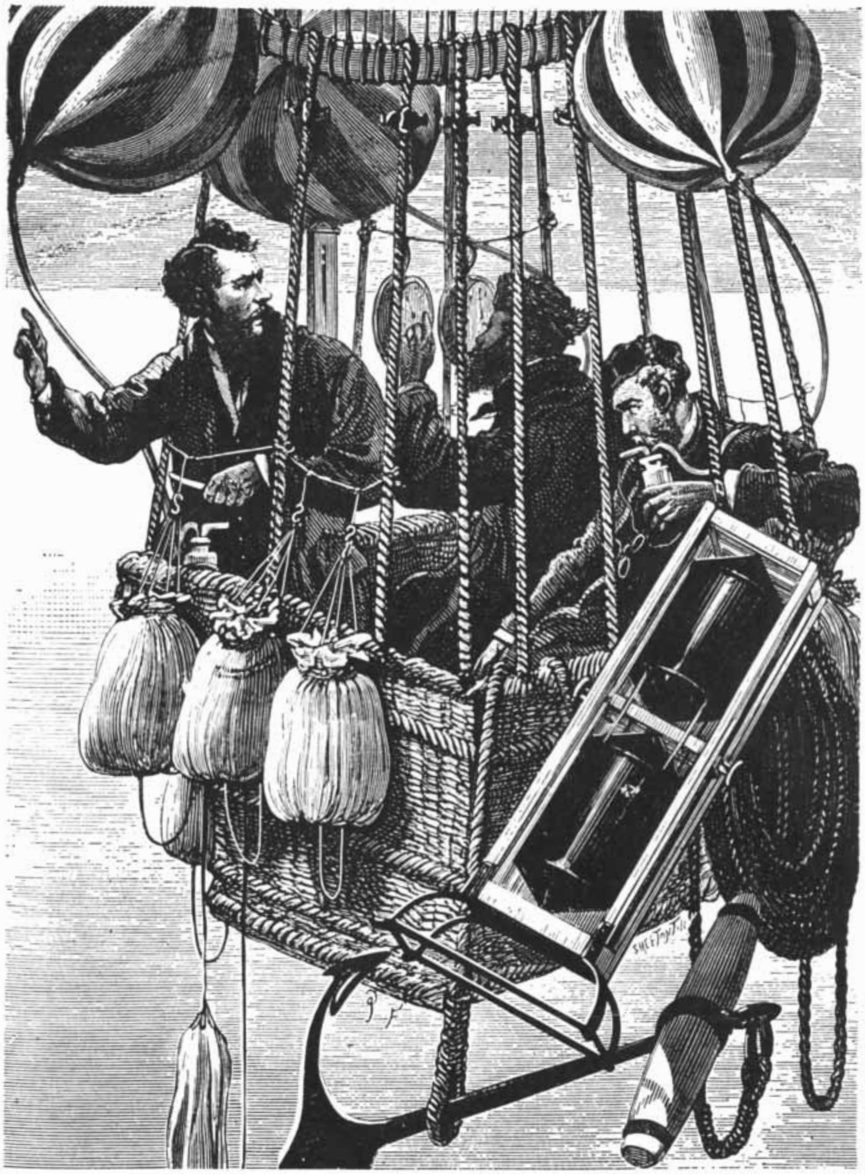
"To instruct women, to confirm their judgment, to discipline their imagination, to open their minds to natural truths is the surest way to throw into shadow their intuitive mystic exaggerations, and is the way to work at one and the same time both for peace in the bosom of the family and for the general progress of society."

Throughout his life Bert was almost as intensely interested in politics as in science. He was an outspoken freethinker in religion, and carried on a lifelong war with the Jesuits. The feud with the Church went back several generations in the family. The house in Auxerre where Paul grew up was a former religious retreat which had been bought from the state by his maternal grandfather just after the French Revolution, when Catholic monasteries and convents were declared national property. Its ownership by Bert's family was still a thorn in the flesh of the local Church dignitaries in Paul's day. During one of his acrimonious battles with the Jesuits in the daily press, a Jesuit priest named Père Chapontin declared that during the Revolution Bert's grandfather had been the official whipper of boys at the *Collège Amyot*, receiving a fee of 12 sous for each whipping he administered. Bert thought some of the statements were scurrilous and sued the priest. He won his case and turned over the damages awarded to him as an endowment for prizes to the school children of Auxerre. About 1880 Bert published a collection of his articles attacking the Jesuits as a book under the sarcastic title, *Jesuit Morality*.

In 1948 I visited the Bert home in Auxerre, still designated by a bronze plaque as "Paul Bert's House." Standing in the very center of the city, it has a rather unimpressive street entrance, but after passing through the gate and down a short lane one finds a tree-sequestered establishment that looks like a charming country château. In the main residence are many relics of Paul Bert, including an oil portrait of him wearing the red academic gown which originally belonged to Bernard. Even more interesting to the historian of science than the main house is Bert's low, two-room studio in the garden. Here he worked in summer; here was his library, consisting mainly of bound volumes of the proceedings of the Paris *Académie des Sciences* and of the *Société de Biologie*. Except for his writing table, which took the fancy of a German officer during the World War II occupation, all of Bert's furnishings are still there just as he left them. On the walls are signed photographs of Bernard and of Léon Gambetta, the celebrated French politician, who represented the other main interest of Bert's life.

AFTER Bert had worked at the University of Bordeaux for a year or so, Bernard decided that he had spent

BERT was born in 1833 and died in 1886. He studied law, and then went into physiology. This drawing was made from a contemporary photograph.



BALLOONISTS OF THE "ZENITH," shown in a contemporary engraving, ascended 26,300 feet to collect data for Bert. They had neglected to consult him about the amount of oxygen they would need, and two of them died.

enough time in the provincial city and should return to Paris. Though no politician, the master is said to have pulled what political wires he could to get the Minister of Public Instruction to give his favorite pupil a good appointment. He had himself named professor at the Museum of Natural History, and gave up his chair at the Sorbonne to create a vacancy for Bert. Although the bishops were solidly against Bert because of his militant anticlericism, Bernard, with the help of Louis Pasteur, succeeded in having Bert placed in the chair he had vacated.

On his appointment to the post in 1868, Bert, a man of terrific energy, entered upon a career of great and varied activity. Besides lecturing on general physiology at the Sorbonne, he lectured at the Museum of Natural History, organized a laboratory at the *Ecole Pratique des Hautes Etudes* and gave courses in natural history to teen-age girls, an undertaking of which he became so fond that he continued the courses for 10 years. Meanwhile he also became more and more deeply involved in politics. At the outbreak of war in 1870 he was made secretary-general of the Préfecture of the Yonne. In 1874 he was elected to the National Assembly and divided his time between his duties as a professor and a deputy. After finishing his lecture at the Sorbonne at 1:30, he would hop into his carriage, which he had waiting outside the lecture hall, and drive to the Gare Montparnasse, where he would take the train for the Assembly sessions at Versailles. In the Assembly Bert campaigned incessantly for the secularization of France's schools, and he finally succeeded in getting the necessary legislation passed. Bert was later to become France's minister of education, when his good friend Gambetta came to power in 1881, and ultimately, a few months before his death, he was appointed minister-general to Annam and governor-general of Tongking, France's newly acquired protectorate in Indo-China.

BUT it was in the field of the physiology of respiration that Bert did his most important work. In his researches at the Sorbonne he became particularly interested in how respiration was affected by changes in barometric pressure. His interest in this subject had been aroused by reports on the anemia and other effects shown by natives living at high altitudes in Mexico, published by a physician named Jourdanet, who for some years had lived in that country.

Bert remarked: "To carry out experiments, it would be necessary to have at one's disposal huge and costly apparatus which we cannot for an instant dream of installing with the resources of our French laboratories." But the physiologist constructed a homemade apparatus which enabled him to administer various mixtures of oxygen and nitrogen at normal atmospheric pressure to experimental dogs and to analyze the dogs' blood for oxygen content. From these experiments he concluded tentatively that "the blood of a man transported suddenly in a balloon will be deprived of oxygen, while the blood of a diver under a bell or of a miner in a compression chamber will contain a certain quantity of it." Bert publicly appealed for money to extend the experiments, asking: "Who will come forward to do for this study of respiration under diminished or augmented pressure what the King of Bavaria did for Pettenkofer, when he supplied the apparatus necessary for the study of the products of normal respiration?" To this cry for help Dr. Jourdanet himself responded, providing funds for construction of a more elaborate apparatus.

Within a year Bert reported to the *Société de Biologie* that he had found that when the pressure of oxygen in the air was reduced to 16 centimeters or less, cats and guinea pigs were asphyxiated. After the interruption of the Franco-Prussian War he went on to construct a chamber for compression and decompression of human subjects. In the intervals when he was not attending the National Assembly or making speeches around the country, Bert and his wife and laboratory assistants experimented on themselves and others in this chamber.

Among the subjects who served as guinea pigs in these experiments were two balloonists, J. E. Crocé-Spinelli and H. T. Sivel. In March, 1874, they made an ascension in a balloon called *The Polar Star* to collect data for Bert. Accompanied by a physician, they rose to

nearly 23,000 feet and came down without mishap. The physician published a medical description of his two companions which reads like a medieval document: "M. Crocé-Spinelli is blond, of a phlegmatic temperament, nervous, ordinarily disposed to bronchitis. M. Sivel is brunette, of sanguine temperament, very vigorous and very little sensitive to aeronautic influences because of the great number of ascensions he has made."

After their first successful ascension for Bert the two balloonists immediately laid plans for another to a higher altitude. They insisted that a friend, Gaston Tissandier, an enthusiastic balloonist who was also a chemist, accompany them on the new venture. Although the president of the *Société de Navigation Aérienne*, sponsor of the ascension, opposed a third passenger, on the ground that his extra weight might prevent their attaining the desired height, the balloonists overruled him.

Bert was not in Paris at the moment; he was probably making a speech in some provincial city. Crocé-Spinelli wrote him a letter informing him of the plans for the ascension in a new balloon named *Zenith*. On receipt of this letter Bert at once realized that the amount of oxygen they were intending to take was not enough for three persons at the height to which they aimed to rise. He immediately wrote back: "At the heights where artificial respiration is necessary, for three men you must count on a consumption of at least 20 liters per minute; you can see how quickly the amount you are proposing to carry will be used up." But this letter with its warning arrived too late.

JUST before noon on April 15, 1874, the *Zenith* floated upward with the three men. Tissandier, who was to be the only survivor, vividly described the ascension later in *Nature*. At 14,000 feet they began to breathe oxygen from their tanks, not, Tissandier said, because they felt the need of it but to see if the oxygen apparatus, designed by Bert and made by a skilled mechanic, was in working order. They rose slowly to 24,500 feet, and the balloon then started down. The three balloonists were feeling the effects of altitude and were having difficulty in coordinating their movements with their thoughts. By this time even their thoughts were none too clear, as their oxygen had begun to give out. Tissandier tried in vain to write sensible notes of what was happening. Sivel, he of the sanguine temperament, vaguely conscious that they had not yet reached the height desired, seized a knife and cut the cords to the sandbags. The balloon thereupon rose to 26,300 feet, as the recording instruments later showed. Almost at once all three passengers lost consciousness.

When Tissandier came to, a little later,

BUSINESS IN MOTION

To our Colleagues in American Business . . .

The Revere Technical Advisors call upon manufacturers from coast to coast, when requested to collaborate on special problems concerning the selection, fabrication or application of copper and copper alloys, and aluminum alloys. The procedure is this: the T.A. sits down with the customer or prospect, and together they study the project put before them by circumstances. It is a close collaboration, a joint effort that frequently results in marked improvement in quality or lessening of costs, or both. Here are some examples:

• Customer staking diamond inserts in free-cutting brass rod reported that the rod was turning color under the diamond, resulting in rejects. The brass was machined with a water-soluble oil, and cleaned with a special preparation. It was discovered that parts machined with sulphur-bearing oils were being cleaned in same container. This was the cause, and the obvious remedy eliminated discolor.

• Plumbing goods manufacturer was puzzled by the fact that brass tube purchased in small grain sizes for good plating qualities was giving both bending and plating troubles. Inspection of the processes of the manufacturer showed that the tube was being annealed with a torch before expansion and plating. This annealing resulted in a large grain size of .250 mm., as shown by a typical sample sent to the Revere Laboratory. Thus the apparent anomaly was explained, and close control of annealing was established to keep grain size within the necessary limits for satisfactory plating.

• An electrical manufacturer was using a very special and expensive copper alloy as a liner for a plunger housing. He felt this extremely hard alloy was necessitated by the large amount of wear on the part. Revere suggested that Herculoy, a silicon bronze, would be worth trying in hard temper. Tests were made, and the Revere alloy was found completely satisfactory. Substitution provides a metal that is more easily available, and at the same time costs less than the original.

• A maker of a timing device was having trouble blanking cleanly a small gear part. Detail was so fine and ratio of tooth height to width so great that leaded brass had a tendency not to form full teeth. A study of this problem brought forth the suggestion that a more ductile metal was needed, namely, ¾ hard cartridge brass. This worked beautifully when tried, and customer is extremely pleased with the tremendous reduction in rejects of this difficult part.

These are just a few of a number of cases that went into the "closed" file during a single month. Almost every other supplier to industry today does much the same sort of work with his customers. He feels it is not only a fine way to build good will, but also a part of his obligation to the customers who have helped him grow. It is a fact, of course, that every dollar you pay, whether for chemicals or metals, glass, cements, papers, carries a small charge for the research and know-how and skill required to make fine products. Your suppliers have knowledge you have helped pay for — why not use it as well as their materials? The results may be as pleasing as those in the four instances just cited.

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the balloon was descending at a fearful rate. He cried out to his companions and tried to rouse them. In his report he says, "Sivel's face was black, his eyes dull, his mouth open and filled with blood. Crocé had his eyes half shut, and his mouth was bloody. We were still at 6,000 meters [about 20,000 feet]. Soon the earth approached; I wanted to seize my knife and cut the cord to the anchor; I was like a madman, I continued to call, 'Sivel! Sivel!' By good luck, I got my hand on my knife and cut the anchor rope just in time. The shock of hitting the earth was extremely violent. The balloon seemed to flatten out, and I thought it was going to remain where it was, but the wind was strong and caught it. The anchor would not bite and dragged along over fields; the bodies of my unfortunate friends were shaken here and there, and with every movement I was afraid that they would fall out. Nevertheless I was able to pull the rope of the safety valve, and the balloon soon emptied and wrapped itself around a tree. It was 4 A.M., and when I set foot upon the ground I was overtaken by a feverish over-excitement, became livid and faint. I thought I was going to join my companions in the other world. Nevertheless I came to myself little by little. I approached my two unfortunate companions, and found them stiff and cold. Sobs overcame me."

THE press blamed Bert for the disaster, since the object of the trial had been to obtain data for him. But the following year the *Académie des Sciences* awarded him a prize of 20,000 francs for his barometric pressure studies. The knowledge Bert had obtained from these studies could have saved the balloonists had they consulted him in time. As his monumental 1,100-page work on *Barometric Pressure*, published not long afterward, pointed out, he had proved in his decompression-chamber experiments that the ill effects of high altitudes were not merely a matter of diminished mechanical pressure but of diminished partial pressure of the gases, so that the amount of oxygen was not sufficient to maintain life there. He had demonstrated the fundamental point that if air has a sufficiently high concentration of oxygen, life can be maintained in it even though the mechanical pressure may be reduced to one third of the normal atmospheric pressure at sea level. Had the balloonists taken up more oxygen tanks, or even conserved what they had until they really needed it, or had Sivel not thrown out the ballast for the second rise, all three probably would have lived to tell the tale.

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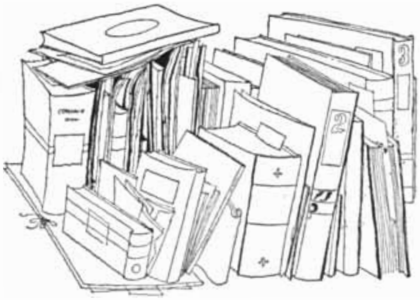


BOOKS

A popular account of how man has studied the meaningful material remains of his past

by James R. Newman

GODS, GRAVES, AND SCHOLARS: THE STORY OF ARCHAEOLOGY, by C. W. Ceram. Alfred A. Knopf ($5.75).

MAN scratches the food and materials he needs from a thin top layer of the earth's crust. In due course the earth reclaims what he has borrowed. Cultures and civilizations vanish, and for all but a tiny fraction of human history no written records exist. Yet another kind of record endures in the form of monuments and ruins and buried tools, weapons, ornaments, pottery, bricks, temples, roads, houses. The excavation of these material remains, their description and interpretation, the reconstruction of forgotten ways and cultures—this constitutes the study of archaeology. It is a study of wide range and rapid growth; not long ago it dealt almost exclusively with classical art and architecture; now it embraces "practically the whole of the history of races and things" from prehistory to the Middle Ages. Closely associated with it are other disciplines such as geology, paleontology, paleobotany, anthropology and ethnology.

What may be called scientific archaeology is scarcely more than 100 years old, but the interest in antiquities is of course much older. Plato and Aristotle conjectured about pre-Grecian history and early peoples; Lucretius made shrewd guesses "at what had actually been the industrial development of early man in Europe"; Herodotus recorded the beginnings of Egyptian society, the culture of the Scythians and of Macedonia; Hesiod seemed aware, *"as a fact,* and not as a matter for speculation," that bronze preceded iron in the history of technology (here I follow Glyn Daniel's reliable survey *A Hundred Years of Archaeology*); Nabonidus, the last King of Babylon, was an enthusiastic antiquarian who went so far as to dig for relics under the pavement of the sacred Temple of Shamash at Sippar. In the 15th century popes, cardinals and others who could afford it began to gather examples of ancient art. Private excavations were conducted and great collections formed. If the treasures were not examined for information they might yield about the past, they were at least prized for their beauty. In 16th-century England a number of persons busied themselves exploring prehistoric sites and recording the location of antiquities; John Leland was appointed King's Antiquary, a post of which he was the first and probably the last incumbent.

The first approach to a systematic evaluation of the already immense accumulation of classical remains was made in the mid-18th century by J. J. Winckelmann, a Prussian cobbler's son. His *History of the Art of Antiquity* was mainly based on what he had learned from Roman materials, from copies of original statues and from crumbling rolls of papyrus. Not a few of its assumptions were unsound and its conclusions were superficial. It was nonetheless a masterpiece, and must be adjudged a landmark of archaeology for having inaugurated the "developmental" point of view in appraising ancient art. It imposed a "provisional order on what before had been outright chaos."

Prehistoric archaeology began in the 19th century with the discovery in several parts of Europe—the caves of Devon, the gravels of the Somme Valley, the Danish bogs—of flint tools associated with the fossils of extinct animals. These discoveries strengthened a hypothesis already put forward by the more irreverent among the learned: namely, that Archbishop Ussher's chronology and the Mosaic version of *Genesis* might not be altogether correct. This branch of archaeology may therefore be regarded as an offspring of the revolution in geology, and in its further development it has become an increasingly valuable handmaiden to related sciences.

Gods, Graves, and Scholars is a popular account of historic archaeology, describing the remains of societies about which written records, sometimes contemporary but invariably fragmentary and often adulterated by legend and myth, have come down to us. The author is a German journalist writing under the pseudonym "Ceram," which I discover is an island in the Dutch East Indies, but perhaps the name is designed to make us think of ceramics. (I must confess that the use of a pseudonym in writing a book of this kind strikes me as curious, if not faintly ridiculous.) Ceram has read widely on archaeology, though evidently favoring the German authorities, and we have the publisher's assurance that the text has been "systematically checked by experts." I have compared it at a number of points with the standard works and have nothing disquieting to report. There are, to be sure, permissible differences of interpretation and emphasis, and specialists may find minor inaccuracies.

Beginning his narrative with Winckelmann's work, Ceram relates the story of the major archaeological excavations and discoveries of the past 150 years in the Near East, Mexico and Central America. It is a chronicle with many exciting interludes. Today archaeological research is in the main a decorous, highly specialized activity which even the timid and short of breath can safely pursue. It was not always so. Archaeology was once a highly competitive game, apt to attract adventurers, soldiers of fortune, charlatans and dilettantes; it had a slightly raffish air. There were those, however, who combined the spirit of the explorer and the scholar. They were hardy men, prepared for every hazard and vicissitude; they were also stubborn, persevering and unmoved by ridicule, so often heaped on them before they succeeded. A folk tale or legend, an obscure Biblical reference, a colorful episode by an ancient historian better known for his imagination than his veracity—these were typical of the clues which beckoned the pioneers of archaeology to hair-raising adventures in search of lost palaces, buried cities, hidden treasures, vanished temples. It was not easy to kindle the same enthusiasm in others; frequently the archaeological explorer had to set out on his expedition alone. His journey through strange lands was often grueling and perilous, his destination vague, his arrival uncertain. Having found the spot where he wanted to dig, he had the task of recruiting help among superstitious natives, of procuring water, of fighting disease. There were the usual camp followers, eager to mislead, to filch supplies, to steal anything valuable that was found, to cut the leader's throat, should circumstance require. Local authorities were inefficient, corrupt and invariably distrustful of foreign busybodies. The excavating itself was a backbreaking job, and frequently it was futile. Yet despite the obstacles and hardships, extraordinary feats were achieved and the perspectives of history immensely enlarged.

Among the great figures was Heinrich Schliemann, a German traveler and businessman who became a practicing archaeologist at the age of 46. His schooling was brief, and his early adult life entirely nonarchaeological. His five-year apprenticeship to a grocer where "he retailed herring, brandy, milk and salt"; his experiences as a cabin boy, clerk and bookkeeper; his phenomenal career as a merchant; his service as a Judge of the St. Petersburg Commercial Court; his visit to North America in 1850 (he was in California at the time it entered the Union and thus, quite accidentally, acquired U. S. citizenship)—none of these activities can be said to have prepared him for a career as an archaeologist. But from boyhood he was driven by a desire to explore the places described by Homer, and he never lost sight of this objective. By an "unusual method of self-teaching" he mastered within two years half a dozen languages, including English, French, Italian and Russian. On a journey to the Near East he learned Latin and Arabic; Greek he made a second mother-tongue by reading and rereading the Greek historians and poets. His costly explorations were financed by the fortune he amassed from various ventures, including a bank he set up in California during the gold rush.

In Schliemann's day little credence was given to the events recited by Homer. The places he described, the chariots, weapons, household articles, ornaments, were thought to be irretrievably lost, if, indeed, they had ever existed. Schliemann, however, believed every word—he was sure that he would find Troy, the palace of Priam, the Scaean Gate, the Temple of Athena. In 1870 he went to Turkey and began to dig at Hissarlik, the site of ancient Troy. He found spears, earrings, vases, household goods. He later found that the hill where he was digging was like a "tremendous onion which he proceeded to dismember layer by layer." Having set out to find the city around which Hector chased Achilles three times—a distance, by Schliemann's reckoning, of nine miles—he discovered the ruins of no fewer than nine buried cities, though which of these was Homeric Troy could not then be definitely established.

The crown of his discoveries was an immense cache of ivory and gold ornaments—diadems, brooches, chains, plates, buttons, bracelets, golden wire and thread—buried for 3,000 years under ashes and stone. These he smuggled out of the country to enrich his own collection. A precedent had been set for this sort of thievery by the Earl of Elgin and Kincardine, who 70 years earlier had stolen 200 cases of invaluable sculpture from the Parthenon and shipped them to London. No doubt Schliemann soothed himself, as did Elgin, with the thought that the liberation of these treasures from the Turks was a boon to scholarship. In the final outcome a small measure of justice was meted out to these distinguished vandals. It had cost Elgin 75,000 pounds to move his marbles to the British Museum, but an ungrateful Parliament voted to reimburse him with less than half that amount. And "Priam's treasure," the finding of which had made Schliemann delirious with joy, was later shown to have belonged to a king antedating Priam by 1,000 years.

Schliemann continued his labors with excavations at Orchomenus, the opening of the royal graves at Mycenae, and the unearthing of the dead city of Tiryns. At Mycenae he mistakenly concluded that he had found the graves of Agamemnon and his followers; at Tiryns and elsewhere his interpretations and dates were "almost without exception erroneous." On occasion his enthusiasm blurred even his eyesight, as for example when he identified as a Mycenaean alabaster vase what turned out to be an ostrich egg. Yet his service to archaeology and history was of the first rank. His discoveries laid the foundation for a reconstruction of early Minoan culture and together with his writings gave an immense impetus to archaeological research. Even his conjectures were valuable: carrying out a plan Schliemann did not live to fulfill, Sir Arthur Evans excavated the magnificent palace at Knossos and explored elsewhere in Crete to make discoveries which substantially widened historians' knowledge of Hellenic antiquity.

I can mention only briefly some of the other archaeological advances and episodes described by Ceram. What is known today about ancient Egypt derives in great part from the ability of scholars to read hieroglyphics. The decipherment of the Rosetta Stone, the key to this skill, was the feat of Jean François Champollion, a child prodigy of languages, who at 12 wrote his first book, a *History of Famous Dogs,* and at 17 was a member of the teaching staff of the lycée in Grenoble. Other investigators, notably Thomas Young, the physicist celebrated for his discovery of interference and other optical phenomena, recognized the demotic inscription on the Rosetta Stone as "alphabetic writing." Young, in fact, deciphered a few of the hieroglyphs and rendered correctly 76 of 221 groups of characters. But Champollion was the first to grasp "the underlying linguistic system" and to make the Egyptian script "readable and teachable." Giovanni Battista Belzoni was one of the oddest of the odd crew of amateurs in the history of Egyptology. Successively a strong man in a London music hall, a student of mechanical engineering, the inventor of a water wheel for use in Egypt and a "collector" of antiquities for the British consul-general in Egypt, Belzoni succeeded during his various plundering expeditions (anything from a scarab to an obelisk was fair game) in discovering a number of tombs in Thebes and in opening the second pyramid of Gizeh. Another of the prodigies who turned to archaeology was Flinders Petrie. He joined to his interest in antiquities a passion for experiment and scientific measurement. His first archaeological research was at Stonehenge, about which he published a book. In 1880 he went to Egypt where, "with some interruptions, [he] dug for forty-six years." He discovered buried towns and trading centers, the Temple of Rameses at Nebesheh, the ancient fort at Kantara, the Temple of Amenophis III; he became the foremost authority on Egyptian ceramics, miniature sculptures and the "most sublime of Egyptian artifacts," the pyramids.

Ceram's account of the Egyptian tomb-robbers, whose intricate tunnels and passageways through the pyramids thwarted the most elaborate traps and safeguards set up by the priests to protect the furniture of departed kings, provides a series of fascinating episodes. Tomb-robbing in the Theban Valley of the Kings was a profession "handed down from father to son in an apparently unbroken line since the thirteenth century." Howard Carter, who unearthed the tomb of Tutankhamen, recounts the story of an entire village in which every able-bodied man was a tomb-robber descended from tomb-robbers.

One learns from these pages that the renowned Egyptian "secrets" of embalming consisted mainly in a messy and meaningless routine. The preservation of Egyptian mummies must be ascribed to the unusually dry climate and the absence of bacteria in the sand and air; the chemical treatment "had about as little preservative effect as the religious and mystical adjurations." The "curse of the Pharaohs," which allegedly disposed of Lord Carnarvon and a number of other persons who either had something to do with the Tutankhamen excavations, knew someone who did or merely were named Carter, had the same firm basis in fact as the art of embalming. A German Egyptologist named Georg Steindorff demonstrated first that those who had died, died of the causes of which men usually die; and second that the Pharaohs themselves, while taking all other precautions against desecrators of their graves, had omitted to inscribe preventive curses on their tombs.

Ceram devotes the third section of his book to the excavations and discoveries in Mesopotamia. Paul Émile Botta, a physician and diplomat, dug at Nineveh and Khorsabad; Austen Henry Layard, a solicitor, at Nimrud, Babylon, Nippur, Kuyunjik and many other sites in Assyria and Babylonia; George Smith, the bank-note engraver and self-taught Assyriologist, found the missing portions of the Gilgamesh Epic that gave the principal version of the Biblical legend of the flood; Major Henry Rawlinson, dangling on a rope 400 feet from the ground, copied from the face of the great cliff of Behistun its Old Persian and Elamite inscriptions, and succeeded later in translating these examples of Babylonian cuneiform; Robert Koldewey, an architect and scholar, found what was probably the terraced Tower of Babel. Through the labors of these and many other explorers much was recaptured of the history of the kingdoms of Assyria, Babylonia and Sumer. Sir Charles Leonard Woolley, another famous archaeologist, aptly epitomized this broadening of knowledge: "We have outgrown the phase when all the arts were traced to Greece, and Greece was thought to have sprung, like Pallas, full-grown from the brain of the Olympian Zeus; we have learnt how that flower of genius drew its sap from Lydians and Hittites, from Phoenicia and Crete, from Babylon and Egypt. But the roots go farther back; behind all these lies Sumer." Elsewhere Woolley tells us that from the "dumb witness of bricks and mortar and the odds and ends of jetsam" more is known today about ordinary life in Egypt in the 14th century B.C. than is known about that of England in the 14th century after Christ.

The remains of pre-Columbian civilization in Central America are among the most remarkable discovered anywhere; this phase of archaeology is discussed in the last section of Ceram's book. John Lloyd Stephens, a lawyer born in New Jersey, is credited with having rediscovered one of the magnificent abandoned Mayan cities, Copán, in the jungles of Honduras. (A good American, he promptly bought the city for $50.) Forty years later an Englishman, A. P. Maudslay, conducted seven expeditions into the jungle, gathering a vast amount of data on the Mayan culture. Since then many others have entered the field of Central American archaeology and have undertaken to reconstruct the history of the Toltecs, Aztecs and Mayas. One of the many questions remaining unanswered is why the great Mayan cities were abandoned. An ingenious explanation by Sylvanus G. Morley rests on the fact that the Mayans, though capable of building fabulous temples and palaces, were almost unbelievably primitive in their agricultural methods, ignorant even of the use of the plow. Thus it came about that when the fields, especially those where maize was grown, were worn out, the Mayans had no alternative to abandoning their cities after a comparatively short stay.

Ceram has "deliberately chosen," as he says, examples of archaeological exploration "richly fraught with romantic adventure." A good deal has been omitted: research and discoveries in China, Turkestan, South America, Africa, and the U. S. Southwest; the everyday habits of men and women in earlier societies as revealed by archaeological research; modern advances in methods of excavation, interpretation and preservation; the study of prehistoric archaeology; the relation between archaeology and its associated disciplines. The author is disposed to a breathless and ornate style, and tends to overdo his climaxes. Certain of his elucidations of difficult feats of decipherment fail to elucidate—a defect which cannot be ascribed entirely to the translation, which occasionally falters. Nonetheless I have no hesitation in recommending what is altogether a most enjoyable and informative book.

THE PAPERS OF THOMAS JEFFERSON: VOL. IV. Julian P. Boyd, Editor; Lyman H. Butterfield and Mina R. Bryan, Associate Editors. Princeton University Press ($10.00). Another valuable installment of this masterly historical project. The period covered is October, 1780, to February, 1781, when the already heavy responsibilities of Jefferson's governorship were further burdened by the problems arising from the invasion of Virginia by General Benedict Arnold. Included in this volume are a great number of routine letters dealing with such matters as inflation, recruitment, prisoner exchange and military supplies. (In Jefferson's attention to, and obvious relish for, the minutest details of his office one is reminded of Winston Churchill.) Also recorded are the plans evolved by Jefferson for the expedition, under the famous George Rogers Clark, against Fort Detroit, and a full account of the events surrounding the British invasion, in regard to which Jefferson's conduct as Governor came into question, and issues were raised (negligence, incompetence and even personal cowardice) that plagued him for the rest of his life.

THE AMERICAN OXFORD ATLAS. Oxford University Press ($10.00). A conspicuously well-designed, intelligently planned atlas of moderate price. It contains 120 pages of maps, each newly drawn and incorporating the latest geographical data. The typography is unusually clear, political boundaries are well delineated, inks and paper are of good quality. The value of the work is enhanced by a 25-page section of maps showing the distribution of populations and economic goods. It also has a comprehensive gazetteer including the names and locations of historic places (*e.g.*, Nineveh) now vanished.

RAND MCNALLY-COSMOPOLITAN WORLD ATLAS. Rand McNally & Company ($12.50). The New Census Edition of this atlas is 40-odd pages longer than its predecessor, published in 1950. Among its added features are six new maps, mainly of areas of timely political interest; 27 pages of new comparative world maps showing the distribution of economic and natural resources, population, climate, religions and languages; several surface-, ocean- and air-transport charts; various population tables. The *Cosmopolitan* maps are clear and serviceable; there are many more of them than in the *Oxford*, and if you are looking for a small American town—a Martinsburg or a Hillsboro, say—you are more likely to find it in this work. On the other hand, the *Oxford* maps are larger; and in the use of color, in typography, and in general elegance of execution, they far surpass their *Cosmopolitan* counterparts.

ENCYCLOPAEDIA BRITANNICA WORLD ATLAS. Encyclopaedia Britannica, Inc. ($25.00). This unabridged work offers an impressive set of maps concerning population, climate, literacy, transportation routes, land and water features, and so on; a section of physical-political maps produced by Rand McNally (the same as those used in the *Cosmopolitan Atlas*), and a large compendium of statistical data covering the various countries and regions of the world. This is an acceptable reference work, undoubtedly comprising a great mass of reliable information; yet it would have been better if the effort expended to make this big book had been concentrated more on the maps themselves. An atlas, after all, should remain an atlas; observe the unhappy evolution of the modern drugstore.

ECOLOGICAL ANIMAL GEOGRAPHY, by Richard Hesse, W. C. Allee and Karl P. Schmidt. John Wiley & Sons, Inc. ($9.50). The second edition—revised, rewritten and expanded—of a fascinating book based on a noted pioneering monograph by the late Mr. Hesse which dealt with the geography of animals and with the "mutual influence of environment and animals upon each other." The authors have added considerably to Hesse's survey and, while this treatise of zoogeography is intended mainly for professional consumption, there is scarcely a chapter that will fail to awaken the interest of the general reader with a taste for zoology.

THE GROWTH OF SCIENTIFIC IDEAS, by W. P. D. Wightman. Yale University Press ($5.00). This is a readable book and an acceptable introduction to the subject. It pretends, however, to be something more than a conventional history of science. Wightman attempts to present the assessment of major scientific problems by the "leading thinkers of each age," to show in the various solutions the "proportion of essential truth to psychological imagery," to exhibit science as a "struggle no less charged with humanistic value than the struggle for political liberty or national expression." In this ambitious endeavor, unfortunately, the author is beyond his depth. He reveals himself as neither a provocative nor a particularly original thinker; in chapter after chapter commonplaces are proffered in the guise of profound new insights.

THE AMATEUR ASTRONOMER

Conducted by Albert G. Ingalls

IT has long been the policy of this department to publish descriptions of two categories of telescopes built by amateurs: simple ones that almost anyone can make, and elaborate ones that all may at least examine, perhaps envy, and hope someday to emulate or excel. As a matter of fact, so many amateurs have first-class equipment and the skills to use it that a fairly large proportion of amateur telescopes do fall in the elaborate class. But it is still true that a small, unpretentious telescope, especially if it is well thought out and built, is as worthy a member of the telescope community as those made by the more fortunately equipped. Probably there are many beautiful little instruments that have never been described in print because of the modesty of their builders. Such will take precedence over merely showy instruments.

The 10-inch reflecting telescope described below falls in both the elegant and excellent categories. It has been described by those familiar with it, neighbors of its builder, as "a first-class, ultra-perfectionist job, better than professional in quality." These are not idle boasts. A professional could not sell enough ultra-perfectionist telescopes to break even; he must make compromises in order to set a price that the average buyer can afford. John S. Stewart of 1007 South Seventh St., St. Charles, Ill., an engineer and amateur telescope maker, was the designer and builder of this instrument, which is chiefly described in Roger Hayward's drawings on pages 81 and 83.

The skeleton tube consists of 16 lengths of tubular steel welded into two zigzag units attached to cast-bronze rings at the ends and to a one-piece, square cast-bronze saddle box at the balancing point. With this design the whole assembly is highly rigid. A section of circular aluminum tube is attached to the upper ring of the skeleton tube and rotated to place the observer's eye in the most convenient position. Two sections of tube are available for this purpose; the shorter is used with an $f/5$ mirror to view faint objects such as nebulae and Milky Way star dust, and the second much longer one goes with an $f/10$ mirror for observing extended objects such as planets. The amount of light collected by the two 10-inch mirrors is the same, but the short-focus mirror concentrates it by reflecting it to a narrower circle, while the long-focus mirror magnifies it more by spreading it over a wider circle, which can be afforded because the planets give more light.

The excellently designed fork is cast in duralumin and has a 14-inch clearance between the tines. The tapered polar-axis shaft attached to it rotates in a plain bronze taper bearing at the top and in a tapered roller end-thrust bearing at the bottom. Pinned on this axis shaft with a taper pin is a hub and web, forming the fixed plate of a clutch. Surrounding this plate at its periphery is a 100-tooth worm gear, free to rotate, like a dog's collar around its neck, when the capstan screw that holds the clutch pressure plate against it is temporarily loosened. For convenience any one of the four screws will lock the clutch, which will also act as a slip clutch if the screw is only moderately tightened. The tube can then be pushed around by hand, yet the clutch will drive when the hand lets go. The right-ascension slip ring can be rotated at any time, being held in position by friction.

The welded channel steel frame of the mounting is attached to a four-foot cube of concrete flush with the ground. A streamlined case covers the telescope's vital organs as high as the fork.

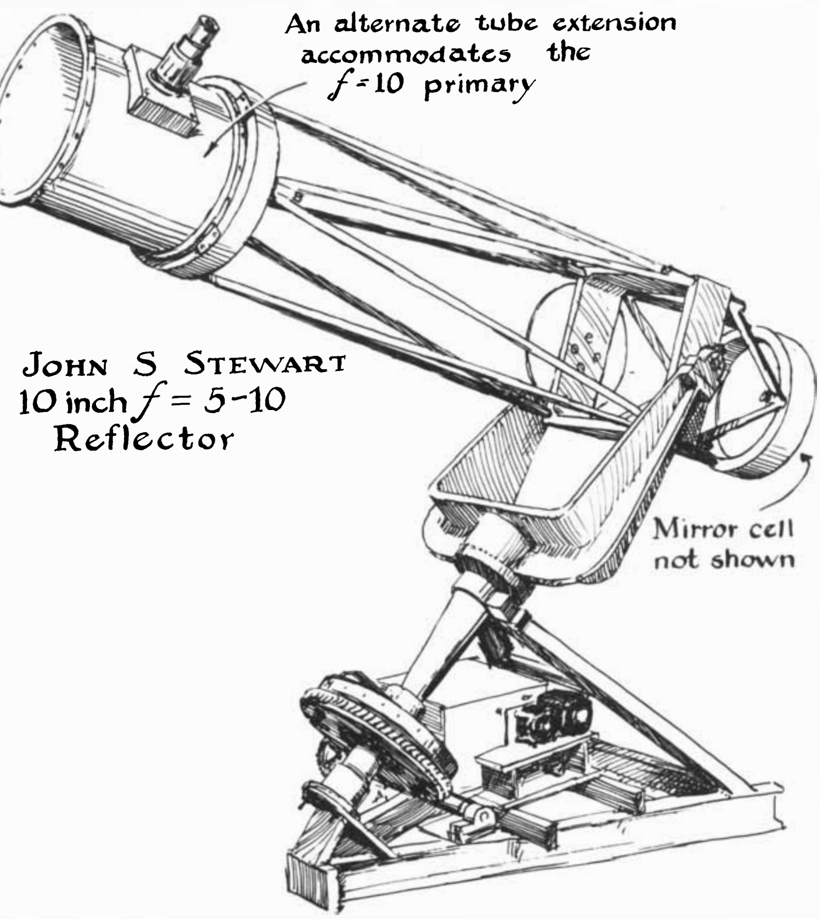
Within the square gearbox, submerged in one gallon of lubricating oil, is the precise mechanism for driving the telescope as the earth turns, so that the observer need not be continually distracted by the necessity of moving it by hand. This drive also permits making celestial photographs with time exposures if desired. Outside of the box are two electric motors, the driving motor and a smaller correction motor. The first is a 1/20 horsepower Bodine motor of the synchronous capacitator type running from power lines at 1,800 revolutions per minute. It turns a 120-tooth worm gear and shaft within the box by means of a flexible coupling. At the nearer end of the same shaft in the drawing (passing for the moment over six gears pertaining to the correction motor's functioning) is a 51-tooth 20-pitch gear. This meshes with a 79-tooth spur gear on a countershaft. The drive next passes outside the gearbox by way of a shaft and worm on a countershaft. This countershaft carries another worm that drives the worm gear on the polar axis. This combination, 51-79-41-98, is the fifth in the list of gear ratios for converting standard to sidereal time given by Alan E. Gee on page 322 of *Amateur Telescope Making—Advanced,* and it leaves a driving error of only .02-second per day.

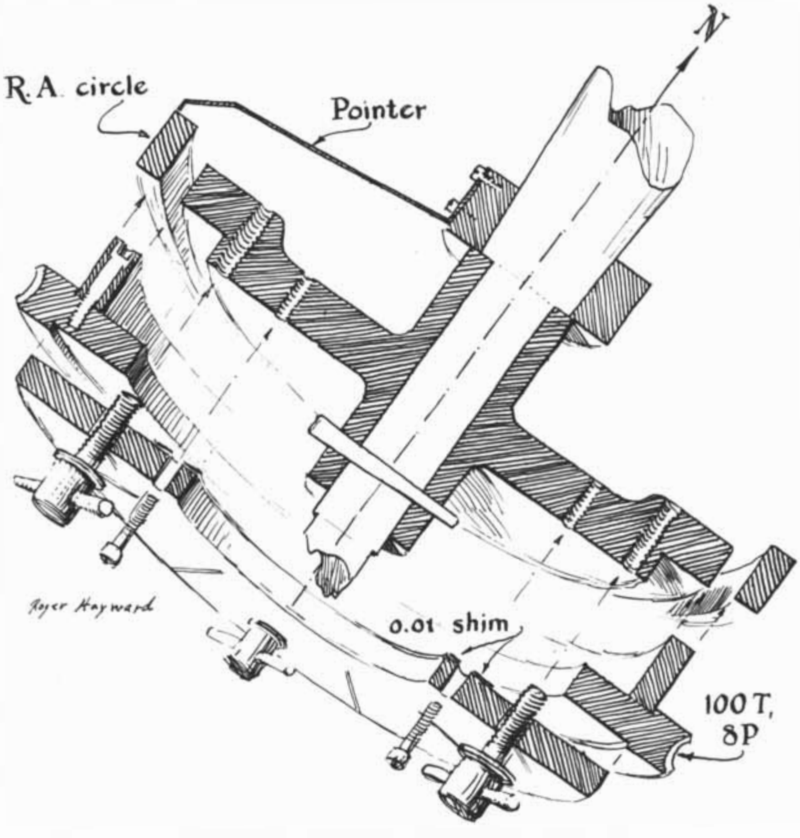
To correct the driving error and larger transient errors due to unpredictable variations in atmospheric refraction and other causes, intervention in the drive is obtained by means of a second, separate motor. This is started, stopped or reversed at will by a push button held in the observer's hand at the end of a flexible cable. This occasional interference is artfully accomplished without altering the speed of the main driving motor even slightly and, indeed, without its knowledge of the impertinence. It is achieved by a differential gearing unit working on the planetary principle. This is the system we temporarily skipped over in the last paragraph.

In this unit the small central sun gear is pinned to the input shaft and rotates with it at all times, at its rate of 15 revolutions per minute. The sun gear meshes with three planetary gears, so these also constantly rotate on their pinions, which are fixed in the side of the large worm gear. Since this worm gear remains stationary most of the time, the planetaries merely idle around without effect within the internal gear that encircles them. But now if the observer, finding the telescope is gradually falling a little behind the stars, pushes the "add" button, the worm on the correction motor shaft will rotate and turn the large worm gear a little. Since it has a reduction gear of its own built into it, the speed of its input shaft is but 10 revolutions per minute.

This new motion, introduced without disturbing the main or driving motor of the telescope, is transmitted through the pinions, planetaries, internal gear and hub plate and will be added to the rotational speed of the input shaft. If, on the other hand, the telescope creeps ahead of the stars, the correction motor is reversed and kept rotating until the error is removed. With the gearing combinations and speeds shown in the drawings, these increases or decreases in speed are obtained at the gentle rate of only one tenth of a revolution per minute. (The 10 revolutions per minute of the motor has been reduced this much by the 100-tooth worm gear.)

A NEW BOOK entitled *La Construction du Telescope D'Amateur,* by Jean Texereau, is so thoroughly practical that if it were in English it would





A telescope that not everyone could make

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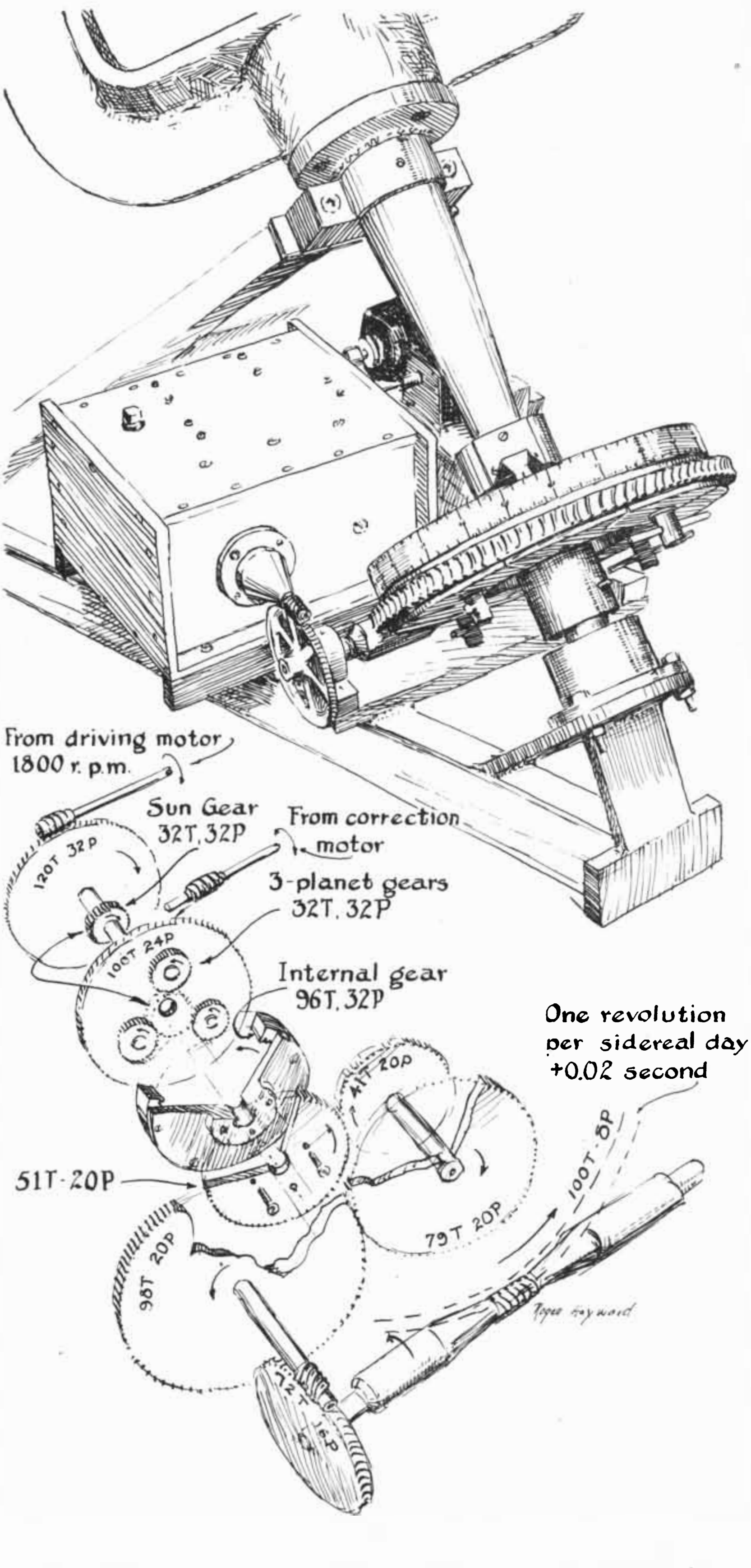
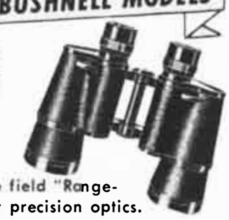
be an event in the telescope-making world and would be given an extended review in this department. Its author has stated in personal letters that he began as an amateur in 1938 with *The Amateur's Telescope* and *Amateur Telescope Making* and its companion volume as his guides in mirror making. He is now a technical collaborator (optician) at the Paris Observatory and has made a 24-inch Cassegrainian telescope for the Meudon Observatory. He has illustrated the 136 pages of his book with numerous drawings of the highly explanatory kind that the American illustrator Roger Hayward made for John Strong's *Procedures in Experimental Physics*. Half of the book is devoted to mirror making, the remainder to plane-parallel diagonal making, eyepiece making, mountings, accessories and collimation. The publisher is the Société Astronomique de France, 28, rue Serpente, Paris (VIe), France, and the price is 650 francs, about $1.90 (the amount to remit is currently ascertainable at any post-office money-order window).

A LARGE lunar map drawn in infinite detail by H. P. Wilkins, the director of the Lunar Section of the British Astronomical Association, was described in this department in August, 1949. At that time the map was available only from England, but now it may be obtained in its third edition for $8 from Walter H. Haas, editor of *The Strolling Astronomer*, organ of the Association of Lunar and Planetary Observers, 1203 North Alameda Blvd., Las Cruces, N.M. The map is in 25 sections, each a separate sheet 20 by 21 inches.

AN ARTICLE in this department last July, describing a home-made Synchronome clock that is precise within a single second a week, aroused considerable interest among amateur telescope makers and others. Several books on horology were named in the article, but one important book was overlooked. This is *The Science of Clocks and Watches*, by A. L. Rawlings, published in 1948 in a second and revised edition by the Pitman Publishing Corporation. While this book contains one chapter on electric pendulum clocks, it is devoted mainly to mechanical timekeepers: to time and its measurement, the physics of oscillatory motion and the pendulum, escapements and their errors, balance wheel timekeepers, the marine chronometer, the Atmos 400-day clock, gear trains, springs, friction, striking clocks and the selection and management of a domestic clock and a good watch. The treatment of the material, with emphasis on the physics and not on the construction and repair of timekeepers, yet without going beyond elementary physics, makes this book possibly the best suited to the needs of the amateur horologist.



The gearbox and its two trains of gears



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IDEA-CHEMICALS

... from Du Pont Polychemicals Department

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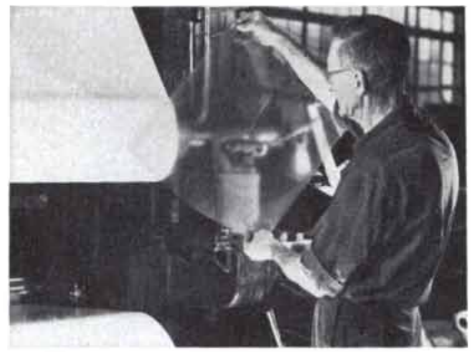

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