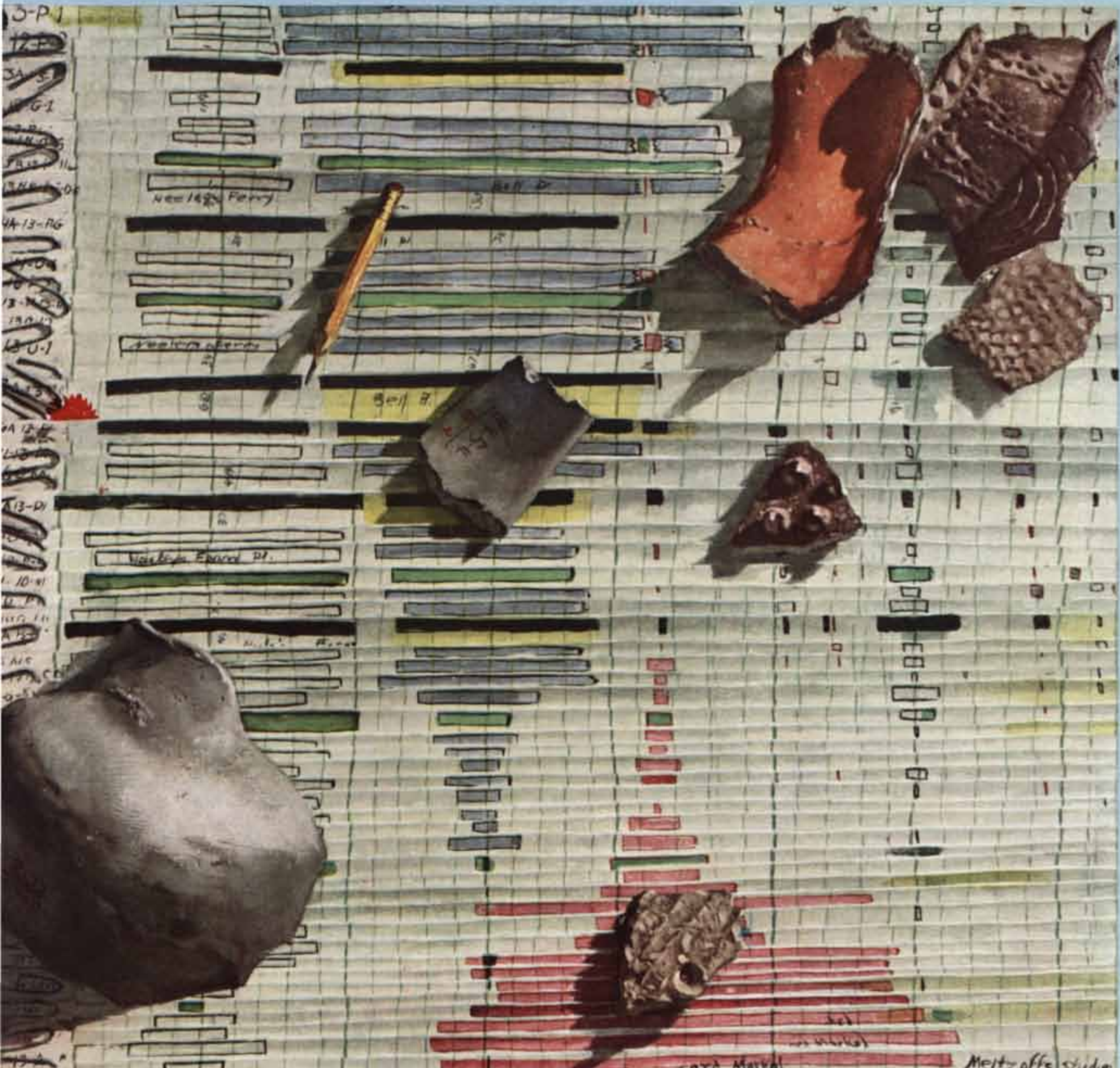
SCIENTIFIC AMERICAN



POTTERY SEQUENCE

FIFTY CENTS

March 1952

Clearing the track of clickety-clack

You ride in comfort on longer-lasting rails because the song of the track is being stilled

Like the paddleboat whistle on the river, the clickety-clack of wheels on rails is on its way to becoming a memory.

This familiar clatter and chatter has been like music to some of us when we travel. But it's been a headache to others . . . particularly our railroads.

Wheels pounding on rail joints cause jolting and wear as well as noise. And wear means expensive repair or replacement of rails and the bars that connect them.

ELIMINATING RAIL JOINTS—"Ribbonrail" is becoming important news because it provides a way to solve the high cost of joint maintenance by eliminating the joints themselves.

RAILS BY THE MILE—"Ribbonrail" is formed by welding the rails together under pressure in the controlled heat of oxy-acetylene flames. The welding is done on the job before the rails are laid . . . and they become continuous ribbons of steel up to a mile or more in length.

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A UCC DEVELOPMENT—"Ribbonrail" is a development of the people of Union Carbide. It is another in the long list of achievements they have made during 40 years of service to the railroads of America.

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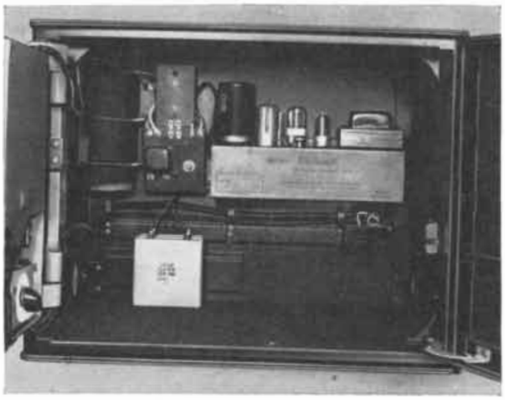
Important to
Engineering, Research & Testing



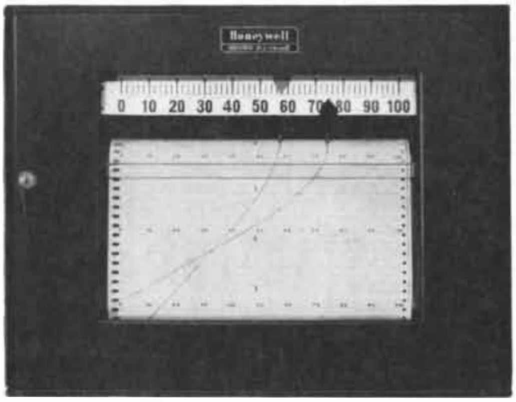
Internal view showing amplifier and damping circuit components.

• NEW HIGH SPEED *ElectroniK* RECORDER

For accurate records of rapidly changing variables

• Now you can accurately record, on a wide chart and on a *null-balance instrument*, full scale signals which vary as rapidly as 20 cycles per minute. Signals with a peak to peak amplitude of 10% of scale can be reproduced at variations up to 3 cycles per second.

The instrument develops a pen speed that traverses its eleven inch graduated chart in *one second!* It has chart speeds up to 4 inches per second—20 feet per minute. It incorporates an adjustable damping circuit . . . has a motor driven reroll mechanism to maintain constant tension on the chart . . . and is adaptable to the measurement of practically any d-c signal.



• THE *ElectroniK* DUPLEX RECORDER

Simultaneously records two independent variables
ON ONE CHART

• On a single chart, the *ElectroniK* Duplex Recorder provides a clear, easily read record of the measurement of practically any combination of two independent variables. A "natural" for such applications as atomic energy, stress analysis and acoustics . . . this instrument is particularly useful in before and after comparisons made by recording a measurable characteristic of a substance as it enters and emerges from a processing stage or reaction.

Auxiliary switches can be supplied on one pen for control or signalling . . . a solenoid-actuated third pen can be provided to register in time conformance with one of the standard pens.

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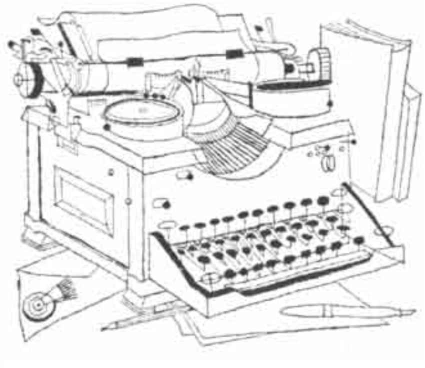

LETTERS

Sirs:

J. M. D. Olmsted's piece about Paul Bert, "Father of Aviation Medicine" (Scientific American, January), oddly omits to mention that deep-sea divers consider him the "father of submarine physiology." *La Plongée en Scaphandre,* the recent advanced treatise on diving by Jacques-Yves Cousteau, so terms Dr. Bert in its dedication. . . .

JAMES DUGAN

Westbury, N. Y.

Sirs:

Surely someone on your editorial staff has heard of "Serutan"! I refer specifically to James R. Newman's review of *Gods, Graves, and Scholars* in your January issue, in which he discusses the derivation of the author's pseudonym, "Ceram." Quite true, Ceram is one of the Moluccas in the Dutch East Indies, or possibly it could have some connection with ceramics. However, if Mr. Newman had gone to the Public Library to get the book, as I did, I am sure that he would have solved the mystery.

The author of the book is Kurt W. Marek. The Anglicized version of the given name would be Curt, and following the same reasoning, Marek, reversed, becomes Ceram. . . .

D. J. MACDONALD, JR.

Glendale, Calif.

Sirs:

In his readable article about solar flares (Scientific American, December, 1951) John W. Evans cites the meaningless clatter of telegraphic instruments as one practical consequence of magnetic storms. Your readers may be interested to know that the engineering files of telephone companies both confirm and dramatize this observation. Telephone men still talk, for example, about the great magnetic hurricane which swept the nation back in 1940. Magnetically speaking, the weather had been foul for nearly a month. Relays had been misbehaving, condensers breaking down, heat coils and other protective devices operating faster than maintenance crews could replace them. Then on March 24 the big storm suddenly broke. Heavy springs in protector-block assemblies guarding the Pittsburgh-Washington line grew red-hot. Five springs at the Dallastown, Pa., repeater station melted. A section of the toll switchboard in Philadelphia burst into flames.

A little later at Fargo, N. D., a blinding flash startled maintenance men standing outside the toll office. An intense arc developed at about the mid-point of a section of lead-covered cable through which a 16-pair open-wire line entered the building. As the startled men watched, molten lead and copper splattered to the ground. Subsequently engineers estimated that the open-wire line had picked up a potential of 15 to 20 volts per mile, a value which on extended runs can easily reach a total of several thousand volts.

Needless to say, the problem of service protection subsequently received much attention, and major magnetic storms attending the sunspot cycle, which reached its maximum intensity in 1947, did little damage.

C. L. STONG

Western Electric Company
New York, N. Y.

Sirs:

I enjoyed the article by George H. T. Kimble entitled "The Geography of

Scientific American, March, 1952, Vol. 186, No. 3. Published monthly by Scientific American, Inc., 2 West 45th Street, New York 36, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York, N. Y., Post Office as second-class matter June 28, 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

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Steel" in your January issue. The complexity of this subject doubtless made it necessary for Dr. Kimble to omit some interesting points. Perhaps you will be interested in a few of these.

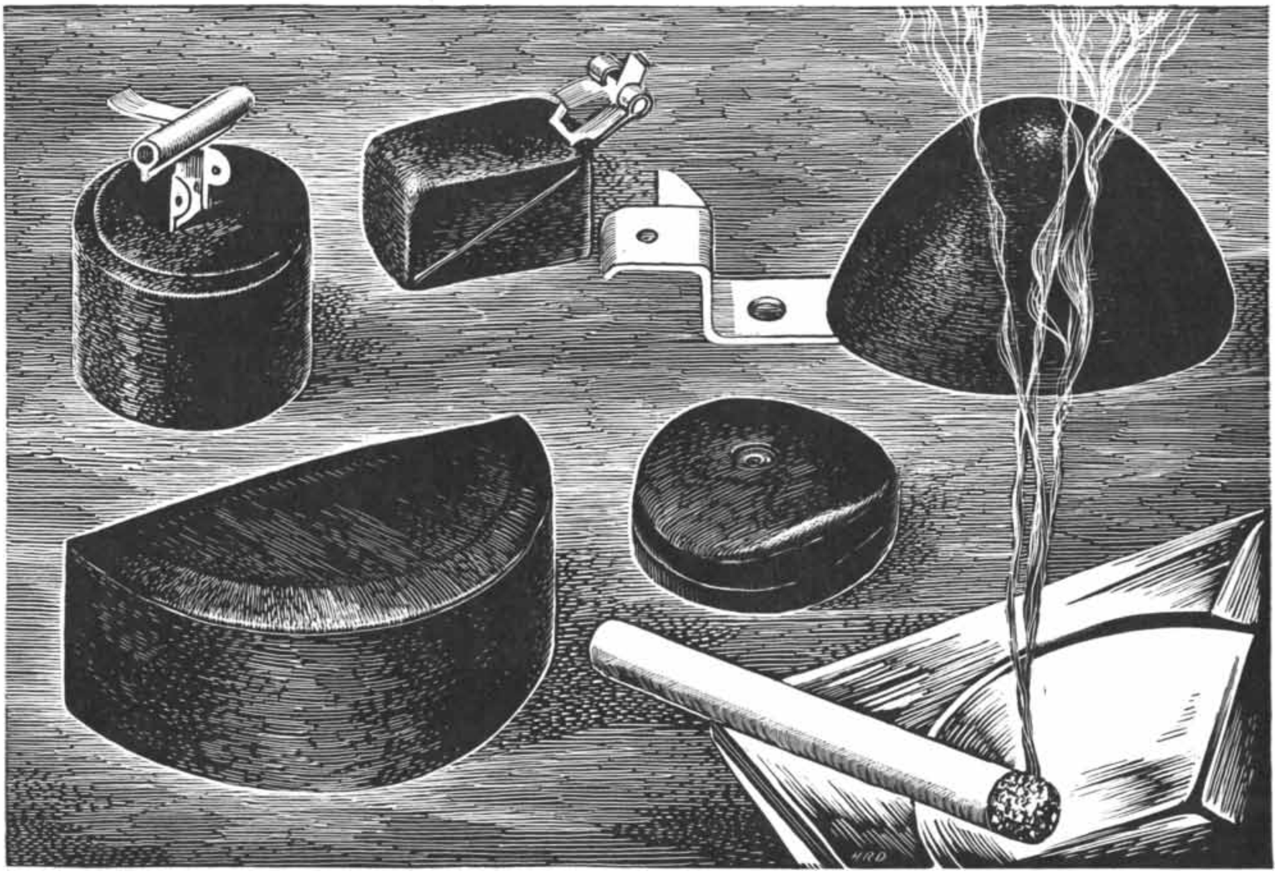
Dr. Kimble did not distinguish between coal resources for power generation and coal required for metallurgical use. It is quite true that the life expectancy of the former is to be reckoned in thousands of years, but the high-grade coking-coal picture is hardly a bright one. It has been contended by the writer for several years, and confirmed in conversations with operators and analysts in the field, that the U. S. coking-coal situation may soon become as critical, if not more so, than the iron-ore problem. In the case of the latter it has been generally known for many years that economic foreign sources such as South America and elsewhere were available. A similar situation does not exist for metallurgical fuel.

Much work has been done since the end of World War II in the development of "formed coke," using carbonaceous materials which at present cannot be used in the blast furnace. There has been a wide and general interest in this work, which points to the concern that steel operators feel regarding the future availability of suitable metallurgical coal. The development of processes which will make all types of coal as well as lignites and other "low grade" fuels suitable for iron and steel production may have a marked effect on steel-plant location, both in this country and abroad.

Finally, the availability of low-cost electric power will become an increasingly important determinant in the geography of steel. This will result from the increase in the use of electric furnaces as compared to open-hearth practice. Fifty years ago the open-hearth furnace replaced the Bessemer converter, and in those years has been developed to a point where steelmakers are getting from it nearly as much as is technically possible. With rising costs, a new process capable of more efficient and cheaper operation, and requiring smaller capital investment, must inevitably replace the open hearth. Some of us who have been closely allied with the industry during the past decade and longer believe that this will be the large-diameter, high-powered electric furnace, operated with high hot-metal (molten pig iron) charges. Such a development will cut the tie which has hitherto bound steel plants to locations within economic distance from coking-coal sources. The availability of low-cost electric power, however, will then become a major consideration.

JACK R. MILLER

Ramseyer & Miller, Inc.
New York, N. Y.



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50 AND 100 YEARS AGO

MARCH 1902. "Mendeleeff found that when he arranged the different chemical elements in groups, on the principle of similarity in qualities, a mathematical relation existed between the atomic weights of the members of each series. When argon was discovered, it was impossible to place it in the table. After finding helium, though, Prof. Ramsay was satisfied that he had started a new group. He is more convinced than ever now, having identified three more elements and having ascertained their atomic weights. He arranges these as follows: Helium, 4; neon, 20; argon, 40; krypton, 82; and xenon, 128. All five, moreover, possess this trait in common: they show a peculiar reluctance to form chemical combinations."

"Sufferers from nervous complaints may have reason to bless the memory of certain great apes who have cooperated unselfishly with some British scientists and surgeons in a series of privately conducted experiments to demonstrate new facts about the brain. The animals were anesthetized, and tiny openings made in their skulls. After the wound had healed entirely one electrode from an electric battery was fastened to the wrist of the chimpanzee in the form of a bracelet and the other electrode, in the form of a fine platinum point on a spring, was brought to touch the outer surface of the brain. Thus the areas that controlled the movement of the organs and limbs of the body became mapped out bit by bit. If a certain part of the cortex of the frontal lobe of the brain received the current, the ape thrust out his fingers; the current applied to another place made him thrust out his tongue. After the experiments had been concluded it was found possible to make a map of the brain as to its function. Two cases of injury to human brains which have since been treated according to the knowledge obtained from these experiments proved that the discoveries of the motor centers furnished fair working bases for treatment of the patient."

"Successive steps in the establishment of wireless telegraphy follow each other with a rapidity which is quite unprecedented in the development of a new invention. It is not many weeks since the first successful signals were transmitted across the Atlantic, and in the interim the inventor has returned to England, completed his arrangements, and is now on his way back to America for the purpose of establishing a permanent station for the regular transmission of commercial wireless messages. Furthermore, it is announced that a contract has been made with the Canadian government for the transmission of ordinary transatlantic messages for ten cents a word, with a press rate of five cents a word."

"Prof. Alexander Agassiz is in charge of an expedition to the Maldive Islands in the Indian Ocean which has recently been sent from the Agassiz Museum at Harvard. They expect to find rare and beautiful coral formations and will gather as exhaustive a collection as possible. The islands of the Indian Ocean are the only group remaining which Mr. Agassiz has not examined in his explorations for the study of coral. The islands are unfrequented, and it is expected that the expedition will prove fruitful."

"Sven Hedin, who started out some time ago to explore Central Asia, has returned to Cashmere, after stirring adventures in Thibet. Like many another explorer before him, he could not resist the temptation of trying to enter the forbidden city of Lhasa. Disguised as a pilgrim, he succeeded in approaching within a few miles of his goal, when he was at once captured and imprisoned. Not content with the failure of his first attempt, Hedin tried a second time to enter the town. Without any warning 500 soldiers attacked him, and destroyed a large part of his caravan. His ardor was then so far cooled that he determined to return to Cashmere, after rescuing his notebooks and the data which he had collected."

MARCH 1852. "There are two theories respecting the motion of light; one is the *emission* theory of Newton, the other the *undulatory* theory by Euler and others. By the emission theory, it was asserted that light passing from a rarer to a denser medium was increased in velocity. M. Foucault of Paris, at the request of M. Arago, has recently made a number of experiments to test the two theories, and it is said, 'has fully established the theory of undulation,' *viz.*, that light travels with less velocity through a dense than a more rare medium—swifter through the air than water."

"There are many men who have a scientific reputation, much of which is

derived from mere assertions respecting natural phenomena—their own deductions—which may be altogether erroneous. This, we believe, is the case with the 'World Makers,' those Astronomical and Geological philosophers who have given utterance to their opinions respecting the manner in which this world and other worlds have been formed. Prof. Guyot, of Cambridge, Mass., asserted that the *days* in which certain great creative acts were performed, as mentioned in the first chapter of *Genesis,* were not days of 24 hours' duration, but great cosmogonic periods. Of chaos, as mentioned in that Book, he says 'Dark, invisible gaseous matter was the true state of chaos.' Laplace thought the solar system was, at first, one vast nebula, in a high state of heat from chemical action. Planet after planet was formed as the original nebula condensed and shrank. We have quoted enough for our purpose, which is to object entirely to the nebular hypothesists; they have no business to propound such a theory and link it with religion, and endeavor to make the Mosaic account of the Creation as flexible as india rubber to square with their notions. Logic, chemistry, mathematics and observation incline us to believe that this globe—the various substances of which this earth is composed—were made and arranged in a very short period by the Great Architect of the Universe."

"An interesting paper from Baron Humboldt, upon the Mississippi River, has been recently read at the Academy of Sciences at Paris. The paper states that at Memphis the river rolls away at the rate of 13,709,006,232,791 cubic feet a year. The 2,950th part, or 4,600,000,000 cubic feet, of this volume is mud. In this mud are found 82 different kinds of microscopic creatures."

"Every person in our land has heard of the 'Ether Discovery,' as it is termed; that is, the application of ether by making patients inhale it, so as to render them nervously insensible while undergoing surgical operations. The discovery, we believe, is a most valuable one, but there are no less than three claimants of it, two of whom are now living; the other, Dr. Wells, is dead. The Legislature of Connecticut examined the claims of Dr. Wells, and awarded him the honor of being the first discoverer. The Paris Academy of Sciences examined the claims of Dr. Jackson, and awarded him a gold medal and the honor of being the first discoverer. Dr. Morton, the other claimant, made an application to the present Congress for a reward for being the first discoverer, and a majority of the select committee, to whom the petition of Dr. Morton was referred, have agreed to recommend that $100,000 be granted to him for his useful discovery."

THE COVER

The painting on the cover shows seven fragments of the pottery made by the prehistoric Mound Builders of the Mississippi Valley (*see page 22*). Behind the fragments is a seriation diagram, in which the relative abundance of each kind of pottery is plotted against time. Each horizontal row of bars represents the relative number of fragments of various pottery types found in one place. The bars are then arranged vertically according to the age of the site, with the youngest sites at the top. Thus the red bars behind the small fragment at bottom center indicate that it represents a pottery type which is found in relative abundance at earlier sites; at the same sites fragments of the type at lower left are found in less abundance. As time went on, however, the type of the large fragment became more popular and that of the small fragment less so. The diagram shown in the painting is a trial one made by James A. Ford of the American Museum of Natural History.

THE ILLUSTRATIONS

Cover by Stanley Meltzoff

Page	Source
17	Chicago Aerial Survey, courtesy The Dorr Company
18-19	Eric Mose
20	Department of Public Works, New York City
21	Eric Mose
22	Mississippi River Commission, U. S. Army Corps of Engineers
24-25	Philip Phillips, Harvard University
26-27	Irving Geis
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49-50	Bernarda Bryson
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71	Irving Geis
81-82	Roger Hayward

BUSINESS IN MOTION

To our Colleagues in American Business . . .

Revere began to make aluminum extruded shapes in 1922, and hence has had thirty years of experience with the metal. During those years it has gained invaluable experience, and has installed new equipment in order to expand the list of aluminum mill products it offers to industry. This expansion has been conducted at an accelerated pace during the past ten years. Today it may come as a surprise to some people that Revere's present installed capacity makes it the largest independent fabricator of aluminum in the United States.

Revere is sometimes asked why we should have sought the same position in aluminum alloys that we occupy in copper and copper-base alloys. The fundamental reason is a simple one: we wished to increase our service to industry, which is demanding more and more metals of every kind. Thirty years ago we recognized the growing importance of aluminum, and we also perceived that aluminum and copper are in many ways complementary metals. Being able to offer both means that Revere can be impartial in recommending the one most certain to give the best results in a given application.

So successful has been our experience with aluminum that we are now pursuing a comprehensive program of expansion in regard to it. In one of the Revere plants in Baltimore, new aluminum rolling mills and annealing furnaces were installed before Korea, making possible tripled production of coiled sheet. Right now, in another Revere Baltimore plant, new extrusion presses and draw benches are being put in place. Equipment for the production of aluminum coiled sheet was installed in our Detroit plant over a year and a half ago. In about a year, the Los Angeles mill, now working with copper and copper-base alloys only, should begin to produce aluminum tube and extruded shapes in both the heat-treated and non-heat-treated alloys.

These plans to increase materially the Revere output of aluminum mill products will make them more quickly and easily available in various industrial centers. Here is evidence of our belief that the future of aluminum is as great as that of copper. Each has its place, in peace as well as war.

Revere's thirty-year growth in aluminum is in the American tradition of freedom to seek new ways to serve customers. It is typical of the business world, for in many thousands of companies the original products or lines have been expanded to include more or less related items. So we suggest that no matter what you buy, you ask your suppliers if they have other materials or products that would be of value to you. The more you know about what your suppliers make, the greater the possibility of improving your products or productivity.

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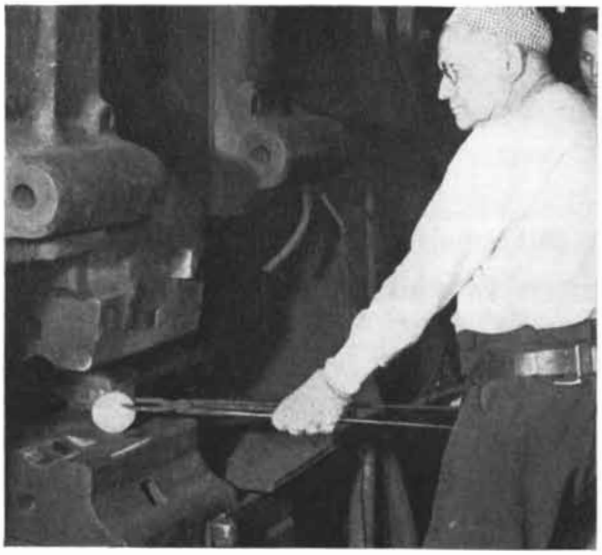
What's Happening at CRUCIBLE

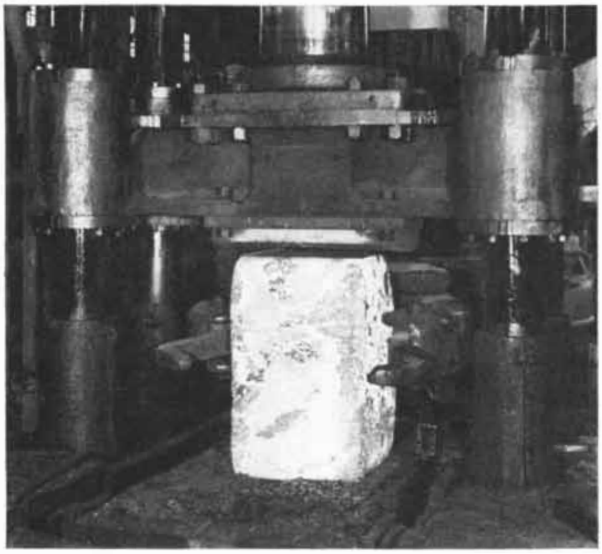
about tool steel forgings

Whether 1½ pounds or 7 tons . . . forgings get the same sensitive handling

Crucible's reputation as the specialty steel leader is built on a devotion to the smallest detail . . . regardless of the size of the order.

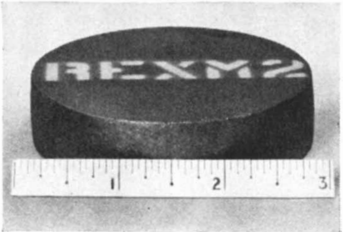
These forgings are good examples of Crucible specialists at work:

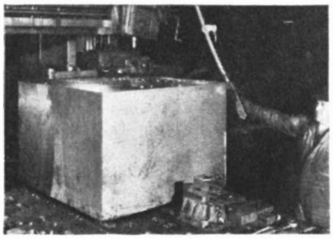




Rex M-2 High Speed Steel Disc Forging (1½ pounds)

Pancake forgings such as these are used extensively by small tool makers. Extreme care is taken in the preparation of the slug stock. The upsetting insures proper flow lines. Milling cutters, gear shavers and similar cutting tools that require maximum toughness, coupled with the best cutting ability, are made from these forgings.





CSM-2 Plastic Mold Forging (14,000 pounds)

This CSM-2 plastic mold steel forging was made from a 25,000-pound ingot. This block will be heat-treated and worked to produce a mold for the manufacture of large plastic parts. The finished weight of the forging is 14,000 pounds. And it is the largest mold forging yet produced by Crucible.

Engineering service available

Crucible's engineering service is geared to meet your research and development problems. If you use special forgings, or any special purpose steel, check with Crucible. Crucible Steel Company of America, General Sales and Operating Offices, Oliver Building, Pittsburgh, Pa.

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SCIENTIFIC AMERICAN

MARCH 1952 VOL. 186, NO. 3

STREAM POLLUTION

The wastes of our civilization threaten one of its vital resources: pure water. The solution to the problem is the fuller utilization of modern methods of waste treatment

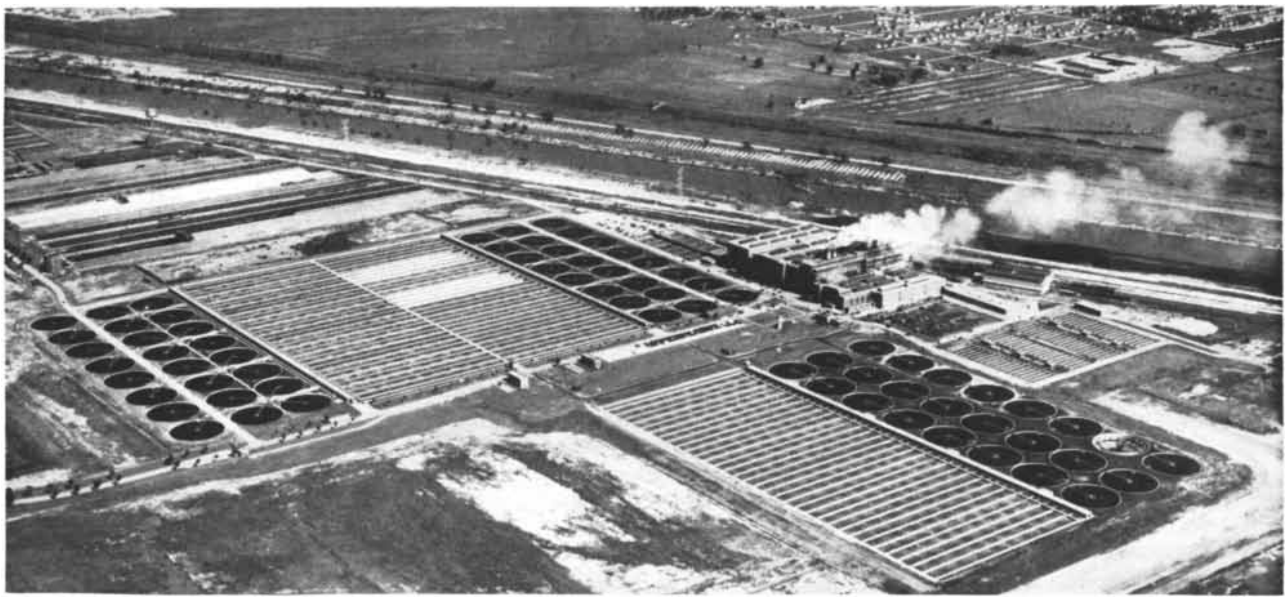
by Rolf Eliassen

POLLUTION of the surface waters of the U. S. threatens one of the nation's most valuable natural resources. It menaces not only the water supplies of many of our cities, which consume over 15 billion gallons of water per day, but also recreational fishing, boating and bathing, commercial fishing, agricultural irrigation and even the very industries that produce much of the pollution. It must be remembered that the industries themselves require billions of gallons of water daily for processing and cooling purposes, and the pollution of river water may destroy its usefulness to them. Each river is a natural resource which one must expect to use and re-use from source to mouth.

The social and economic costs of pollution are beyond computation; they include such diverse items as effects on the health of our people, the expense of water purification, limitation of industrial expansion, loss of revenue to fishermen and recreational interests, decline of real-estate values.

There are approximately 20,000 significant sources of stream pollution in the nation; about 10,000 of them are municipal sewage systems and the other 10,000 are industrial plants. A single river such as the Delaware is estimated to receive each day 500 million gallons of domestic sewage and hundreds of millions of gallons of industrial wastes. The industrial needs for water are staggering: according to a recent survey by the National Association of Manufacturers, the manufacture of viscose rayon requires an average of 180,000 to 200,000 gallons of water for each ton of product; rayon yarns, 250,000 to 404,000 gallons per ton; woolens and worsteds, 140,000 gallons per ton; rolled steel, 110,000 gallons per ton; whiskey, 80,000 gallons of water per 1,000 gallons of whiskey; synthetic gasoline, 15,800,000 gallons per 1,000 barrels, and aviation gasoline, 1,050,000 gallons per 1,000 barrels.

There are three categories of pollution—chemical, physical and biological. The chemical pollutants include such toxic substances as cyanides, acids, chromates, copper, zinc, arsenic and mer-



ACTIVATED SLUDGE METHOD is used at the West-Southwest Sewage Treatment Works in Chicago. The sewage is aerated in the large rectangular chambers; it is then allowed to settle in the circular tanks.

cury, which kill fish and other life and render water unfit to drink. Among them also are organic chemicals which, though not toxic themselves, serve as food for bacteria. The physical agents of pollution are often overlooked, but they, too, are important. For example, heat, which not many people would consider a form of pollution, has become a major problem; after being used and re-used many times by industries for cooling purposes, the water of a stream sometimes is raised as much as 50 degrees above its natural temperature, and it loses its cooling value. Another physical contaminant, which will give increasing trouble, is radioactive waste. In addition there are physical agents, such as clay particles, that make waters colored or turbid. The third type of contaminant—biological—of course is familiar to everyone; responsible for typhoid fever, dysentery, gastroenteritis and a host of other diseases, it has been the concern of health authorities for centuries.

BEFORE discussing methods of reducing stream pollution, it would be well to consider the characteristics of streams and their ability to absorb pollution. Water is not dead—it is alive with flora and fauna, with energy and movement, with all sorts of matter. One of its most important assets is its content of dissolved oxygen. If the oxygen content falls to less than four parts per million, the water becomes unsuitable for game fish. When it drops to zero, as has happened in a good many streams in this country, the stream becomes septic, generates foul odors and is a serious nuisance to the nearby population. But most important is the fact that oxygen helps give a stream the power to purify itself.

Organisms in a stream use the dissolved oxygen in their metabolic processes as they consume organic matter. Their oxidation of this material, plus coagulation and settling, reduces the concentration of polluting organic matter in the stream. By this self-purification a stream into which a city pours its wastes may regain its original purity many miles downstream from the source of the pollution.

There is a limit, however, to this capacity. The stream loses its ability to absorb organic pollution and purify itself if its microorganisms use up the dissolved oxygen faster than it can be replenished from the atmosphere. The rate at which the microbe population uses up oxygen depends primarily on the amount of organic matter in the water. This establishes what is known as the biochemical oxygen demand (B.O.D.) of the stream. In the unending struggle of a river for self-purification, the B.O.D. must never be allowed to get out of hand and reduce the oxygen balance below a certain level. This minimum is generally considered to be four parts of oxygen per million parts of water.

The problem, then, is to reduce the amount of organic matter to the stream's capacity to absorb it, and to get rid of toxic materials. Sanitary engineers and scientists have developed many ways to do this. One of them is the settling tank, where sewage and industrial waste is held for a short time (usually about two hours) until enough of the solid material settles to the bottom so the liquids can be discharged into the stream. On the average settling will remove about 55 per cent of the suspended solids and 35 per cent of the organic matter that would exert an oxygen demand in the stream. By chemical treatment still more of the pollutants can be precipitated. Iron or aluminum salts, particularly sulfates and chlorides, are added to the liquid, and by reaction with the water they form particles which serve as nuclei to adsorb and coagulate colloidal and suspended material. This method is widely used to precipitate inorganic and organic matter in industrial wastes, particularly toxic substances such as come from metal-finishing plants using chrome-plating processes.

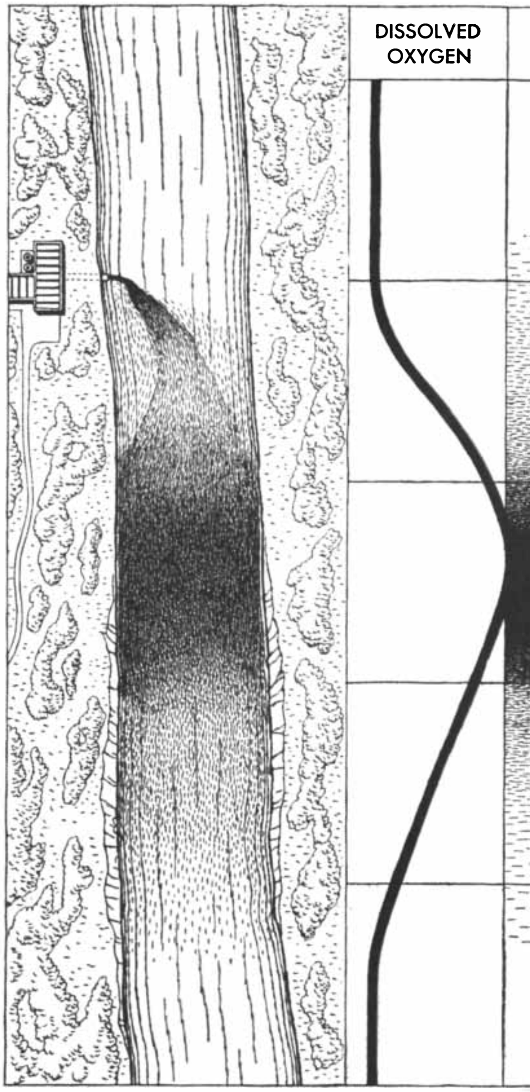
There are a great many other treatments, but we shall consider in detail only a few of the important biochemical ones. Essentially these are based on the same natural processes by which a stream purifies itself; that is, they use microorganisms to break down the organic matter.

ONE DEVICE is the trickling filter. This consists of a large bed of crushed rock or gravel, from 10 to 200 feet in diameter and 3 to 8 feet deep, with microorganisms growing in the bed so they cover the stones with a coat of slime. The population of organisms in this slime is very complex, and the myriads of different kinds of bacteria and multicelled animals, acting together, can break down many varieties of organic material—cellulose, fats, greases, proteins, and so on.

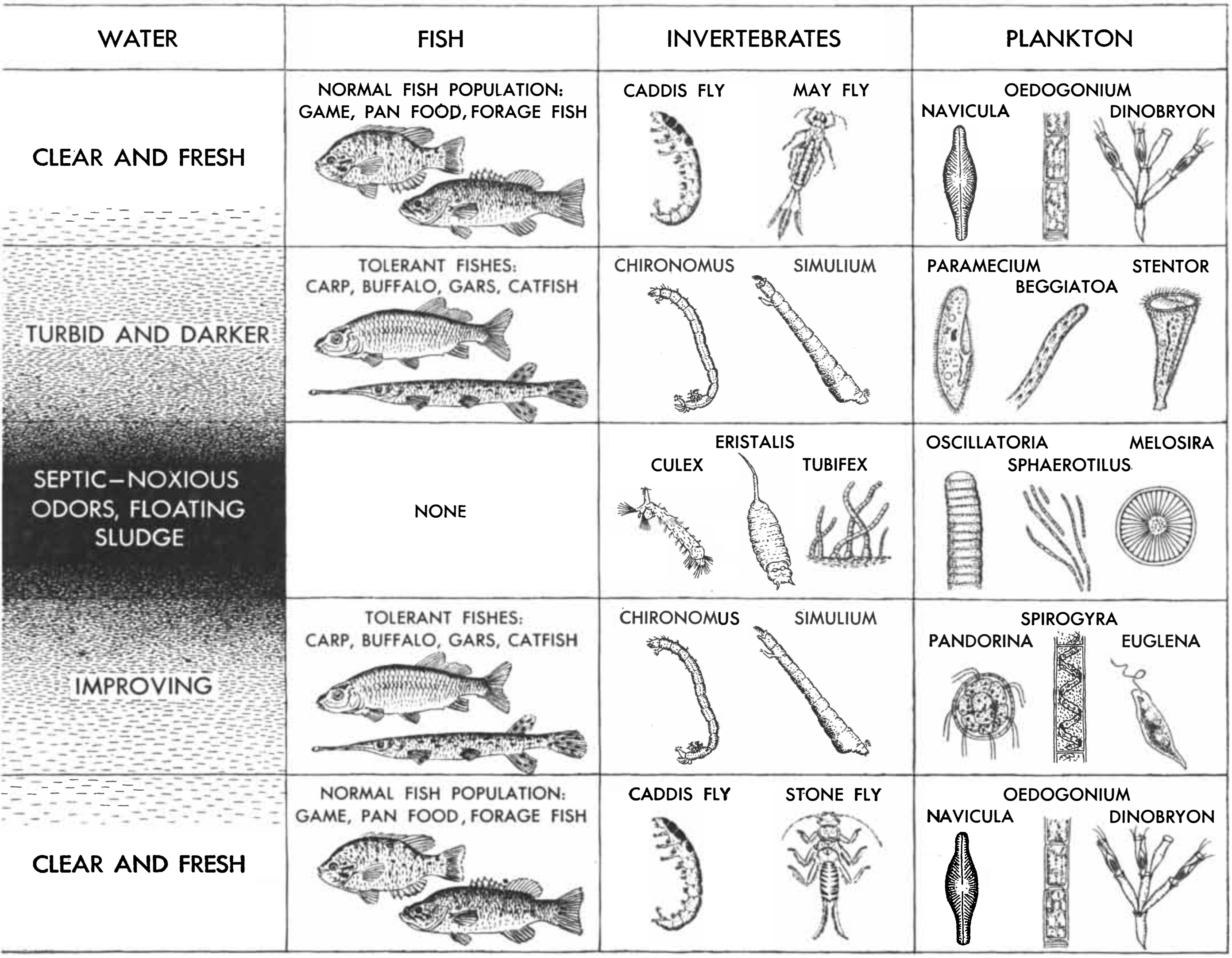
The sewage to be treated is trickled through the rock bed, and the bacterial slime goes to work on its solids. With the aid of their enzymes the bacteria consume soluble organic matter directly as food. Material that is in colloidal form may be adsorbed on the surface of the slime; it is then ingested directly by protozoa or may be hydrolyzed and become soluble food for bacteria. If necessary, the sewage or waste is recirculated through the bed several times—as much as 30 times in the case of some industrial wastes. The trickling filter can remove from 60 to 95 per cent of organic matter from liquid wastes. It has proved to be the answer to many of the pollution problems of industries and of small and moderate-sized cities.

Some of the largest cities have resorted to a more economical method, called the activated sludge process. Activated sludge is a mass of gelatinous material consisting of fuzzy particles about one millimeter in diameter. It is generated from microorganisms that occur naturally in sewage, and it is built up by letting the organisms "brew" for several months until they attain the proper balance of population. Once the sludge is formed, it purifies sewage in much the same way as the trickling filter, except that the operation takes place in a large tank instead of a bed of rock. Fine air bubbles are blown through the liquid in the tank to furnish dissolved oxygen for the organisms as they work on the sewage. The mixture then flows to settling tanks where the sludge, carrying the converted organic matter, is deposited. This process removes 90 to 95 per cent of the organic matter from sewage and usually yields clear water as the effluent. The sludge, after settling, can be used again.

After the organic matter has been re-



POLLUTION AND RECOVERY of a stream is reflected in an intricate



physical, chemical and biological system. As the oxygen dissolved in the water decreases (*curve at left*), so do certain microorganisms and, in turn, the invertebrates and fishes that depend upon them for food.

moved—by the trickling filter, by activated sludge or by some other process—the water often needs to be treated further to kill disease-producing bacteria before it is discharged to the stream. The most commonly used disinfectant is chlorine. By adding from 5 to 15 parts of chlorine per million to the effluent and keeping the liquid in a tank for about 15 minutes, it is possible to destroy more than 99 per cent of the bacteria.

The sludge removed from the sewage also must be treated. Much of its material is putrescible, and it is about 100 times more concentrated in the sludge than in sewage. The most common method of handling sludge is anaerobic fermentation, that is, breakdown of the material in the absence of dissolved oxygen. This is done in large "digestion" tanks. In these tanks, where the sludge is kept anywhere from 2 to 100 days, bacteria and other microorganisms decompose most of the putrescible organic matter into simpler compounds of carbon, oxygen, hydrogen, nitrogen, sulfur and phosphorus. Some of the end products are discharged as gases, mainly methane, carbon dioxide and hydrogen sulfide. The gas mixture, about 65 per cent methane, has a heating value of 600 British thermal units per cubic foot (better than manufactured cooking gas). It can be used to heat the digestion tanks and furnish power for pumping and other equipment in the disposal plant. The solid residue from the digestion of sludge is a humuslike material which makes a good fertilizer; it may contain from one to five per cent nitrogen and some phosphorus and potash. Some large activated sludge plants dry the sludge without digesting it first, and sell the dried sludge as a fertilizer base. Dried sludge from the sewage plants of Milwaukee is marketed and known throughout the country as Milorganite.

New York City, Chicago, Los Angeles, Philadelphia, Cleveland and London all have large activated sludge plants; Chicago's, the largest, treats an average of 1.1 billion gallons of sewage per day. Not all make use of the sludge products; for example, New York City dumps its liquid sludge into the Atlantic Ocean, because this is more economical at present than processing the sludge into organic fertilizers. The need for such fertilizers is great, however, and someday New York's sludge will be used.

IT WILL COST substantial amounts of money, of course, to make the streams and other waters of the U. S. reasonably free of pollution. The construction costs of municipal sewage treatment plants such as have been described in this article run from $10 to $50 per person served by the sewerage system. Added to this are operating costs, which range from $10 to $40 per million gallons of sewage treated.

Los Angeles has just spent $42 million for a treatment plant to protect the Santa Monica bathing beaches; New

York City is spending $200 million for treatment plants; Pittsburgh and neighboring towns in Allegheny County will spend about $80 million; Miami is completing a $10 million project. Since 1915 municipalities in this country have spent about $10 billion for sewers and sewage-treatment plants, and it is estimated that they will have to spend another $10 billion in the next 20 years to build enough plants to handle their sewage.

In addition, U. S. industries will probably have to spend about $10 billion more to change processes and build plants to dispose of their wastes. Management realizes that public opinion is gradually forcing industry to shoulder its part of the burden of alleviating stream pollution, and that waste treatment must be considered an integral part of invested capital and production costs. Operating, maintenance and financing costs for these plants will eventually amount to a quarter of a billion dollars yearly, the cost of which can only be passed on to the consumers of the industries' products. If the public wants stream-pollution control, it must be willing to pay in terms of increased taxes and increased costs of consumer goods.

To control pollution intelligently we need standards for the discharge of wastes and the degree of purity we want in our streams. The standards of course will depend on the priorities to be given the various possible uses of the available water—domestic and industrial water supply, bathing and other recreation, fishing, the transport of wastes. To develop water standards for each of these uses and for regulating them, we shall need surveys. Very little has yet been accomplished in this direction, nor have many states passed enabling legislation for pollution control.

Every state has an agency in which this function may be vested, whether it is the Department of Public Health, as in Massachusetts, or a specific Water Pollution Board, as in California. Primarily stream pollution is a state problem. But where a stream runs through more than one state, regional authorities are needed, and several have already been formed, including the Ohio River Valley Water Sanitation Commission, the Interstate Commission on the Delaware Basin, the New England Interstate Water Pollution Control Commission and agencies for the drainage basins of the Hudson and Potomac Rivers. The states have also found that they need the cooperation of the Federal government. The Taft-Barkley Act of 1948 authorized the U. S. Public Health Service to assist the states in developing pollution-control programs.

The Public Health Service, with the aid of states, regional agencies and industries, has collected and analyzed some data on the needs for waste-treatment facilities in the major drainage basins in the country. These studies have helped citizens to realize that their pollution problems may originate far upstream, even in another state. Industry is cooperating extensively in these surveys, particularly through the National Task Committee on Industrial Wastes sponsored by 22 of the nation's leading industries and the Public Health Service.

There are still many unsolved problems in the treatment of wastes. It should be possible to develop more economical processes than those now used. Moreover, for some of the organic pollutants no effective treatment has yet been found. The hope for solution of these problems lies in further research.

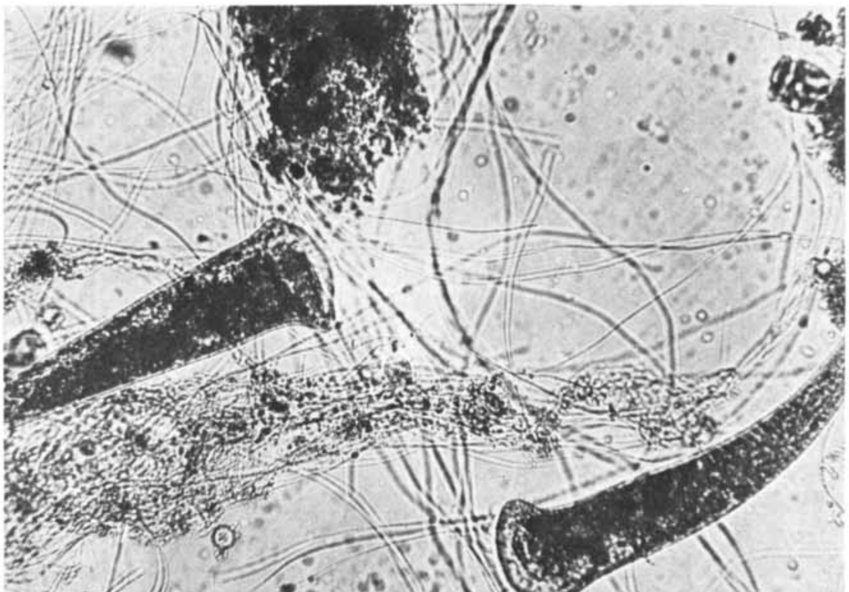
Microbiologists and sanitary chemists have made great strides in the treatment of toxic wastes such as phenol and formaldehyde. Studies are currently in progress in the Sedgwick Laboratories of Sanitary Science at the Massachusetts Institute of Technology on the fermentation of a number of concentrated organic wastes from the chemical, paper and cotton textile industries. Experiments are being conducted on the effectiveness of various microorganisms, combinations of nutrients, temperatures and degrees of acidity. These studies are making available new processes which can handle a greater variety of organic industrial wastes.

Radioactive wastes have created a serious problem for the sanitary engineer. With the growth of the nuclear industry in such fields as atomic power and tracer research, to say nothing of nuclear weapons, stream-pollution control is becoming a matter of primary concern. The processing of radioactive wastes is being studied intensively in many laboratories.

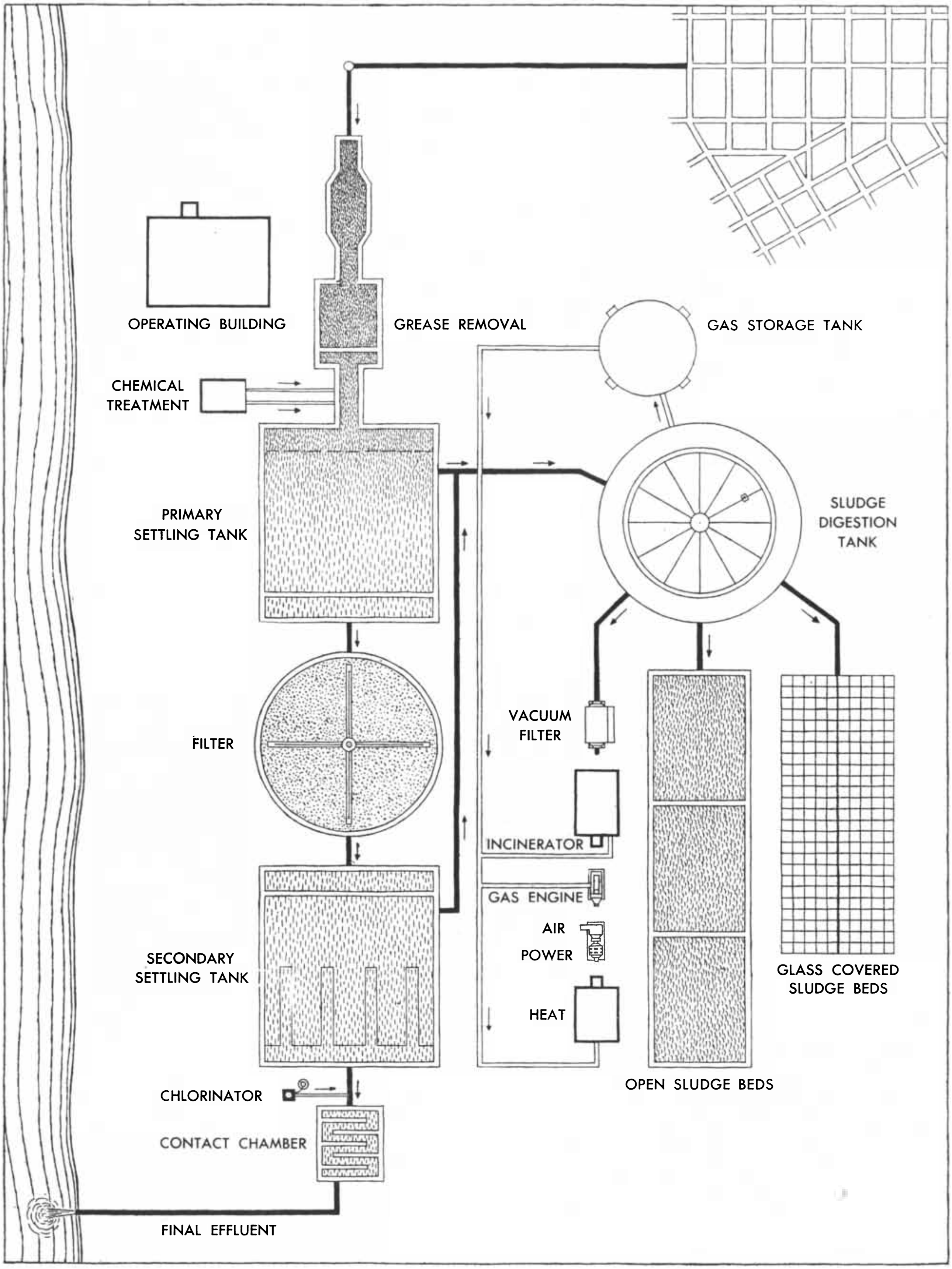
Under the sponsorship of the Atomic Energy Commission the author and his colleagues have been investigating the removal of low concentrations of radioisotopes from liquid wastes by chemical coagulation, sedimentation and filtration. Evaporation is effective in separating radioactive material from liquids, but it is too expensive. The M.I.T. studies have disclosed that coagulation is a good and economical method of removing radioactive substances when they are in colloidal form or suspended as solids. Dissolved substances present a more complex problem, but it has been partly solved; certain special coagulants that precipitate ions can remove more than 90 per cent of the radioactive material. Research is also in progress on the possible toxic effects of beta and gamma radiation from substances such as radiophosphorus and radioiodine wastes on microorganisms that help a stream to purify itself.

We can clean up our streams to almost any degree we like by spending enough money. To restore our heavily populated rivers to their pristine purity would be much too costly, but sound engineering and the expenditure of about $20 billion by municipalities and industries could reduce the pollution of the streams of the U. S. to a reasonable level.

Rolf Eliassen is professor of sanitary engineering at the Massachusetts Institute of Technology.



MANY MICROORGANISMS are found in activated sludge. The organisms at the left and right in this photomicrograph are *Stentor*. The photomicrograph was made in the New York City Department of Public Works.



MODEL SEWAGE PLANT employs sedimentation, filtration and digestion. In the latter process sludge is attacked by anaerobic bacteria. The gas evolved by the bacteria is utilized to provide heat and power for the plant. The remaining sludge is then dried either in a vacuum filter, open sludge beds or glass-covered beds.

AERIAL PHOTOGRAPH of the Jaketown site near Belzoni, Miss., shows two mounds (*white rectangle*). To the left of the mounds is Wasp Lake, an old bend of the Ohio that was isolated when the river shifted its course.

MOUND BUILDERS OF THE MISSISSIPPI

Between the expeditions of De Soto (1541) and Marquette (1673) this thriving culture vanished from the valley. Its history is now being reconstructed, principally by an ingenious statistical method

by James A. Ford

WHEN Marquette and Joliet made their voyage of discovery down the Mississippi River in 1673, the entire Indian population of the great valley was less than the number of people in one of the small towns on the river today. To the two French explorers the region seemed an even more primitive wilderness than the wild Atlantic Coast where white men had first set foot on the continent. But as the U. S. pioneers cleared and settled the Mississippi Valley through the 18th and 19th centuries, they gradually discovered that other large populations and civilizations had been there before them. All over the huge fertile plain their plows ripped open ancient cemeteries and unearthed pieces of pottery and curious tools. And up and down the valley they found thousands of remarkable man-made mounds of earth, ranging from small conical piles to great flat-topped pyramids covering several acres. Some were in the shapes of animals—one of the most famous, in Ohio, is in the form of a serpent with open jaws 75 feet across and a tail 1,348 feet long.

The prehistoric people who left these structures are now well known as the "Mound Builders," and their artifacts fill the shelves of many a museum in the U. S. For a long time it was thought that they represented a superior, vanished civilization, but investigations by the Smithsonian Institution in the late 19th century showed that they were actually ancestors of the Indians the Europeans found when they arrived in the valley. Indeed, when Hernando De Soto and his little Spanish army discovered the Mississippi in 1541, they apparently found one of the late phases of the Mound-Builder civilization at its apogee. They told of a people living in many well-fortified towns and of an active and flourishing culture.

The story of this civilization, and of what happened to the Mound Builders in the scant 132 years between the De Soto and Marquette expeditions, has long been an intriguing puzzle. Many patient investigations have combined to give a broad outline of the Mound-Builders' history. In 1938 James B. Griffin of the University of Michigan, Philip Phillips of Harvard University and the writer, then at Louisiana State University, decided to try to fill in one of the blanks in the picture. Concentrating on the section of the Lower Mississippi between Memphis, Tenn., and Vicksburg, Miss., we undertook to reconstruct the history of the Mound-Builders' culture over an extended period.

PEOPLE often ask: How does an archaeologist know where to dig? The answer is that this is one of the most difficult parts of the job, particularly in an unexplored area. In our case, before even touching a spade (except to dig a car out of the mud), we made an archaeological survey of the whole region. Equipped with large-scale topographic maps, simple surveying instruments and a large supply of cloth bags, we systematically combed the section of the valley where we intended to work. We questioned almost every person we met and collected all the material available. Nearly everyone in this region had seen Indian mounds, and the more observant farmers remembered places in their fields where the soil was darker than normal (an indication of ancient human occupation) and where their plows had turned up broken bits of pottery, flint tools and mussel shells. We visited all these sites, noted their locations and mapped their surface features. From each place we gathered samples of ancient cultural refuse, especially fragments of pottery vessels. We wanted a large sample of these pottery bits, for reasons that will presently be explained, and we collected hundreds or thousands from each locality. After two summers of field work we had 346,099 fragments of pottery from 383 ancient village sites.

The next step was to classify the styles of pottery and try to arrange them in a time sequence—a crucial part of the investigation. The technique we used, known as "seriation," is based on the fact that a culture changes gradually and constantly, and that particular styles of pottery or clothing or other manifestations of the culture rise to peaks of popularity at certain times and then give way to other styles. Suppose, for example, we had representative collections of various kinds of clothing worn by people in the U. S. during the past 50 years. In a segment of the sample covering the period 1910-1915 we would find a high frequency of bowler hats, celluloid collars, peg-top trousers, button-top shoes, tight corsets, and so on. In later samples the popularity of these items would decline (though not all at the same rate) and others would become dominant. The series of frequency curves would give us the pattern of development of clothing in the U. S. between 1900 and 1950 and a kind of chronological yardstick for that period.

In the case of our pottery samples, we could assume that usually each collection gave what amounted to a momentary glimpse of the popularity of a pottery style at a particular time and place, since most of the village sites probably were occupied only for a relatively short time. If our survey was sufficiently thorough, the individual collections should cover the whole sequence of pottery development in the region. By arranging our set of "still" pictures in the correct order, we could reconstruct a "motion picture" of this sequence. Proceeding on these assumptions, we classified the 346,099 fragments of pottery we had collected, calculated the popularity of each type at each site and made graphs showing the proportions and kinds of styles in each collection. These graphs were arranged and rearranged in relation to each other until the chronological pattern was discovered. We were able to check the accuracy of this reconstructed pattern at certain sites where the Indians had evidently lived much longer than the usual brief period. At 20 of these places we dug pits through several consecutive layers and found that the pottery showed the same sequence of changing styles as our graphs had indicated.

We now had a kind of calendar by which we could date sites in relation to one another, but we still needed some way of determining their actual age. For this, fortunately, we had a convenient calendar handy—the Mississippi River itself. During the past 5,000 years the river has been restlessly changing its course ("Paradoxes of the Mississippi," by Gerard H. Matthes; SCIENTIFIC AMERICAN, April, 1951). Its old courses are etched on the surface of the valley and show clearly in air photographs. In a study for the Mississippi River Commission Harold N. Fisk has worked out the sequence of channel changes and the rate at which the river has been meandering; projecting this rate back into the past, he mapped the successive locations of the main channel at each 100-year interval during the past 2,000 years. When our prehistoric villages were plotted on these maps, we saw that 79 of them were on the banks of ancient Mississippi channels. On the assumption that the villages were inhabited after the river was there, we determined that the cultures represented by our samples dated from about 600 to 1500 A.D.

TRENCH IS DUG to expose the strata of the Jaketown site. At the bottom of the trench are the excavated postholes of an ancient Indian house.

WE WERE now ready for the intensive excavation that is usually thought of as synonymous with archaeology. Phillips and I began this phase in the spring of 1951. We chose a site called "Jaketown," near the modern town of Belzoni, Miss. The Indians inhabited this site continuously for a very long time; geological evidence and Fisk's map of channel changes indicate that they first occupied it about 1500 B.C., when it was an island in the Ohio River. We excavated a series of layers down to 10 feet below the surface, and from their contents we were able to trace the successive cultures back some 3,000 years. With this background and data from other places it was possible to sketch the history of the Lower Mississippi Valley.

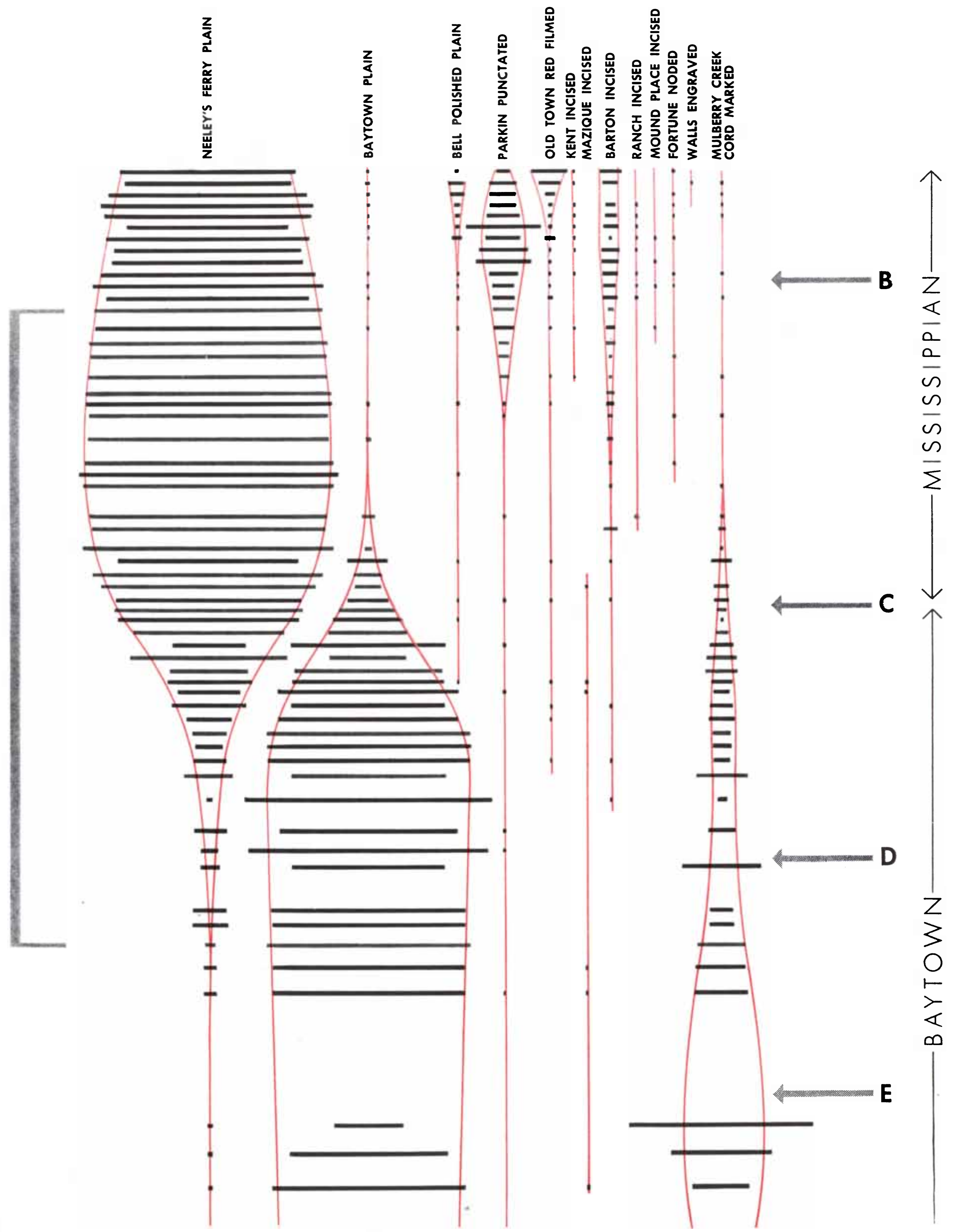
The first settlers there apparently were a short, slender people with rather long skulls. They built their houses by sticking saplings into the ground in a circle about 12 feet in diameter, bending them over to form a dome, weaving small branches between the saplings and covering the framework, probably with palmetto fronds and mats. They did most of their cooking in wooden and skin containers, which of course could not be put over a fire; the heat was supplied by small heated stones dropped into the stew. In this stoneless land, however, the "stones" had to be made of baked lumps of clay. We found thousands of these artificial boiling stones in the lower levels of Jaketown.

The hunting weapons of these early people were the atlatl and bolas. The atlatl was a contrivance for throwing a spear with greater force than it could be thrown by hand. It was a stick two to three feet long with a hand grip at one end and a bone hook to hold the spear at the other. Its user cast the spear—a light, stone-pointed affair—with an overhand motion. The bolas was a set of cords with egg-shaped stones tied to their ends. The cords were tied together at the other end; spread out, the weapon looked a little like a pinwheel. The huntsman grasped the knot of string ends and threw the device like a sling. In flight the stones spread apart and whirled around; they would stun small game or enmesh it in the cords.

THIS rather simple culture changed very little until about 600 A.D., when its people began to practice agri-

FLAT-TOPPED MOUNDS, introduced from Mexico, were the foundations of wooden temples. Some of the largest mounds of this kind were built around the 13th century. This mound is in Washington County, Miss.

CONICAL MOUNDS were built before approximately 1000 A. D. Although this mound has not been opened, work in similar structures suggests that it may contain 1,000 skeletons. The mound is in Phillips County, Ark.



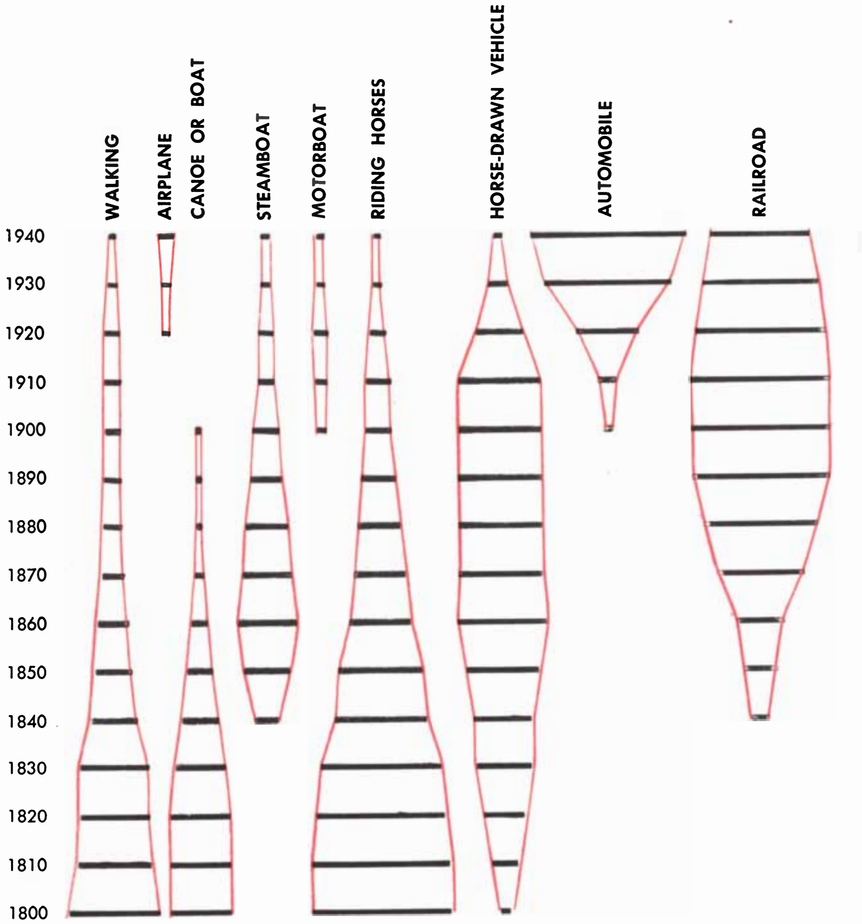
POTTERY SERIATION DIAGRAM presents a quantitative picture of changing pottery styles, and hence a changing culture. At the top of the diagram are the names of several kinds of pottery found in one part of Arkansas. The length of the bars in any one horizontal row represents the relative number of pieces of each kind of pottery found in one place. The rows of bars are arranged according to the age of the sites, with the youngest sites at the top. Surface sites are indicated by black bars; excavated sites, by gray bars. The gray bracket at the left denotes a single excavation. Each gray bar within it corresponds to a stratum of the excavation; each black bar, a surface site whose age can be correlated with that of the strata. The widening of the bars at left and the narrowing of those in left center reflect the transition from the Baytown to the Mississippian culture (*vertical arrows at right*). The horizontal arrows pertain to chronological periods.

culture and make pottery vessels. By that time a new physical type, with heavier body-build and a more rounded skull, had begun to appear in the population, and in time this became the dominant stock. With a better and more certain food supply, the population increased and apparently developed a more complex social structure. They built large conical burial mounds that sometimes contain the remains of as many as 1,100 persons. Some of the mounds were arranged in irregular clusters and protected by earth walls that probably were topped with wooden palisades. These clusters of mounds were sacred places; there is usually very little evidence of people having lived around them. The population was scattered over the countryside in small hamlets consisting of a few circular houses.

By 800 A.D. these Indians were a part of a widespread "burial-mound" culture. They carried on an extensive trade: their materials include conch shells brought from the Florida coast, galena from western Missouri and copper from deposits near Lake Superior. Over a wide area of the East, from Florida to Wisconsin and from western Missouri to New York, remains from this period show the same pattern of burial customs, ceramic bird-designs, pipes of a distinctive "platform" shape and other common features.

The next major cultural change in the Lower Mississippi Valley came about 1000 A.D. At this time a new complex of traits was introduced from Mexico. The central feature was the custom of building rectangular earth-mounds arranged around a court. These mounds had flat tops on which circular temples were erected, and on many there was a graded stairway leading down into the central plaza. Apparently the people destroyed the temple at intervals and each time built the mound higher with a new capping of earth, so that ultimately some of the structures reached a height of 60 feet. The earlier burial mounds apparently had held the dead of a single large family or a clan; these larger temple-mounds suggest that the Indians had now progressed to a true religion with a specialized priesthood and a political organization sufficiently extensive to control the large groups of people necessary to build and maintain the temples.

Along with the rectangular mounds came the bow and arrow and other additions to the culture. Rectangular houses with mud-plastered walls replaced the round houses. It became the custom to bury the dead beneath house floors. The economy was firmly based on a variety of agricultural products: corn, beans and squash. A number of new ceramic forms appeared. By about 1200 A.D. all this had been combined into a relatively advanced cultural pattern called the "Mississippian." At this stage the Lower Mississippi Valley had a high density of population, as indicated by the fact that our rather superficial survey found 84 sites in a 200-mile section of the valley.



TRANSPORTATION SERIATION DIAGRAM is an imaginary illustration of the diagram on the opposite page. The length of the bars in each horizontal row represents the relative number of miles traveled by each of the methods listed at the top of the diagram for every decade from 1800 to 1940.

After 1400 A.D. small towns began to grow up around the temple-mounds. They were protected by palisades and ditches. Very likely the trend toward urbanization in this region was promoted by two factors: the increase in population made it necessary for groups to build fortified villages to protect themselves, and at the same time their more centralized and effective religio-political organization made it possible to put larger armies of warriors in the field for expeditions of conquest.

Even before 1400 the round-headed people of the Mississippian culture had started spreading out of the central valley and taking possession of territories held by their weaker and less well-organized neighbors. Eventually they penetrated north as far as lower Wisconsin, east to southern Indiana and Kentucky and southeast to the Gulf Coast of Florida and the Atlantic Coast of Georgia. The distinctive Mississippian culture gradually merged with that of the peoples in those areas. By 1500 the Mississippian pattern prevailed over most of the valley and eastward to the Appalachians.

THERE REMAINS the question of what had happened to this large Mississippi population by the time the French explorers arrived in the 17th century. Some have suggested that the Mississippi Indians were overrun and destroyed by less advanced Indians of the hills. Perhaps a more tenable theory is that they fell to new diseases introduced by the early colonists from Europe—the English in Carolina and Virginia, and the Spaniards in Florida. The Indians were highly susceptible to diseases such as measles and smallpox, to which they had not previously been exposed, and the dense population concentrated in the towns of the Mississippi would have been particularly vulnerable. Probably the white man's diseases opened the continent for him more effectively than did his musket and rifle.

James A. Ford is an archaeologist on the staff of the American Museum of Natural History.

Smell and Taste

Two of the five senses depend upon chemical stimuli rather than physical. The chemistry of the substances that these senses can detect and differentiate are important clues to their mechanism

by A. J. Haagen-Smit

OUR SENSES of taste and smell constitute a most astonishing chemical laboratory. In a fraction of a second they can identify the chemical structure of compounds it would take a chemist days to analyze by the usual laboratory methods. A trained nose can recognize, for example, nearly every member of a series of homologous alcohols, aldehydes or acids. Moreover, from exceedingly small amounts of material it can analyze not only single compounds but complex mixtures of them in food.

Our chemical senses are of great importance for our well-being. They determine our reaction to foods and set the stage for digestion. The odor of broiled steak has an immediate effect on metabolism: it starts secretions of saliva and stomach juices even before eating begins. By setting up a favorable condition for digestion the flavor factors in food play a role in nutrition comparable to those of vitamins and hormones.

The science of nutrition has gone through successive phases in which there was great concern about the body's needs of calories, carbohydrates, fats and proteins, vitamins and, lately, amino acids. Now it seems to be flavor's turn. Nutritionists are paying more and more attention to our nearly forgotten senses of smell and taste. But to put the improvement of flavor on a scientific basis we need to know what substances are responsible for the various tastes.

This is a complex problem. The chemist must start with thousands of pounds of raw material to isolate weighable quantities of the pure essences that our senses of smell and taste can detect in such small traces. This difficult analytical work has been carried out in only a few foods, mostly fruits such as strawberry, apple, raspberry and pineapple. When the juices of these fruits are distilled, the residue, consisting mainly of sugars and fruit acids, has a taste which is usually not very characteristic of the original flavor. All of the odor substances, and some of those responsible for the taste, are in the volatile part that is distilled away. This volatile part consists of various alcohols, aldehydes, acids and esters.

The natural ingredients do not entirely account for the flavors of the products we eat and drink. New flavors are added when the raw material is cooked or processed. For example, the flavor of wine is due not only to substances originally present in the grapes but also to compounds produced by fermentation through the aid of microorganisms. More than 50 substances have already been identified as contributors to the flavor of wine, and there are undoubtedly a great many more. Frying or roasting adds new flavors to food by breaking down proteins and carbohydrates. The chemical complexity of an elaborate flavor system such as that of Soy sauce is indicated by the involved process by which this condiment is manufactured: various fungi are inoculated into a mixture of rice and grain; the broth they produce is then heated, and the mixture is fermented again and again, alternately in the presence of dissolved oxygen and in the absence of oxygen. On the other hand, our chemical senses readily recognize and enable us to reject substances produced by other organisms that spoil or rot the food. We have learned to associate these foul smells and bad tastes with adverse reactions of our digestive system. Actually the substances responsible for the bad flavors are harmless in the concentrations in which they generally occur, but they serve as warning signals against dangerous toxins the organisms produce at the same time.

OUR perception of flavor depends on both taste and smell; indeed, it is often difficult to distinguish between the parts that odor and taste play in our food. Of the two, the sense of smell is by far the more sensitive, and it may be stimulated at a great distance. R. W. Moncrieff, in his classic book on the chemical senses, recounts how a female Great Peacock moth hatched in the laboratory attracted the same evening about 40 male specimens, which must have traveled several miles, because these insects were rare in the neighborhood. As everyone knows, the odor of a skunk is noticeable several hundred feet from where its glands are emptied. Because of the distances at which odors are perceived, some think the stimulation cannot be entirely chemical, on the ground that the odor substances must be too diluted when they reach the olfactory receptors; it has therefore been suggested that physical vibrations are responsible for odor. But it can be shown that in a barely perceptible dilution of an odoriferous substance a single sniff still contains many millions of molecules. When the molecules arrive at the olfactory hairs and cells in the upper part of the nose, they must produce a reaction in the cells, giving rise to electrical impulses which are transmitted to the olfactory lobe of the brain.

To be smellable a substance apparently must fulfill two conditions: it must be volatile at ordinary temperature and must be soluble in fat solvents. All the known odor substances either are gases or have a high vapor pressure, boiling below about 300 degrees Centigrade. Most inorganic substances, being salts of very low vapor pressure, have no discernible odor. Among the minority that do are the halogens (fluorine, chlorine, iodine, bromine), phosphorus, ozone and certain compounds such as hydrogen sulfide, sulfur dioxide, nitrogen oxides and ammonia. Their odor is usually rather unpleasant and often irritating.

In organic chemistry the situation is very different; the organic compounds are much more likely to be odoriferous and their odors have a vastly greater range. Of nearly half a million synthetic compounds listed in a well-known encyclopedia of organic substances, a large proportion have a high enough vapor pressure to make them odoriferous.

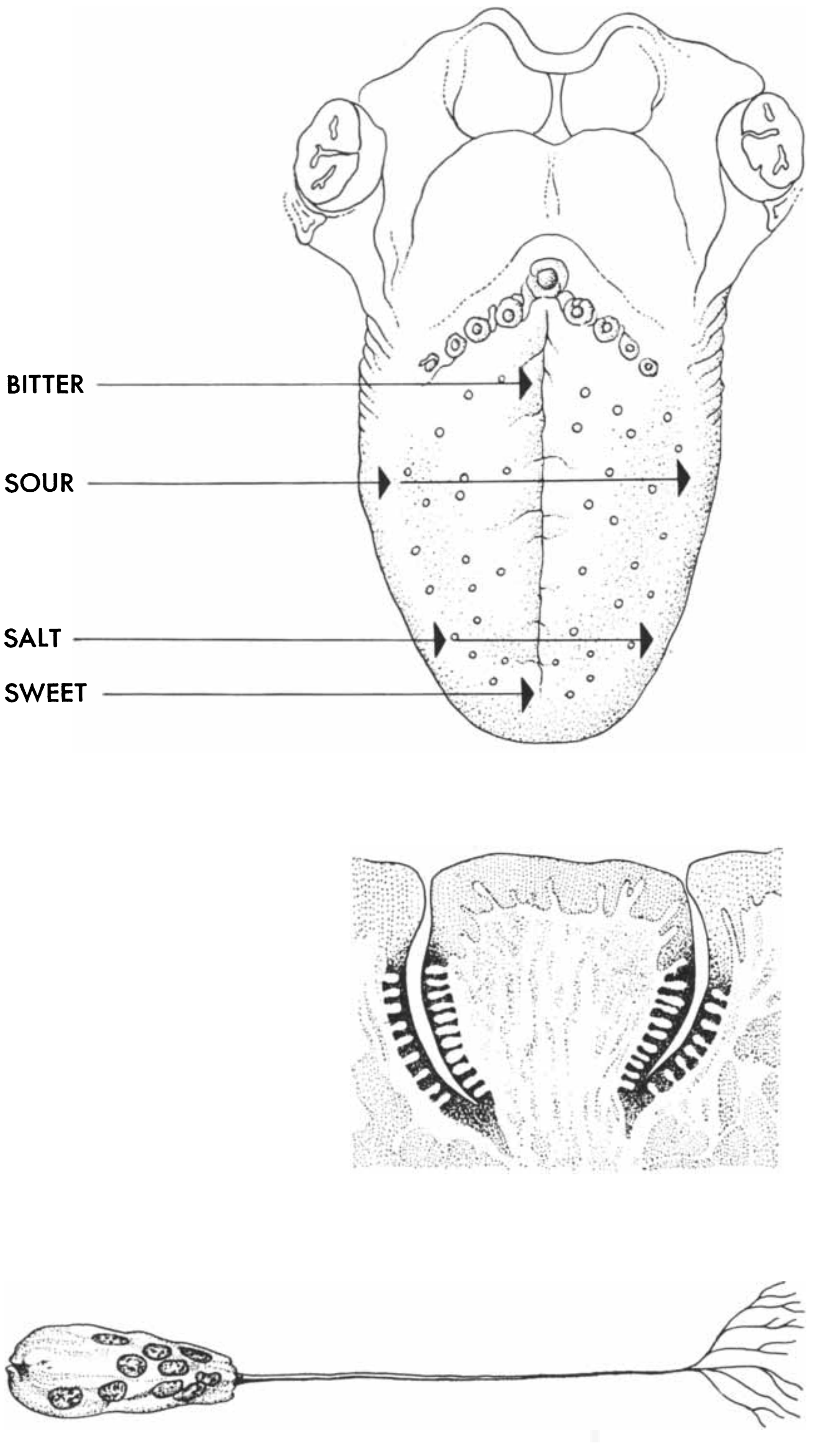
CAROLUS LINNAEUS, the father of taxonomy, who in the 18th century began to establish laws of order in the living world by cataloguing plants, also attempted to classify substances according to their odors. But his classifications were necessarily subjective, and early odor taxonomists were severely handicapped by the lack of an assortment of pure organic chemicals to serve as standards of comparison. In 1895 Hendrik C. Zwaardemaker, one of Linnaeus' followers, devised a system in which all odors were reduced to nine main types, with subdivisions in each type:

1. Ethereal—fruits, resins, ethers.
2. Aromatic—camphor, cloves, lavender, lemon, bitter almonds.
3. Balsamic or fragrant—flowers, violet, vanilla, coumarin.
4. Ambrosial—amber, musk.
5. Alliaceous—hydrogen sulfide, arsine, chlorine.
6. Empyreumatic—roast coffee, benzene.
7. Caprylic—cheese, rancid fat.
8. Repulsive—deadly nightshade, bedbug.
9. Nauseating or fetid—carrion, feces.

It is possible even today to agree on the proper place of a substance in this system, but it is also clear that the system does not reduce odors to their fundamental elements. As is well known, odor receptors in the nose soon become used to a particular odor and cease to notice it—this is called fatigue. Consequently it should be possible to find out by a fatigue test whether one odor is essentially the same as another (*i.e.*, stimulates the same receptors). Such experiments have shown that the odors of camphor and of cloves, for example, produce fatigue for each other; hence they belong in the same subclass. As a result of these experiments some of Zwaardemaker's classes have been changed.

In recent years Ernest C. Crocker and Lloyd F. Henderson of the Arthur D. Little laboratories have reduced odors to four elementary classes, corresponding to four kinds of receptors. According to their system, all known odors are composites of these types: 1) fragrant or sweet, 2) acid or sour, 3) burnt or empyreumatic, 4) caprylic or goaty. Any odor is described by a formula which gives the strength of each component on a scale from one to eight: thus the odor of a rose is represented by 6423, meaning that it is strong in the fragrant component, has some acid odor and also has a little of the burnt and caprylic odors. The system describes ethyl alcohol as 5414 and vanillin as 7122. The authors of this system maintain that a trained observer can recognize to a certain extent the degree in which the four postulated basic odors are present. To try to describe the vast array of odors in terms of just four basic types may be an oversimplification, but the system has the virtue of emphasizing that every odor is a combination of impressions.

Once we are aware of this fact, we find that we are able to perform such



TASTE RECEPTORS are located in the tongue, the top of which is shown in the drawing at the top of this illustration. On the surface of the tongue are numerous round structures called papillae; the larger of these are indicated by the small circles in the drawing. A cross section of one of the largest papillae is shown in the drawing at the middle of the illustration. The small white structures adjoining the fissure around the papilla are the taste buds. An individual taste bud (*left*) and its nerve fiber (*right*) are shown in the drawing at the bottom. Some areas of the tongue are more sensitive to certain tastes than others; these areas are indicated by the arrows on the top drawing.

analyses in our minds. It is then possible to overcome the difficulty that no substance smells exactly like another, and we can find the dominant odor for proper classification. In the numerous substances that have now been synthesized by the organic chemist we have material to test the different classification systems, and since the substances' chemical nature is well known, a search for correlations between chemical structure and odor is possible.

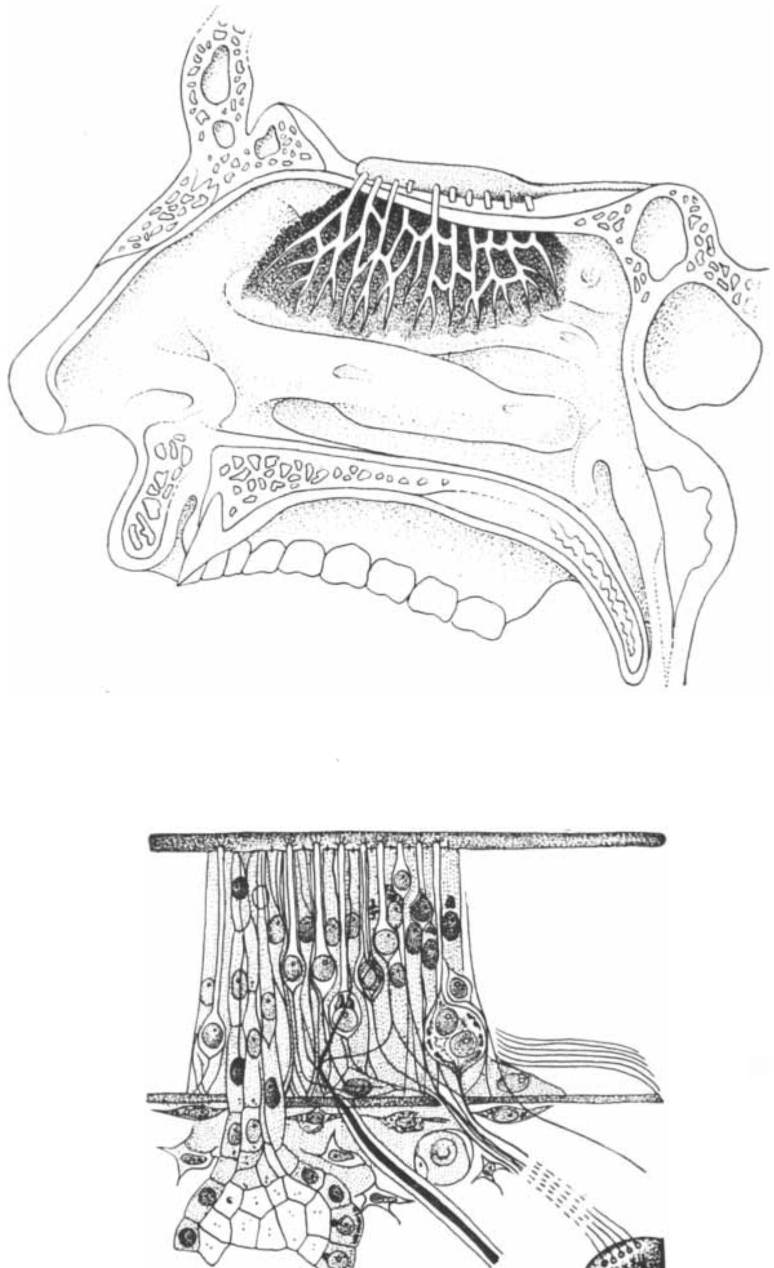
Let us concentrate on two distinctive and well-defined odors—those of camphor and mint. There are more than 200 known compounds with a camphorlike odor and nearly as many with the mint odor. In each group chemists have found a certain common characteristic of structure; when they synthesize a compound with this building principle in its structure, there is a fair certainty that the product will have the odor in question. For instance, one can produce a substance with a mint odor by building a molecule resembling menthol, the main constituent of the oil of peppermint. It is not necessary to follow the whole plan of the menthol molecule; apparently only a small part of its structure is responsible for the mint smell. The requirement seems to be a short carbon chain, with branches preferably not more than two or three carbon atoms long (*see diagrams on opposite page*).

The camphor odor is closely related to that of mint; one can be converted to the other by slight changes in the molecule. Apparently the critical difference that transforms a minty compound into a camphorlike one is the substitution of a methyl group (CH_3) for one hydrogen atom in the mintlike substance. On the other hand, the odor reverts to mint when an ethyl group is substituted for one of the methyl groups in the camphor structure.

In general we observe that the camphor odor is characteristic of compounds which have a number of small groups crowding around a carbon atom. These do not necessarily have to be methyl groups; halogens and nitro groups are equally effective.

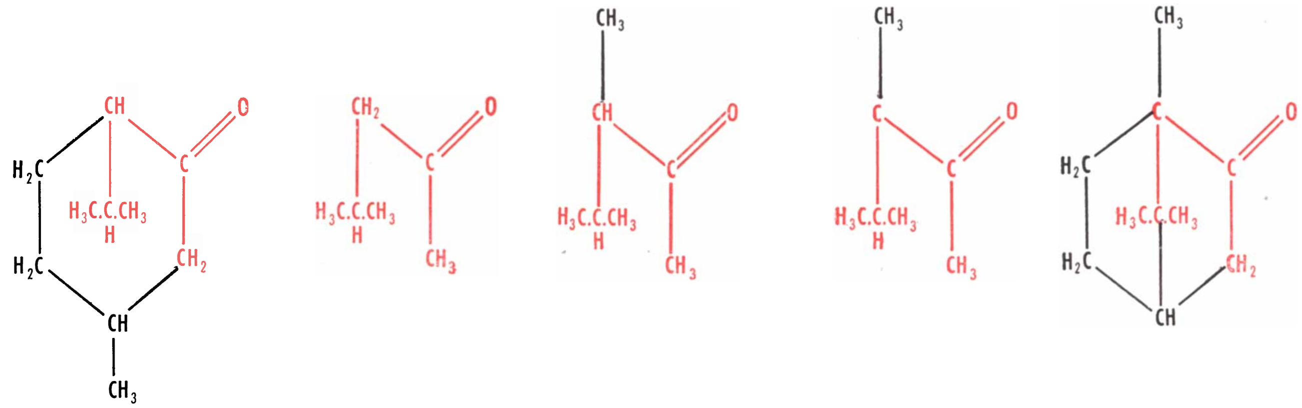
Closely related to the mint and camphor odors are those of cedar, wood, peach, musk and civet. As the number of carbon atoms is increased in the series of ring ketones, for example, the odor gradually changes from camphor to cedar to musk to civet. The odor evidently is governed by the size of the carbon ring. In a similar series of lactones, musk odor develops when the molecules reach a size corresponding to that of the cyclic ketones of musk odor. The typical musk smell is largely due to the structure of the carbon skeleton, and to a lesser degree to the oxygen atom.

These and similar considerations lead to the conclusion that for mint, camphor, turpentine, cedar, lemon, cineole, peach, musk and civet, the hydrocarbon part of the molecule is of dominant importance, and that there is reason to classify all these odors in one group, which corresponds to Zwaardemaker's classes of aromatic and ambrosial odors and to Crocker's class of "fragrant."



SMELL RECEPTORS are in a spongy region at the top of the nasal cavity, a cross section of which is shown at the top of this illustration. At the bottom is a microscopic cross section of the cells in the olfactory mucous membrane.

WE SEE, therefore, that chemical structure can account for the various classes of odors. This explains the failure of the many odor theories based on some general principle such as the reactivity, oxidizability or vibrational characteristics of odoriferous substances. It is reasonable to assume that for each class of odorous materials there is a specific receptor mechanism in the smelling apparatus. For the class to which camphor and mint belong, the mechanism must enable us to detect small differences in the carbon skeleton of a large number of compounds. Just as a specific antibody meshes with an antigen in the body, so the active part of an odorous molecule may fit some part of a protein structure in the nasal receptors, thereby altering cell reactions and giving rise to electric impulses. This theory would account for the fact that only a part of the



MOLECULAR STRUCTURE of substances that smell like mint or camphor is similar. At the right is the molecular diagram of camphor. Second from the right is the diagram of another substance that smells like camphor. The remaining diagrams are of substances that smell like mint. The similar structures are in red.

molecule is of dominant importance for the smell impression. The grouping of odors in classes according to similarity of chemical structure, or, in other words, the fact that small changes in the active part of the molecule produce only slight alterations in the odor sensation, may be explained by the assumption that the various substances in a class fit the receptor molecules more or less closely.

The consulting chemist Jerome Alexander and George B. Kistiakowsky of Harvard University have suggested that odoriferous substances act by interfering with enzyme-catalyzed reactions in the odor receptors. Since enzymes are affected in their action by exceedingly small amounts of a variety of substances, this theory plausibly explains the high sensitivity of our sense of smell and the wide range of compounds that possess odors. The well-known reversibility of inhibitory effects on enzymes would account for the rapid recovery of the reception system to normal, thus enabling it to register new odor impressions.

As HAS BEEN mentioned, odor strongly affects the flavor of food. We are suddenly reminded of this when a cold inactivates our olfactory system. The food tastes flat, since we are dependent on our sense of taste alone. We are left with a distinction between bitter, sweet, salt and sour.

The sensory apparatus of taste is located chiefly on the upper surface of the tongue, at the soft palate, on the epiglottis and at the beginning of the gullet. Here lie the so-called taste buds, estimated to number about 9,000. It is fairly certain that different tastes are located at different places. The bitter sensations are definitely located at the back of the tongue, whereas the sweet and salt receptors are at the tip and edges. It is generally accepted that we possess four different taste senses—bitter, sweet, salty and sour.

We taste things only when they are dissolved in water. To detect a substance by taste we need a far greater amount than we can detect by smell—about 3,000 times as much in some cases.

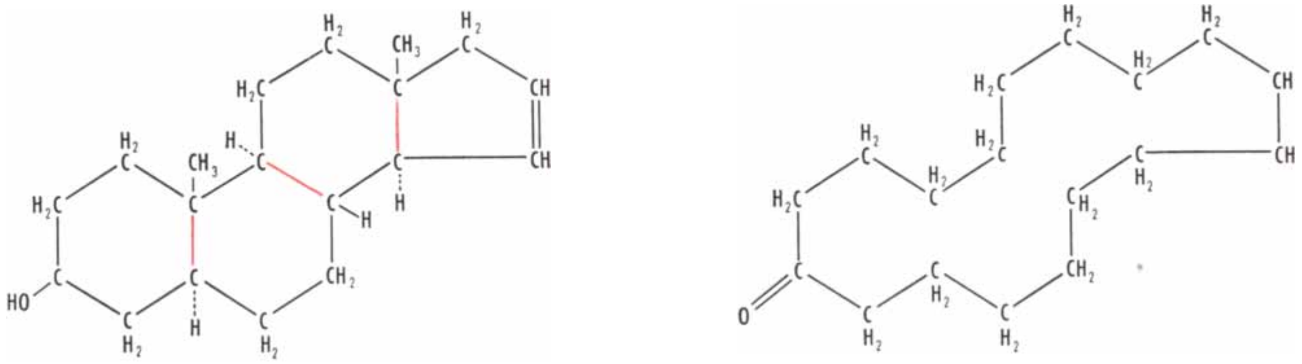
As in the odor field, attempts have been made to find the chemical relation among the members of each of the four taste groups. The sour taste is related to the acidity of the solution, though not in direct proportion; for example, a 1/200 normal solution of acetic acid tastes just as sour as a 1/800 normal solution of HCl, which is four to five times as acid.

Salty tastes are produced by inorganic salts. The anions of chlorine, bromine, SO_4 and NO_3 are especially effective in producing this saline taste when combined with the proper metal ions. For example, sodium chloride is salty, whereas cesium chloride has a dominating bitter taste.

The sweet taste is given by sugars, saccharin, dulcin and beryllium chloride. It is difficult to see what these substances have in common. As in the cases of odor substances, minor changes in these compounds do not remove the sweet taste. For example, compounds somewhat related to glucose, such as glycerol, are sweet.

The bitter taste, similarly, is exhibited by a wide variety of compounds—many alkaloids, certain glucosides, bile salts, magnesium and ammonium salts.

Bitter and sweet are closely related, and a slight modification of the molecule is sometimes enough to produce strongly bitter substances instead of the expected sweet ones. For example, when the oxy-



STRUCTURAL SIMILARITY of a steroid molecule (*left*) and that of a ketone (*right*) causes them to have the same musky odor. The carbon chain of the steroid molecule is cross-linked (*red lines*), while the carbon chain of the ketone is not. The effect of the two molecules on the smell receptors is nonetheless much the same.

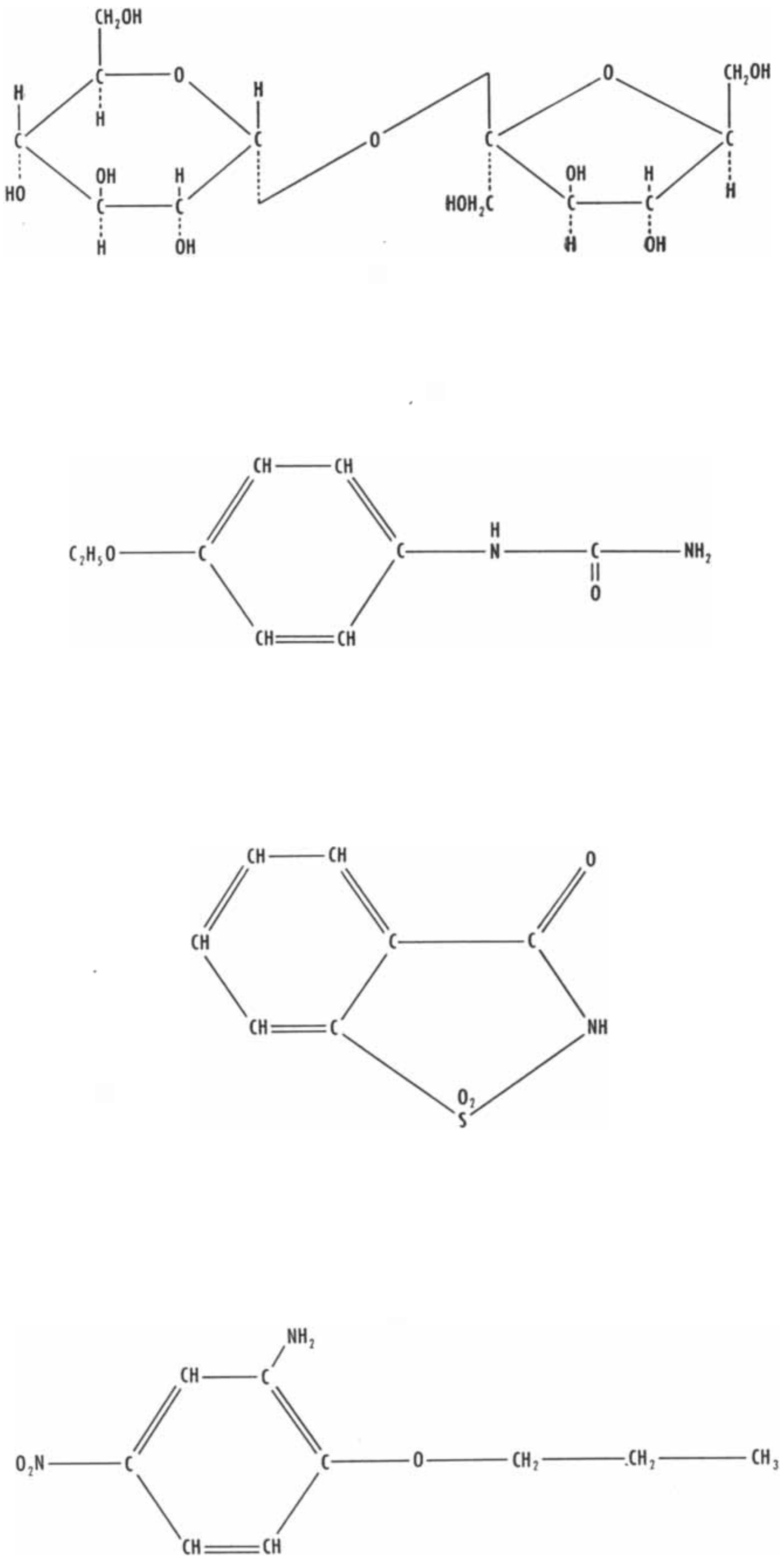
gen in the sweet material dulcin is replaced by sulfur, we get the bitter compound p-ethoxy-phenylthiocarbamide.

This substance, and the material from which it is derived (phenyl thiourea), brings out an interesting point: just as people may have color blindness, some people have certain kinds of "taste blindness." To three or four out of ten people, this substance is not bitter but tasteless. Apparently it is a hereditary taste deficiency, which started among Caucasians and spread to other races. Since the discovery of this particular type of "taste blindness," many more substances have been found to exhibit similar taste properties. Sodium benzoate, tasteless to most people, tastes either sweet or bitter to one out of four. Such experiments demonstrate vividly the truth of the saying *"De gustibus non est disputandum."*

A search for a common factor that would account for the similarity in taste of the bitter-or-sweet substances is not likely to be successful. As in the odor field, we have to turn our attention to the receptor cells to find the mechanism of taste perception, Here, too, an enzyme theory seems to be the most promising approach. An investigator of the taste mechanism is in a more fortunate position than those studying the odor receptors, because the four basic tastes, though subjective, are a great deal more sharply defined than the basic odor types. In addition, experimental work is aided by the fact that the taste buds are more accessible and are located in different places for the four tastes. This allows one to carry out reactions on the tissues and to study the influence of a number of taste substances on the cell mechanism. By such histochemical methods it has been shown that the skin overlying the taste buds contains relatively high concentrations of certain enzymes such as alkali phosphatases and esterases, and that these enzymes are inhibited by substances having a well-defined taste and are not inhibited by others.

In the past, studies of odor and taste reception have concentrated on the stimulants and attempted to deduce the nature of the reception mechanism from them. At best such deductions will be vague and uncertain. For a real understanding of the basic processes, we must study the happenings in the receptor cells themselves. The enzyme theory and the other new working hypotheses about the tasting and smelling processes illustrate this shift in emphasis. They may stimulate the exceedingly difficult experimental work that is necessary before solutions of the odor and taste problems can be found.

A. J. Haagen-Smit is professor of bio-organic chemistry at the California Institute of Technology.



SWEET SUBSTANCES have molecular structures apparently with little in common. From top to bottom these molecular diagrams represent sucrose (sweetness arbitrarily taken as 100), dulcin (sweetness 265), saccharin (sweetness 675) and 4-nitro-2-amino phenyl propyl ether (sweetness 3300).

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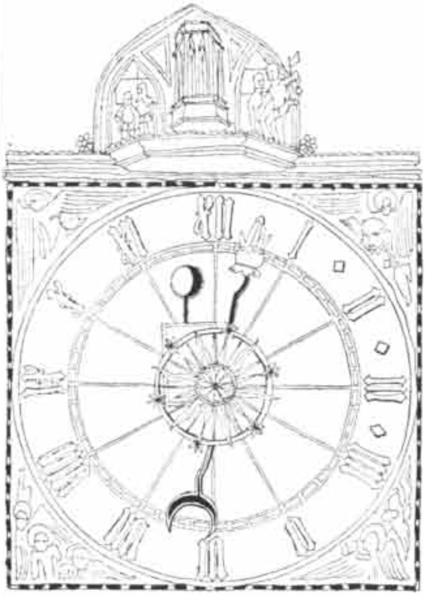

SCIENCE AND

Science in the Budget

PRESIDENT TRUMAN'S proposed $85.4 billion budget for fiscal 1953 includes more than $6 billion for research, education and development programs of various kinds, including the work of the Atomic Energy Commission. He requested:

$1,775 million for atomic energy
$1,400 million for military research
$1,424 million for surveys and conservation of natural resources
$594 million for aid to education
$341 million for promotion of public health
$329 million for agricultural conservation
$151 million for agricultural research and other services
$38 million for housing research
$15 million for the National Science Foundation
$9 million for the National Bureau of Standards
$2 million for the Census.

Meanwhile the Association of American Universities, disturbed by the disruptive effect of the Government's huge military research programs on basic science and education in the U. S., has adopted a cautioning resolution. It asked the Office of Defense Mobilization to keep the number of military research programs to a minimum, to avoid "personnel policies and rates of compensation which might embarrass or weaken other institutions," to pay scientists under contract with it no more than their normal salary and to rotate the workers on military research so that all faculty members will return to their normal duties within two years.

In a reply published in *Science,* Oliver E. Buckley, chairman of the ODM's Science Advisory Committee, expressed general sympathy with the sentiments of the universities. "It is our understanding," he wrote, "that the number of [large-scale military research] projects currently under consideration is small and not likely greatly to increase."

AEC

PRESIDENT TRUMAN announced a five-year program of expansion of atomic energy facilities which will cost $5 to $6 billion and more than quadruple the nation's investment in atomic energy. The new program will start in July, 1953, after the supply of uranium and trained technicians has been increased to the necessary strength.

In its 11th Semiannual Report, issued last month, the AEC noted that the Paducah and Savannah plants under construction, together costing over $1.7 billion, will nearly equal the value of all the plants, real estate and equipment of the General Motors Corporation. The Savannah plant alone will be worth $1,250 million—almost as much as Bethlehem Steel and considerably more than all the fixed assets of E. I. du Pont de Nemours. The report says: "The total amount of earth excavated at the two sites by December 31, 1951, would build a solid wall 5 feet wide and 7 feet high reaching from New York to San Francisco."

The report announces some new discoveries in AEC's affiliated laboratories: physicists at Brookhaven have used a new classification scheme to "predict the existence of several new isomers"; at the University of California's Radiation Laboratory experimenters discovered a nuclear reaction in which bombardment by protons transforms helium 4 to helium 3 with emission of a deuteron; at Oak Ridge workers found that one roentgen of X-irradiation produces one new mutation for every 200 mice. Most of the report is devoted to a review of AEC-sponsored work in plant biology; one new development is the possibility that radiation-created mutations in corn may provide breeders with a renewable supply of genes, obviating the present need for world-wide exploration to find strains with desirable characters.

To replace Sumner T. Pike on the Atomic Energy Commission, President Truman last month nominated Eugene M. Zuckert, Assistant Secretary of the Air Force since 1947 and former Assistant Dean of the Harvard Business School.

The Atom in Brazil

THE government of Brazil is planning to construct an "atomic city of the future," and a special commission has already been appointed to survey a site for a pilot nuclear reactor. Admiral Alvaro Alberto, chairman of the Brazilian National Research Council, made this announcement last month during a visit to the U. S. with five other Brazilian atomic experts.

Brazil's atomic energy program will presumably be based on the country's vast deposits of thorium, which can be transmuted into fissionable uranium 233. Gordon Dean, chairman of the U. S. Atomic Energy Commission, visited Brazil last November to arrange for import of the mineral to the U. S.

Admiral Alberto emphasized that Brazil is planning on a long-range basis; the first step toward the "atomic city" will be the establishment of postgraduate training in nuclear physics to prepare Brazilian scientists to build and run it.

Barred Visitors

SCIENTISTS' organizations in the U. S. have been increasingly disturbed by a series of exclusions of scientists from abroad under the McCarran Act. Several months ago the State Department refused a visa to E. B. Chain, co-discoverer of penicillin and a Nobel prize winner. A visa for the British physical chemist and economist Michael Polanyi, who had been invited to the University of Chicago as a guest lecturer, was held up so long that he resigned the appointment. Two members of a group of Mexican physicists invited to a meeting of the American Physical Society in Houston, Tex., were denied visas, and the party called off the visit.

The council of the American Association for the Advancement of Science adopted a resolution at its December meeting urging modification of the McCarran Act. Last month four prominent faculty members of the University of Chicago filed a protest with Secretary of State Acheson. They were Samuel K. Allison, director of the Institute for Nuclear Studies; Cyril S. Smith, director of the Institute for the Study of Metals; John U. Nef, chairman of the Committee on Social Thought, and Lawrence A. Kimpton, Chancellor of the University, who endorsed a letter by the first three printed in the *Bulletin of the Atomic Scientists*. They said:

"It has become very difficult for a reputable university in the U. S. to invite foreign scholars to participate even temporarily in the intellectual life of the institution. . . . We are losing contact with the scholarship and ideas of the world outside us. Our country is strong enough to hear itself criticized, if visitors and immigrants care to criticize us. We urge that action be taken to replace the objectionable McCarran Act with a set of carefully considered and workable regulations."

NSF Report

THE National Science Foundation's first annual report to Congress, delivered last month, was devoted mainly to urging the need for basic research as a foundation for technological advance. Looking ahead to the coming year, when for the first time it will have an appropriation ($3.5 million) to start its work, the Foundation listed among its high-priority projects: the development of a national science policy, a survey of current research expenditures, a survey of problems in the publication of scientific work, research on improving scientific communication, an inventory of scientific manpower, support of basic research "on as broad a geographic and institutional basis as possible" and, above all, a fellowship program for graduate students of science. Twenty-eight hundred applications have been received for the 400 fellowships that the Foundation will award this year.

Engineers

ENROLLMENTS in engineering schools, which had been declining, showed an encouraging upturn this year, the U. S. Office of Education reports. The schools have 16.2 per cent more freshmen than last year. This means that in 1955 the number of graduating engineers should begin to rise, after dropping to an estimated low of 17,000 or less in 1954. The engineering schools are expected to turn out 28,000 graduates this year—a 25 per cent decline from last June's 38,000.

The increase in this year's freshman enrollment is attributed to an intensive campaign to win new students.

Fellowships Taxable?

THE value of thousands of fellowships awarded annually by foundations, universities, corporations and government agencies may be reduced by a recent ruling of the Treasury Department. The Bureau of Internal Revenue decided that some fellowships are subject to income tax.

The Bureau held that a grant is tax-exempt if it is solely for an individual's training or education and "no services are rendered as consideration therefor," but that it is taxable when the recipient "applies his skill and training to advance research, creative work or some other project or activity." The ruling specifically declared taxable grants made by the Guggenheim Foundation to a chemistry professor for study of structural

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chemistry, to a writer to complete a novel, to a biologist to study aquatic fungi and to a social scientist for research on the relations between government and economic processes.

The Bureau has assigned an agent to work full time on fellowships. It contends that some universities and corporations have abused tax exemption by calling payments for services fellowships. But its ruling appears so sweeping that some believe it will affect all the large fellowship programs, including those of the Rockefeller Foundation, the Atomic Energy Commission, the National Research Council and the National Science Foundation.

$140,000 for Watson-Watt

SIR ROBERT WATSON-WATT, the British pioneer in the development of radar, has received an award of £50,000 (about $140,000), tax-free, from the Royal Commission on Awards to Inventors. The money was part of an £87,000 grant to Watson-Watt and nine of his colleagues, in recognition of their claim that "without radar the Battle of Britain would have been lost and these islands invaded."

Such large government grants to outstanding inventors are a well-established practice in Britain. Four years ago Sir Frank Whittle got £100,000 for developing the jet engine.

On the Nation's Health

ABANDONING his demand for a national health insurance system, President Truman has appointed a 15-member Commission on the Health Needs of the Nation to determine the nation's "total health requirements" and to recommend within a year ways of meeting them. The Commission will look into such questions as 1) the shortage of medical workers, public health units and hospital beds; 2) ways to speed up medical research; 3) what can be done to improve the care of the chronically ill and aged. The Commission's chairman is Paul B. Magnuson, former Medical Director of the Veterans Administration, who is known to oppose national health insurance.

John W. Cline, president of the American Medical Association, nonetheless attacked the survey as "another flagrant proposal to play politics with the medical welfare of the American people . . . a shocking attempt to give White House sanction to the brazen misuse of defense emergency funds for a program of political propaganda." Gunnar Gundersen, a member of the A.M.A.'s board of trustees, whom the President appointed to the Commission, refused the appointment.

Magnuson commented: "If the A.M.A. hierarchy devoted as much time to care of their patients as they do to

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Why Stars Explode

EVERY three or four hundred years one of the stars in the Milky Way blows up in a mighty explosion. These supernovae, which occur in other galaxies as well as ours, are believed to be due to some kind of rapid nuclear reaction that causes the star to collapse and shoot out great streams of hot gas ("Supernovae," by George Gamow; SCIENTIFIC AMERICAN, December, 1949).

Physicists have been speculating for some time about what the nuclear reaction may be. Lyle B. Borst of the University of Utah, who was formerly in charge of the atomic reactor at the Brookhaven National Laboratory, now suggests one. It is the fusion of two helium atoms, of atomic weight four, to produce beryllium 7—a radioactive isotope of beryllium which is not found naturally on earth. Borst said that this reaction, absorbing huge quantities of energy, could account for the sudden collapse of interior pressure in a star and the consequent ejection of its hot matter. The reaction is so rapid that a star could convert all of its helium into beryllium in one day. Borst believes that it would occur after a star had burned up its hydrogen and converted it into helium. Discussing his theory at a recent meeting of the American Physical Society in New York, he pointed out that beryllium 7 has been created artificially at the Brookhaven laboratory.

The half-life of beryllium 7 is 53 days. According to those who described the three supernovae observed in our galaxy (in 1054, 1572 and 1604), in each case the exploding star lost half its brightness in just about 53 days. Borst takes this to mean that the stars consisted of at least 90 per cent beryllium after their collapse.

There is a diffuse object, called the Crab Nebula, in the part of the sky where the first supernova was seen by Chinese astrologers in A.D. 1054. It is an expanding cloud, believed to have come from the explosion. According to Borst's theory, neutrons released in the fusion reaction that creates beryllium should convert nitrogen in the star into radioactive carbon 14. Consequently the Crab Nebula should contain carbon 14, and if this material can be detected in the Nebula, the new theory will be strongly corroborated.

TV Progress

THE number of educational programs on television is increasing, but so is the proportion of time devoted to crime melodrama. This was reported last month by Dallas W. Smythe of the University of Illinois, who made a follow-up study of the offerings of New York's

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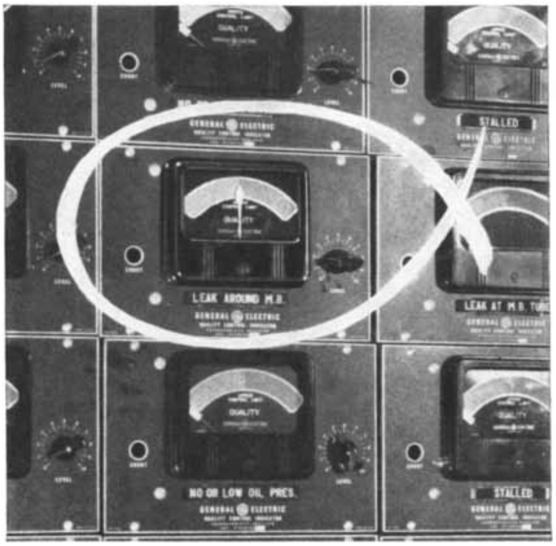

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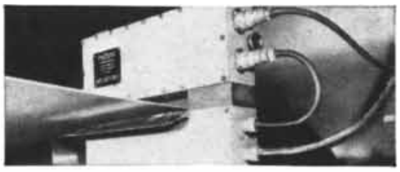

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GENERAL ELECTRIC

687-90

seven television stations, similar to the one he directed last year for the National Association of Educational Broadcasters ("An Analysis of Television Programs," SCIENTIFIC AMERICAN, June, 1951).

Smythe's monitors found that the New York stations now carry 13 programs connected with educational institutions, as compared to only one a year ago. Crime plays have increased from 10 to 14.6 per cent of the total broadcast time, and Westerns account for 8.3 per cent of the total time. The time devoted to commercials dropped from 10 to 8 per cent of the total. The watchers had to sit through 11.3 per cent more program time this year—627 hours and 25 minutes.

Seymour N. Siegal, president of the group for which the study was made, said the appearance of 13 educational programs shows "a distinct improvement in what commercial broadcasters are doing." But educators still felt that the preponderance of crime and variety shows pointed to a need for educational stations. The Federal Communications Commission has received some 500 expressions of interest from various institutions in the 207 channels it has reserved for education.

Group Therapy

TWO psychiatrists at a Veterans Administration hospital in Arkansas report that group psychotherapy can significantly improve the condition of schizophrenics.

Henry N. Peters and Francis D. Jones measured the results of group therapy by two tests that had not been used for this purpose before. One was the Porteus Maze Test, generally applied as an intelligence test for illiterates; it is a simple route-tracing test like the mazes often printed in newspapers' puzzle pages. The other test, the Mirror-Tracing Test, has been used in studies of frustration; it requires copying a six-pointed star from its image in a mirror, while the subject's writing hand also is visible only in the mirror.

Projective tests such as the Rorschach and conventional intelligence tests have failed to show any consistent benefit to schizophrenics from psychotherapy. But in the maze and mirror-tracing tests, which Peters and Jones consider more sensitive, they found that seriously ill schizophrenics definitely improved in performance after several months of group therapy, while a control group did not. The two investigators reported their results in the *Journal of Consulting Psychology*.

The Regents' Tests

AS the result of protests from various groups, the New York State Education Department abandoned its inten-

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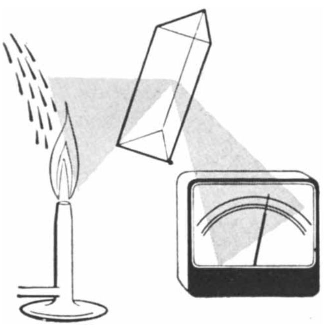


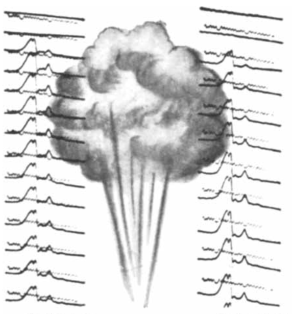
MENTAL DISEASE, ACTH AND FLAME PHOTOMETRY

Flame photometry has uncovered the explanation for one important trait in schizophrenia. Schizophrenics do not respond to stress situations in the same way as other persons. Normally, stress situations evoke an outpouring of steroid hormones from the adrenal cortex, initiated by ACTH from the pituitary gland. These hormones play a significant role in stress situations. But in persons afflicted with schizophrenia, this response is lacking—even after injections of ACTH.

Among the functions of the cortical steroid hormones is regulation of the salt and water balance in the body, particularly sodium and potassium. Changes in concentration of these two salts are among the most useful indices of adrenal cortical hormone levels—and flame photometry is the simplest, fastest and most accurate way of determining body sodium and potassium content.

OSCILLOGRAPHIC INFRARED

No one is quite sure of what the chemical changes are in a shortlived explosion, but a combination of infrared analysis and video-scanning methods is helping to find the answer. Infrared spectra, like those shown, have been taken from a video screen at the rate of 150 per second of explosions in closed chambers. Their study gives the history of the intermediates formed, the effect of varying component concentrations, the time involved. Another use of infrared analysis—chemistry's versatile tool for analysis and product control.



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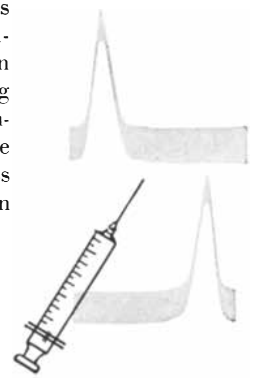

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tion to omit questions relating to the germ theory of disease from the mid-year Regents high-school examination in biology (SCIENTIFIC AMERICAN, February). The examination given last month did include such questions. The New York Academy of Medicine and the Teachers' Guild are still pressing, however, for repeal of the recently enacted law that excludes from the compulsory curriculum health topics which may conflict with Christian Science teachings, and a repealer bill has been introduced in the Legislature by State Senator Samuel Greenberg of Brooklyn.

Disaster Psychology

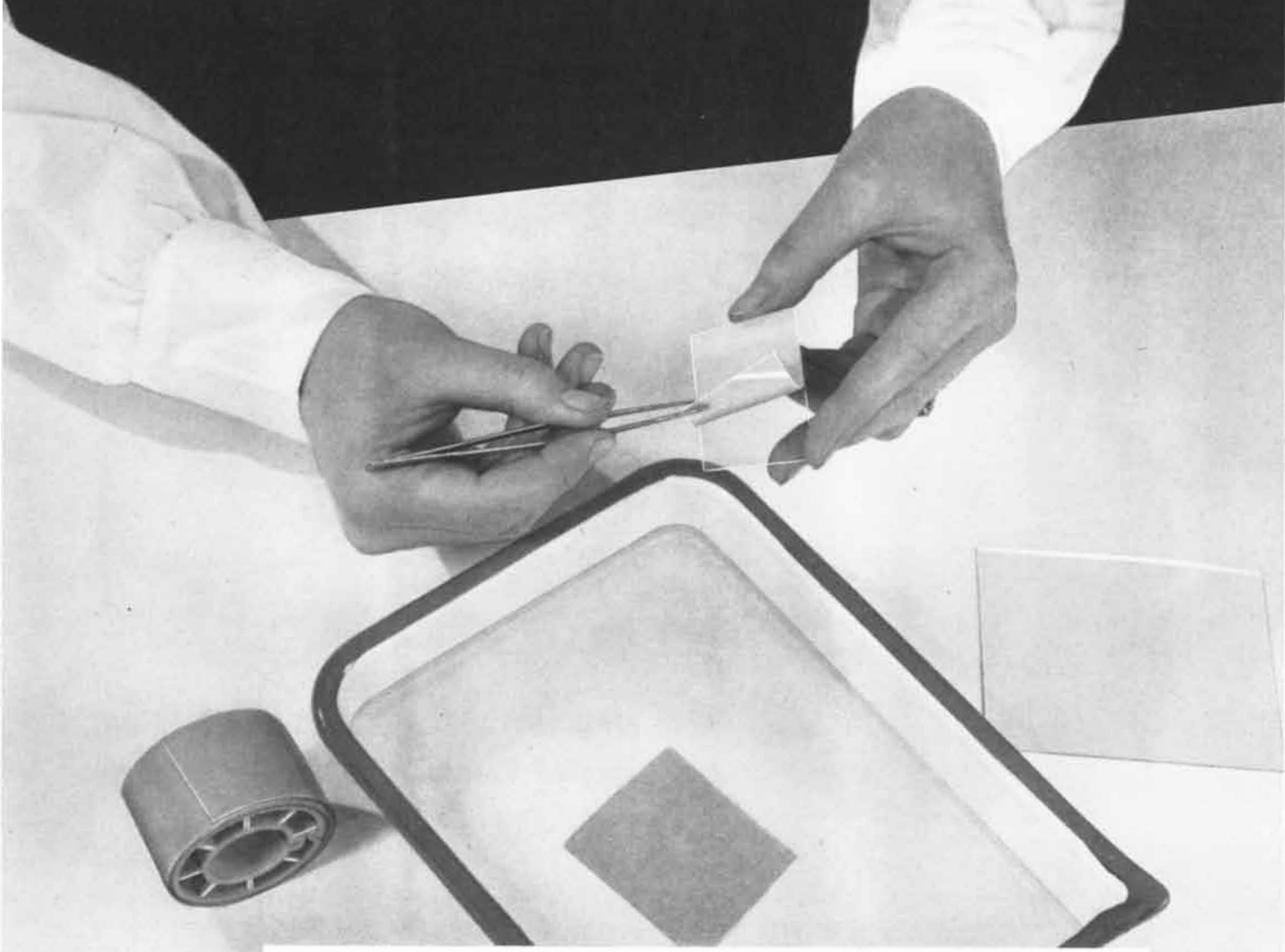
HOW do the citizens of a community react when catastrophe strikes? Lewis M. Killian of the University of Oklahoma interviewed survivors of the Texas City explosion and of three Oklahoma tornadoes to find out how people behaved in those crises, and he reports his findings in *The American Journal of Sociology*.

He learned that the great majority, including policemen and firemen, rushed first to look after their own families. The result was great initial "confusion, disorder and seemingly complete disorganization."

"There were important exceptions," Killian added. "Most of the refinery workers in Texas City did stay on the job until their units were safely shut down, as they had been trained to do." So did public utility workers. "The chief of police remained at his post from the moment of the first explosion until seventy-two hours later . . . (due) to the fact that he knew that his family was safely out of town, visiting relatives, at the time."

Where a conflict arose between property and life, the normal reaction was to disregard property. But one refinery official, who had never lived in Texas City, recounted: "The assistant superintendent told me that their top men had been killed and asked me what I thought he should do. I told him, 'You should take charge of the company's property. That's what the president of your company would tell you if he were here.' "

More typical was the action of one man in a tornado town who "sensed the approach of the tornado only minutes before it struck. In spite of great personal danger he rushed through the storm to a theater where his children were attending a movie. There he prevented the frightened audience from pouring forth into the storm by holding the doors closed. Later he was acclaimed as a hero whose quick action had saved the lives of many of his fellow-citizens. He himself denied that he had any thought of taking the great risk that he took for the sake of the anonymous audience itself; he was thinking only of his own children."



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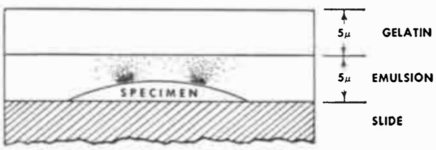

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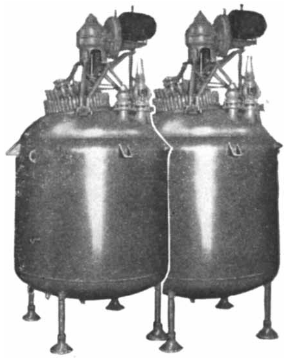

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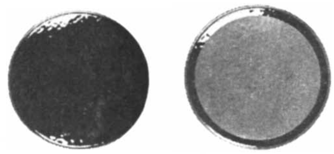

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The Quantum Theory

Concerning the early years of this fundamental concept of modern physics: how Max Planck formulated it at the turn of the century and how others enlarged it up to 1923

by Karl K. Darrow

THIS is the history of a physical theory which began in 1900 by taking over a small province of physics and now has extended its empire over almost the whole of the sciences of physics and chemistry. More precisely, it is half of the history, for it carries the story only to 1923, which happens to be about as far along the road as the nonphysicist can travel easily. The story is that of the quantum theory, and this account will relate the main events in its early history.

Usually a doctrine or discovery in science does not spring unheralded and full-blown from a single man's brain; behind the reported founder of the doctrine there are likely to be others who partly anticipated him, and the origin of the idea may be lost in the mists. This cannot be said of quantum theory. The recognized founder was the actual founder, and there was no one behind him. His name was Max Planck; he was born in Germany in 1858, and he died there in his 89th year in 1947. Tacitus has said of some Roman character that he was *felix opportunitate mortis*—he was lucky to die when he did. Not so for Planck: he suffered grievously in the two world wars, losing a son in each and his house and his library in the second; he would have had a happier life if he had died in 1914. He would also have been equally famous, for his grand idea had come at the turn of the century.

Planck achieved his doctorate by a thesis on an experiment in the diffusion of hydrogen through palladium. This was the only experiment he ever performed: one may suspect that it was imposed on him rather than chosen by him. Even before he won his doctorate, he had devoted himself to the theoretical study of the foundations of thermodynamics. He saw rather more deeply into the second law of thermodynamics than anyone before him, and his textbook on thermodynamics is still a classic.

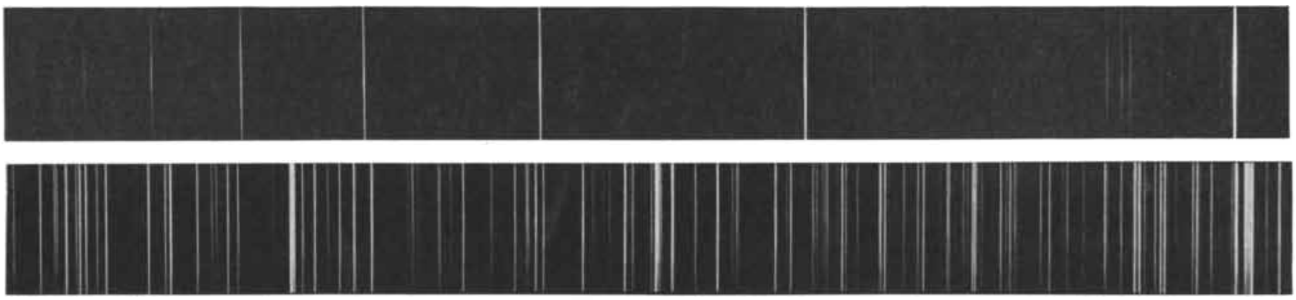
It was by way of thermodynamics that Planck came to the quantum theory. Thermodynamics is a hard subject, and Planck arrived at the quantum theory by the hard way. When he entered upon thermodynamics, it was a science of heat in matter. Planck extended it to light.

The Cavity Problem

Imagine a cavity inside a solid body. There is a small perforation in the wall of the cavity, out of which light can come. It must be large enough so that we can get enough light out of it to analyze with a spectroscope; it must also be small enough so that the light which comes out will be a fair sample of what the light inside would be if the perforation were not there. We have therefore to assume that one and the same perforation can be neither too large nor too small. This sort of double-barreled assumption is frequently made in physics, and in this case at least it has not yet led us into any trouble.

First let us suppose that there is some gas inside the hollow. For definiteness let the gas be helium, which is a nice monatomic gas and nearly a perfect gas. The gas has energy, which is the kinetic energy of its atoms. This kinetic energy we know to be proportional to the absolute temperature. We also know that the energy is proportional to the number of atoms. If I pump half of the gas out of the cavity while the temperature remains the same, the energy of the gas in the hollow is reduced to one-half; if I pump extra helium into the cavity so as to double the quantity, I double the energy.

Let us now imagine that all of the gas is pumped out. The cavity is still not empty, for it still contains light, in fact, just the same amount of light as while the gas was there. Since the cavity contains light, it contains the energy of that light. This energy is proportional, however, not simply to the temperature but to the *fourth power* of the temperature. There is also a much more important difference between light and helium: namely, whereas the energy of the helium in the cavity is proportional both to the absolute temperature and to the amount of helium, the energy of the light depends only on the temperature. There is no point in saying that the



SPECTRA OF HYDROGEN show bright lines which correspond to energy transitions in the hydrogen atom and molecule. The brighter lines in the top spectrum are emitted by atomic hydrogen; the more complex lines in the bottom spectrum, by the hydrogen molecule. The spectra were made at The Johns Hopkins University.

energy of the light is proportional to the amount of light, for the amount cannot be varied. There is no pump by which I can pump out half of the light and leave the rest. I could indeed increase the amount of light in the hollow by shining a searchlight through the perforation, but this would make no lasting difference. The beam of the searchlight would be absorbed in the walls of the cavity and heat them up; as soon as I turned off the searchlight, the temperature would start to revert to its original value, and when it got back to its initial value there would be the same amount of light in the cavity as before.

The light emerging through the perforation has a perfectly distinctive spectrum, and this we have already assumed to be identical with the spectrum of the light inside the cavity. On a graph in which energy is plotted against frequency, the spectrum has a single broad hump, meaning that the energy is greatest at the middle wavelengths in the spectrum and least at the highest and lowest frequencies. This spectrum has several names. Planck called it the "normal spectrum." Germans generally call it the spectrum of "cavity radiation," which is the best name. English-speaking people usually call it the "black-body spectrum," because a perfectly black body would emit light of this composition. (It seems paradoxical that a black body should emit light, but it is no paradox at all when we remember the distinction between emission and reflection. The practical definition of blackness is that it is the quality of not reflecting light. A black body does not reflect, but it may emit; in fact, it is the most powerful possible emitter of light. We ordinarily look at bodies—black, white or colored—when they are reflecting light but are not hot enough to emit an appreciable amount of visible light. At temperatures of incandescence a black body would look brightest of all.)

Little Resonators

Planck set out to explain the black-body spectrum. He postulated that all solid bodies, and therefore the walls of the cavity, contained little oscillators—he called them resonators—of every imaginable frequency. By resonators Planck meant small electrified particles which wiggled to and fro. (A few years later he identified them as vibrating electrons, but in 1900 the electron had only just been discovered and was far from well established in physics.) It followed that in any range of frequencies, however narrow, there must be resonators having frequencies in that range. Take, for instance, the bright yellow spectrum-line of sodium which is designated by the letter D. We are to imagine that there are resonators having frequencies within this narrow range. All of them are emitting yellow light into the cavity, and yellow light is coming right back out of the cavity and bathing them and stimulating them to continued oscillation. There is an equilibrium between the energy of the resonators and the energy of the yellow light. So it is with the energy of blue light and the resonators which have the frequency of blue light, and so it is throughout the entire spectrum. If by any valid line of reasoning one could arrive at the energy which the resonators of any frequency have when they are in equilibrium with the light, one would be able to arrive by one simple further step at the energy which the light of any frequency has when it is in equilibrium with the resonators. This would be the answer to Planck's question, for it would give the black-body spectrum.

There was an answer to this question before Planck, but the answer was a disaster. This "classical" answer was that all of the resonators have the same energy, no matter what their frequency. From this it followed that the quantity of light in the cavity would be infinite, and since the quantity of light in the cavity actually is finite, the theory was sunk.

The flaw in the classical theory lay in one of its assumptions—indeed, a very plausible one—to wit: that any resonator may have any amount of energy; in other words, that it may go continuously up or down the energy-scale through all levels, like a man walking up or down a ramp. Planck replaced the ramp by a ladder, with its rungs, as in any practical ladder, at equal intervals. His assumption was that the resonator must always be on one or another of the rungs, and if it proceeds up or down the ladder, it must proceed by jumping from rung to rung. That is to say, it may absorb or emit energy only in certain discrete units, represented by the equal spacing from rung to rung of the ladder. Planck then affirmed that the spacing between the rungs of the ladder was not the same for all resonators but must be proportional to the frequency of the resonator in each case. He designated the spacing, or energy unit, as $h\nu$, and said that h is a universal constant, ν being the frequency of the resonator.

Planck's substitution of the ladder for the ramp not only avoided the disaster of infinity, but yielded the actual form of the black-body spectrum. To explain just why it did so, it would be necessary to define entropy; to quote what is called Boltzmann's relation between entropy and probability; to define probability in a very special and peculiar way; to derive the formulas for the probability and the entropy of a flock of resonators, among which parcels of energy of the amount $h\nu$ are distributed in the most probable way; to say that the derivative of the entropy with respect to the energy is the reciprocal of the absolute temperature; to show that when all this is done, one arrives at a formula which gives the energy of the resonators of any chosen frequency ν as a function of the temperature, and to conclude by showing that out of this formula comes the black-body spectrum which is ratified by experiment. This skeleton of the argument shows that the argument itself can find no place in an article designed for people who are not mathematical physicists. It will certainly be conceded that Planck got to the quantum theory the hard way.

The constant h is known as Planck's constant. Its value must be determined by experiment; it is not prescribed by theory. It has been measured in a variety of ways, and all of the measurements agree. Planck may be characterized as the man who put h into physics. People who drop the h are sometimes called cockneys; in this sense the physics of the period before Planck may be called cockney physics. If the physicists of that period could return for a glimpse of our physics, they might say that it is cockeyed physics—and yet ours is right, and they would be wrong.

I have said that the rungs of the ladder—the "levels," as they are more generally called—are spaced at intervals $h\nu$; I have not said where the ladder starts. In Planck's original theory the bottom rung was at zero: the energy-values permitted to a resonator were 0, $h\nu$, $2h\nu$, $3h\nu$, and so on. Later Planck revised his theory and located the bottom rung at the energy-value $(\frac{1}{2})h\nu$, so that the subsequent rungs followed along at $(\frac{3}{2})h\nu$, $(\frac{5}{2})h\nu$, and so on. So long as we concern ourselves with black-body radiation alone, it makes no difference where we start, but other phenomena confirm Planck's second choice.

Particles of Light

If light is emitted and absorbed only in units of size $h\nu$, the obvious next step is to infer that light travels around in units or parcels or particles of energy $h\nu$. But this is a step that Planck himself did not take. According to some of those who knew him and to the evidence of his own writings, Planck was a revolutionary of a very conservative kind. He took one radical step when it was necessary, but he was not daring enough to try to revive the corpuscular theory of light, and this is understandable in view of its state at the time.

In 1900 the corpuscular theory of light was very dead. Newton's idea that light consisted of particles had yielded in the 19th century to the wave theory, and almost anyone who might have attempted to restore the corpuscular theory would have run grave danger of being rated a crank. To resurrect it there was needed a man possessed of (a) prestige, (b) courage, (c) knowledge

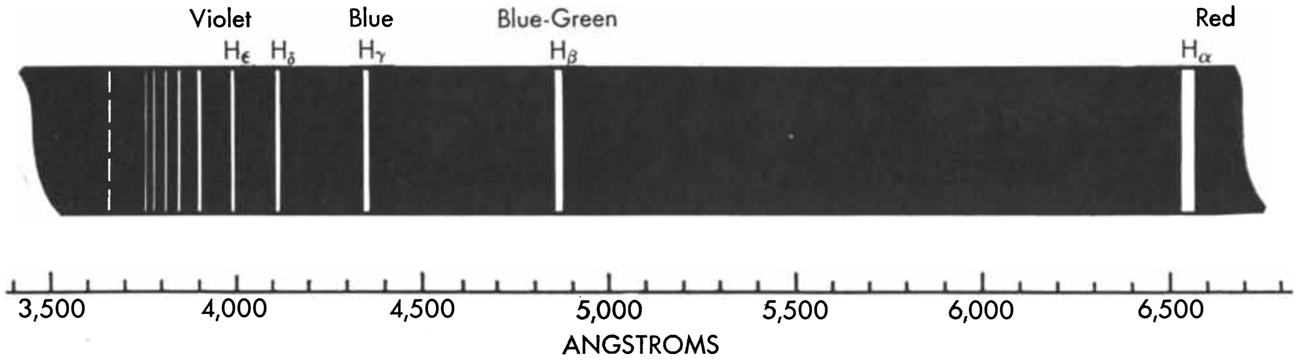
MAX PLANCK was born in 1858 and died in 1947. On the wall behind him in this only partly fanciful reconstruction of his study are the portraits of nine men of notable importance in his scientific life. From left to right they are: Helmholtz, Einstein, Bohr, Clausius, Pringsheim, Lummer, Rubens, von Laue, Sommerfeld.

of Planck's theory and (d) knowledge of certain experiments which had not yet been performed when Planck put forth his theory. There was such a man, and his name was Einstein.

The new experiments were those on the photoelectric effect. This effect consists in the emission of electrons from metals under the influence of light. Think of a beam of light playing on a piece of metal—sodium, for example. The beam of light, Einstein imagined, consists of corpuscles of energy hν. Some of them are reflected from the surface of the metal; these do not concern us. Others enter the metal, and one of these may be absorbed in such a way that it vanishes completely, yielding up its entire energy hν to a single electron in the metal. The electron thereby gains enough speed and energy to spring out of the metal, and it becomes a "photoelectron." Once it is out, we can measure its kinetic energy.

This energy of course is something less than hν. The electron has had to spend a certain amount of its energy in order to leave the metal; we might describe this as the fee it pays at the surface of the metal for its exit-visa. We denote this fee by the letter W; thus the energy the electron has left when it gets out to where we can observe it is hν minus W. If we could measure only photoelectrons released by one frequency of light we should be unable to separate W from hν. But we can experiment with beams of light of many different frequencies, and can find the kinetic energy of electrons emitted under the impact of each frequency. The theory says that if we plot the electron-energy E against the frequency ν, the points should lie along a straight line, described by the equation: $E = h\nu - W$. Experiments confirm that the points *do* lie along a straight line, and that the slope of this line is h, Planck's constant. As for W, it can be determined too; but we will leave that constant to the people who are most interested in it—the students of solid-state physics.

The discovery of this equation and the revival of the corpuscular theory of light are milestones in the history of physics. Einstein's theory inspired many famous experiments; one of the chief experimenters was Robert A. Millikan. It must be remarked that even Einstein was not bold enough to come out for the corpuscular theory of light unreservedly. He qualified his idea with a singular word, which I think proper to call a hedging word—"heuristic." According to the *New International Dictionary* heuristic means "serving to discover or reveal—applied to methods of demonstration which are persuasive rather than compelling, or which lead a person to find out for himself." I interpret that Einstein meant to convey that light acts in the photoelectric effect as though it



SPECTRAL LINES of atomic hydrogen are mapped against their color (*top*) and wavelength in Angstroms (*bottom*). This is the celebrated Balmer series, one of several such spectral series which reflect the energy transitions of the hydrogen atom. The study of these series led to Bohr's model of the atom (*see next page*).

were corpuscular, without committing himself further.

Today there is no longer any reason to hedge. The corpuscular theory of light has been re-established. In its re-incarnation it is the first child of the quantum theory. The art by which it is combined with the wave theory is also a triumph of quantum theory, but this is a part of the later history. A remark about language is appropriate here. It must come as quite a surprise to a student of language to learn that "quantum theory" and "quantum mechanics" and "quantum number" are terms very common in physics, while the word "quantum" itself has practically vanished. Quantum, first introduced to denote the quantity $h\nu$, later came to be applied to the corpuscles of light. In this latter sense it has been superseded by a much better word—photon.

Vibrating Atoms

The next province of physics to be invaded by the quantum theory was the province of heat in matter. The cavity exhibits heat in the form of radiant energy. Heat in solids is identified with the vibrations of the atoms. Since Planck had scored quite a resounding success with the assumption that oscillators interchange energy with radiation in discrete units, nothing could be more natural than to try out the same idea on the oscillating atoms in solids. Like other ideas which seem very natural after somebody else has thought of them, this idea took several years to emerge. Again we must salute Einstein as the theorist, and on this occasion Walther Nernst of Germany was the leading experimenter.

The classical theory (note that in physics the term "classical" is often applied to the last-but-one theory in the field) said that the heat content of a solid is proportional to its absolute temperature. Another way of stating the theory is that the specific heat of a solid, which is the amount of heat needed to impart a unit increase in temperature to a unit mass of the substance, should be independent of the temperature at which the solid happens to be when the heat is applied. Actually the amount of heat needed to raise the temperature of a solid by a unit (say one degree) falls off as its temperature declines. As experimentalists made progress toward lower and lower temperatures, the departures from the classical theory became more and more striking. The quantum theory arrived in time to take care of them. It was found that the ladder of levels is the same for the vibrating atom as for Planck's electrical resonator. Since there is no rung below $(\frac{1}{2})h\nu$, the quantum theory tells us that a vibrating atom can never have a lesser energy than this—not even at absolute zero temperature, where according to classical theory the atoms should be standing absolutely still. This singular result of quantum theory has been attested by experiment.

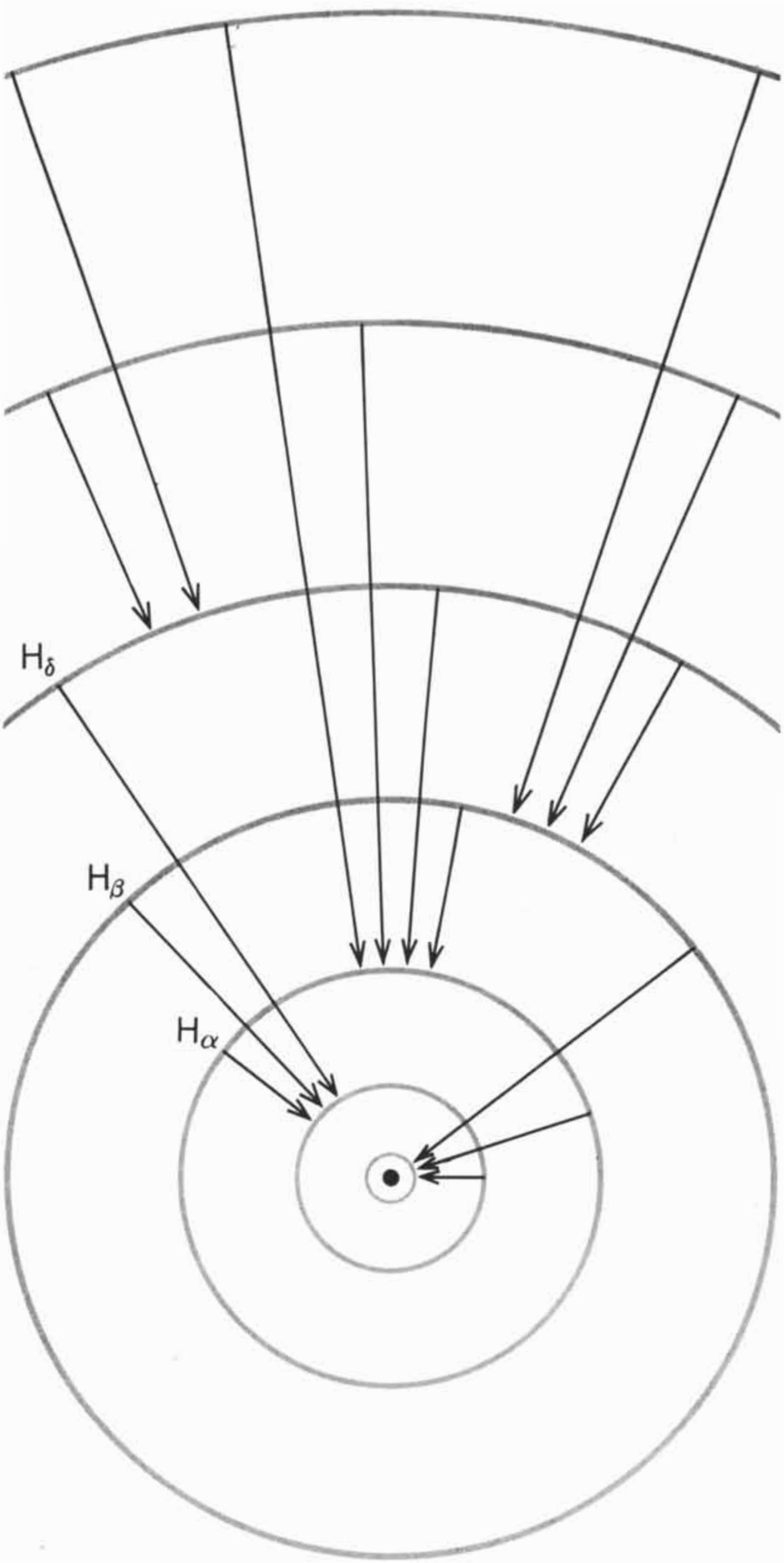
Another type of substance which defers to quantum theory is the gas whose molecules contain two atoms, such as hydrogen, H_2. The energy picture of a monatomic gas such as helium is simple: the kinetic energy of its atoms is purely the energy of traveling motion (*i.e.*, without the complication of rotation of the atoms themselves), and the quantum theory has nothing new to say about it—not at least until the temperature falls extremely low. But the molecules of a diatomic gas not only move about as traveling bodies but also rotate around the axis connecting the two atoms—think, if you will, of a dumbbell spinning end over end. The heat content of such a gas is partly the kinetic energy of traveling motion and partly the kinetic energy of rotatory motion. It was no slight step forward to imagine that rotatory energy may be limited to definite energy-values just as vibratory energy is. Starting from this advance, the quantum theory, which had already extended its domain over the fields of black-body radiation, the photoelectric effect and specific heat, was now to conquer the atom.

Before we begin that part of the story, I should make clear what is meant by the statement that rotatory energy is limited to certain definite discrete values, or, as the physicist says, is "quantized." Rotatory motion involves the concept of angular momentum, one of the most important in physics. For a particle revolving in a circular orbit, the angular momentum is the mass times the angular velocity; for a rigid body rotating around an axis passing through itself, the angular momentum must be found by calculation; often in quantum physics it appears as a quantity which is easy to measure but impossible to separate into mass and angular velocity.

The law of quantization for angular momentum is the simplest of all laws. In this ladder the unit of spacing between the evenly spaced rungs is $h/2\pi$, and the scale of permitted values of angular momentum usually runs: 0, $h/2\pi$, $2h/2\pi$, and so on. It may be surprising to find Planck's constant h reappearing in this new role. First it was a factor by which the frequency of a vibrator must be multiplied in order to get the spacing between the permitted energy-values; now, multiplied by $1/2\pi$, it is the interval between the permitted values of angular momentum of a rotating body. It can play both these roles because it has what physicists call the correct dimensions for both. Planck's constant has the dimensions of energy divided by frequency, and these are also the dimensions of angular momentum.

Bohr

The quantum theory's conquest of the atom began in the year 1913 (remembered with nostalgia by those who are old enough as the last year of the good old times), and the leader in this conquest was a young Dane by the name of Niels Bohr, who came to the University of Manchester to study with the celebrated Ernest Rutherford. Rutherford had just established the conception that the atom is a sort of miniature of the solar system, in which the planets are represented by negative electrons and the central sun by a positively-



BOHR MODEL postulated a hydrogen atom in which an electron traveled around a nucleus in any one of several "permitted" orbits. When the electron fell from an orbit of higher energy to one of lower energy, it emitted light of a characteristic wavelength. In this diagram the electron orbits are indicated as circles or sections of them. Each group of arrows represents a group of energy transitions which give rise to a spectral series. The three labeled arrows at the left refer to the Balmer series shown on the preceding page. The labels correspond to three spectral lines in that drawing.

charged and massive nucleus, around which the electrons revolve in orbits as the planets revolve around the sun. In the simplest case, the hydrogen atom, there is only one electron. Rutherford did not prescribe the particular orbit in which this electron should revolve. To prescribe it required a revolutionary new idea, and Bohr was the man who provided this idea.

The orbit of the electron around the nucleus, like that of a planet around the sun, should be an ellipse, for in both cases the force is an inverse-square force. A circle is a particular case of an ellipse; we will consider only circular orbits. A hydrogen atom, with its electron revolving in a circular orbit about its nucleus, can be regarded as a wheel. It is a peculiar kind of wheel, since it has no spokes and the rim is vacant except for the small region occupied by the electron, but it possesses the major property of a wheel: angular momentum. Bohr made the assumption that the angular momentum of a hydrogen atom is quantized, and that the electron is permitted to revolve in certain orbits which correspond to the integer multiples of $h/2\pi$. In its "normal state" the hydrogen atom has its electron revolving in the circle for which the angular momentum is $h/2\pi$. Its other permitted orbits are those for which the values of the angular momentum are $2h/2\pi$, $3h/2\pi$, and so on. Each of these other orbits, Bohr postulated, represents an "excited state" of the hydrogen atom.

The energy of the hydrogen atom in its normal state is $-R$; R being a constant of which Bohr computed the theoretical value. The general formula which expresses the various energy-values permitted to the hydrogen atom is $E_n = -R/n^2$. In its first excited state, represented by $n=2$, its energy is $-R/4$; in the second excited state it is $-R/9$, and so on. One may be puzzled by the fact that all of these energy-values are negative. This is because we are reckoning energy from a zero which corresponds to the state in which the hydrogen atom is completely torn apart, with the nucleus and the electron infinitely far from each other. It would seem more rational to reckon energy from a zero which corresponds to the normal state of the hydrogen atom, but this actually makes the formula more complicated.

Bohr went on to propose a second revolutionary idea, without which the first would have been of little use. Imagine a hydrogen atom in, let us say, the second excited state—the one for which the energy is $-R/9$. Suppose that the electron transfers itself into the orbit corresponding to the first excited state—the one for which the energy is $-R/4$. The atom now loses the difference in energy $(R/4 - R/9)$. What happens to this energy? According to Bohr's second idea, it leaves the atom, in the form of a single photon. Accordingly, there should be, in the spectrum of hydrogen, a line of which the frequency is equal to $(R/4 - R/9)/h$. Moreover, there should be lots of other lines, and all of their frequencies should be calculable by inserting various integer values for m and for n in the general formula:

$$\nu = (R/m^2 - R/n^2)/h$$

Well, this is a correct description of the actual spectrum of hydrogen, and the theoretical value assigned by Bohr to the constant R agrees with the value derived from experiments. There is nothing in the world which impresses a physicist more than a numerical agreement between experiment and theory; and I do not think that there can ever have been a numerical agreement more impressive than this one, as I can testify who remember its advent.

This is a good place to interpolate that one of the most curious features of quantum theory is that one and the same formula can be derived from markedly different postulates. The picture of the hydrogen atom today differs somewhat from the one Bohr proposed, and yet the new picture leads to the same formula for the spectrum of hydrogen and to the same value of R. The conjurers of quantum theory get the same rabbit out of more than one hat.

Spins

Now let us consider some other wheels. The first of these is the electron. The electron, besides revolving around the nucleus, possesses an angular momentum of its own, and we liken it therefore to a wheel. It may be visualized as a rigid body spinning upon its axis, but this is a rather dangerous analogy, for it leads one to inquire what the electron's angular velocity is, and no one has ever been able to answer this question—indeed, it is very likely unanswerable. The electron's angular momentum is quantized, and in the simplest conceivable fashion: this is a ladder with only one rung. The angular momentum of the electron is fixed forever at the single value $(\frac{1}{2})h/2\pi$.

The electron is considered to be an elementary particle; I call it a "structural elementary particle," meaning a particle which is used in our models of atoms and of the nuclei of atoms. There are two other structural elementary particles: the proton and the neutron. The proton is the nucleus of the commonest and lightest kind of hydrogen atom. The neutron cannot serve as the nucleus of an atom when it is by itself, but it combines with protons and with other neutrons to form composite nuclei. These three structural elementary particles have one quality in common, and only one. Each has the same one-rung ladder of angular momentum; each has the unalterable angular momentum $(\frac{1}{2})h/2\pi$.

The most important feature of angular momenta, on the atomic and the subatomic scale, is the so-called law of composition, meaning the composite angular momentum of a system consisting of two or more particles. I will illustrate this law by three examples.

The first is the common light hydrogen atom, containing one proton and one electron. The spins of these two particles are always either parallel or antiparallel to each other. Thus there are two, and just two, kinds of light hydrogen atoms. The difference in their properties is very slight indeed, and yet it can be detected by a spectroscope operating in the microwave region.

My second example is afforded by the hydrogen molecule, consisting of two common hydrogen atoms. This has two protons and two electrons. The two electrons always have their spins pointed antiparallel to each other. The two protons may be pointed in the same or opposite directions to each other; there are no intermediate cases. Thus there are two, and just two, kinds of molecular hydrogen. Their physical properties differ appreciably, and they can be separated from each other. They even have different names: ortho-hydrogen and para-hydrogen.

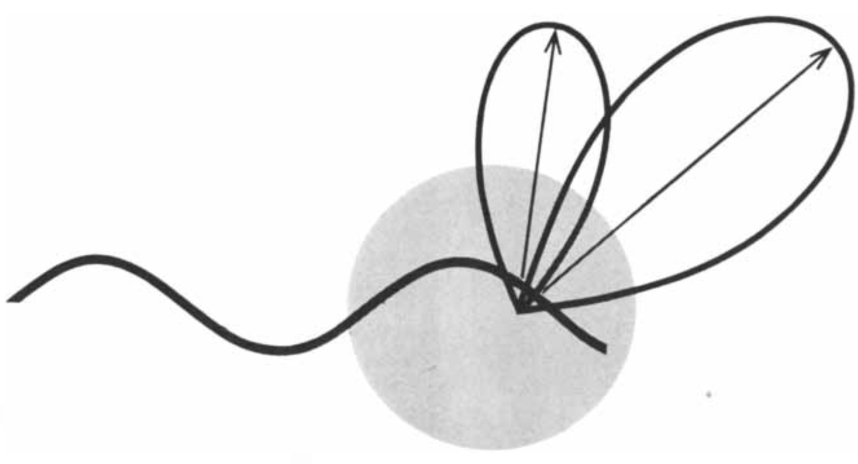
My last example is provided by the simplest of all composite nuclei—the deuteron. This is the nucleus of the isotope which used to be called heavy hydrogen, though this name is waning now that a still heavier isotope is known. The deuteron consists of one proton and one neutron. In every deuteron the spins of the proton and the neutron are parallel. This is a sharper restriction than prevails in my other two examples. The theorists believe that the spins of the proton and the neutron have no objection *per se* to setting themselves antiparallel, but that the forces between these two particles are such that in the antiparallel orientation the proton and the neutron just cannot stick together.

Notice now what would be the consequence if this law of composition of angular momenta did not exist. There would be not just two kinds of hydrogen atom but an infinite variety of kinds, though it is true that they would not differ appreciably in any significant quality. There would be not just two kinds of molecular hydrogen but an infinity of different kinds, with properties lying all the way between those of para-hydrogen and those of ortho-hydrogen; these would spoil the distinctiveness of molecular hydrogen. There would also be a wide variety of kinds of deuteron.

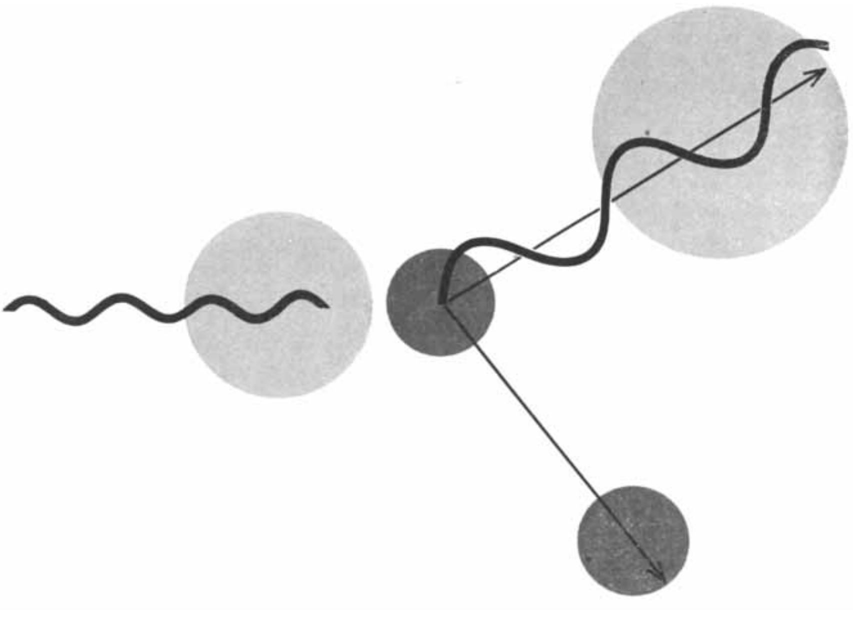
Follow this idea a step further. Suppose that the electron of the hydrogen atom could revolve around the nucleus in any orbit whatsoever, and not just in a limited number of orbits of which one corresponds to the normal state and the others to transient excited states. Were this true, there would be an infinity of different kinds of hydrogen atoms. This in turn would mean that hydrogen would not be the distinctive and individualistic element that it is. The same may be said about every other element. But for the laws of quantization, carbon would not be carbon as we know it, oxygen would not be oxygen, iron would not be iron and gold would not be gold. What the quantum theory explains is the distinctiveness and the individuality of the 90-odd elements of which the world is made. What a long way for a theory to have come, that started out as a theory of the recondite subject of black-body radiation!

Photon Collisions

I will mention one more attribute of light into which Planck's constant has



PHOTOELECTRIC EFFECT occurs when a photon (*wavy line*) encounters an atom (*gray circle*) and knocks out one of its electrons (*arrows*). A low-energy photon causes the electron to leave the atom at a steep angle; a high-energy photon, at a shallower angle. The curves around the arrows show the angular distribution of electrons resulting from many such photons.



COMPTON EFFECT occurs when a high-energy photon (*wavy line and gray circle at left*) encounters an electron (*smaller circle in center*). The electron is knocked away at an angle (*lower right*). The wavelength of the photon is decreased by the amount of energy imparted to the electron (*upper right*).

made its way. It concerns a concept which would have been inconceivable in 1900 and was not as a matter of fact conceived until 1923: namely, that a photon, or corpuscle of light, is so much a particle that it can have an elastic collision with an electron. This phenomenon was observed and interpreted by Arthur Compton, and it is therefore known as the Compton effect.

An elastic impact between two bodies is one in which both kinetic energy and momentum are conserved. After the impact each body has a different energy and a different momentum from what it had before, but the sum of the energies of the two bodies, as well as the sum of their momenta, is still the same. What Compton did was not only to propose that such an impact could occur between a photon and an electron but to state a formula for the transfer of energy and momentum.

If a corpuscle of light has linear momentum, as is implied by the fact that light exerts pressure, the momentum of a photon of frequency ν should be $h\nu/c$, the symbol c standing for the velocity of light. Consider an elastic impact between a photon and a stationary electron. The initial energy and the initial momentum of the photon are $h\nu$ and $h\nu/c$, respectively; since the electron is stationary, its initial energy and momentum are zero. Let us suppose that the electron recoils from the impact in a direction at a certain angle with the direction in which the photon was originally traveling. Now the equations of the impact are easy to solve. One can calculate the angle of recoil of the photon, its new energy, which turns out to be less than its original energy $h\nu$ and its new momentum, which turns out to be less than its original momentum $h\nu/c$.

We can now write an equation which gives the new frequency of the photon: its value is E'/h—the new energy divided by Planck's constant. In short, what this equation and the foregoing theory say is that if the electron recoils in a certain direction, the photon goes off in a certain calculable direction and has a lesser frequency (or longer wavelength) than it had before, this new frequency also being calculable.

To test this theory, it is only necessary to set up an X-ray spectroscope to catch the photons going off in the theoretically calculated direction. When this test was actually made, by directing X-rays (photons) against a target of matter rich in electrons, Compton's theory was completely confirmed.

Now we have reached the twin climaxes of the early quantum theory: the law of composition of angular momenta and the Compton effect. We have also reached the year 1923. At this point in the story quantum theory suffers a mighty change. Its expression in terms of mathematics becomes much harder; its expression in terms of words and of analogies with concepts of the past becomes so very much harder as to verge on the impossible. But if one is interested only in the simpler applications of the theory, it is not necessary to attempt to pass through the formidable portal.

Karl K. Darrow is a physicist at Bell Telephone Laboratories and secretary of the American Physical Society.

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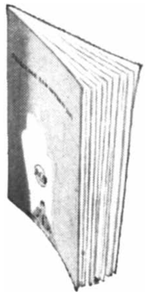

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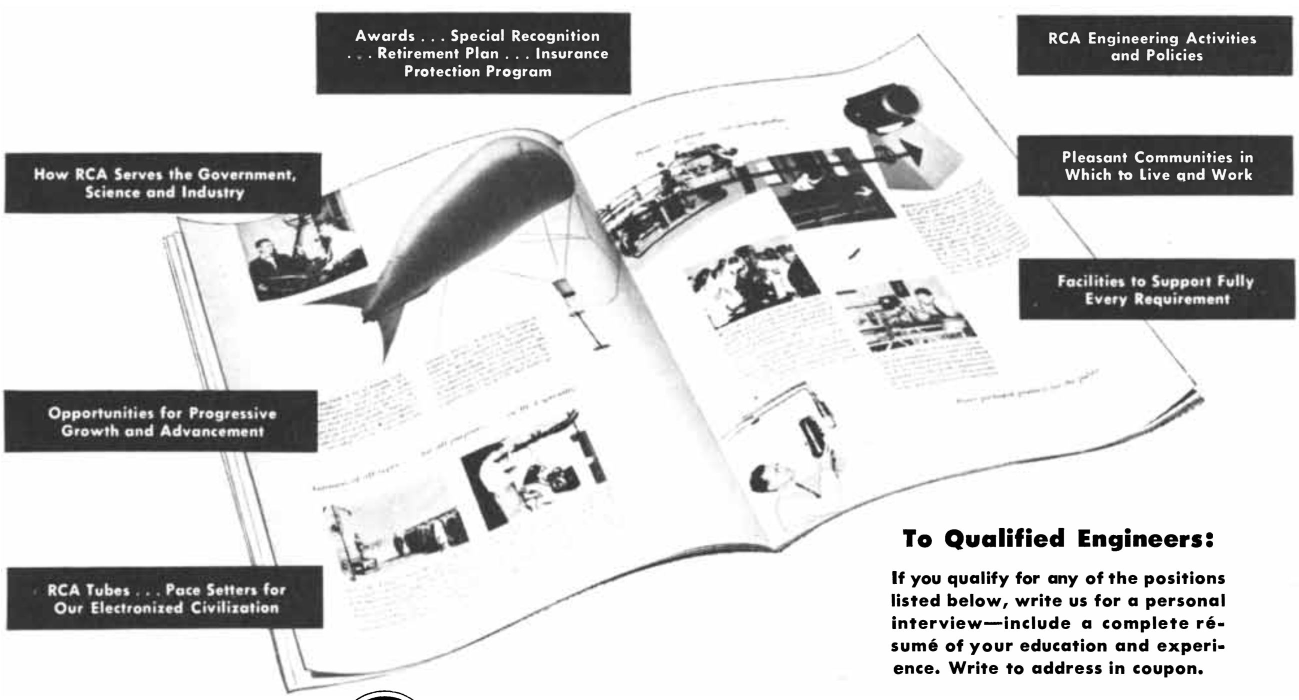

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MEASURING STARLIGHT BY PHOTOCELL

The device which transforms light into electricity, used in conjunction with the telescope, has brought a new insight to some central problems of astronomy

by Joel Stebbins

THE photoelectric cell, or "electric eye," is now a mass-manufactured implement of our technology, like the thermostat or the speedometer. It is the basis of television, of the sound film and of innumerable other everyday applications. Yet photoelectricity is a striking example of how pure science precedes applied science (*see page 47*). At least a quarter of a century before it was applied to talking pictures, the photocell was employed by astronomers to investigate the light of the sun, moon and stars. As early as 1894 the late astronomer George E. Hale used a photocell in an attempt to detect the sun's corona. My own interest in this device began in 1913, when the physicist Jacob Kunz and I collaborated on some experiments in measuring starlight with such a cell. Through the years astronomers have found the photocell an increasingly useful tool, and have themselves helped to perfect it. Today the photoelectric measurement of starlight has become an important branch of astronomy—a major instrument for studying the universe.

The principle of the photocell is simple enough. It converts light into electricity; in a sense it is the reverse of the ordinary electric lamp—with the electric lamp we feed in current and take out light; with the photocell we feed in light and take out current. The photocell does this by means of a photosensitive substance, that is, a material which releases electrons from its surface when light shines on it. The essentials of the device are illustrated by the first photocell, made by the German physicists Julius Elster and Hans F. Geitel in 1890. For the photosensitive surface they used the alkali metal potassium. A film of potassium was deposited on the inside of one end of an evacuated glass tube. A negative electrode was connected to this sensitive film, and a positive electrode was placed at the other end of the tube. The electrodes were connected to the poles of a battery. When electrons were released from the sensitive film by the action of light, the electrical pressure from the battery served to drive the freed electrons across the tube to the anode. Elster and Geitel found that the resulting current, which depended on the number of electrons emitted from the film, was proportional to the brightness of the light striking the film. Hence it gave an accurate measure of the intensity of the light to which the photosensitive film was exposed.

The current of course was very small; to amplify it Elster and Geitel put into the tube some inert gas, whose atoms gave up electrons when bombarded by electrons from the film and so added to the current. With a battery pressure of 100 volts the first photocell was able to produce measurable currents from the ordinary light of a room. In its modern development the photocell is a very sensitive instrument; it has to be to measure starlight. When used in astronomy, the photocell is simply attached to the receiving end of a telescope and pointed at a star. In the telescope is a diaphragm with a tiny opening that allows only light from the single star to reach the cell. The instrument's meter readings of the photocurrent from various stars give their relative brightness.

THE LIGHT we get from a star is faint indeed; the North Star, for example, is no brighter to the naked eye than a candle at a distance of one mile. At the University of Wisconsin we once trained a photocell on an actual candle set up a mile away. The cell was not attached to a telescope nor to any other optical aid except a blank tube to cut out the diffuse night light of the landscape. Not only could we easily measure the light from the candle, but by further trial we estimated that the cell could detect the candle up to a distance of about seven miles. This performance is somewhat better than that of the human eye, which can see a candle at about six miles, but the catch is that the photocell had a one-inch opening—about three times the size of the dark-adapted pupil of the eye. The important advantage of the photocell is not superior sensitivity but its ability to measure differences in brightness much more precisely than the eye or even a photographic plate.

Under the conditions of that experiment our cell, attached to our 15-inch telescope, could have detected a candle 100 miles away. In the past 20 years the performance of photometers has steadily been improved. One important improvement in the instrument was made in 1932 by Albert E. Whitford of the University of Wisconsin. Stray ions in the air around a photocell and certain other factors interfere with the cell's sensitivity; they cause disturbances of the kind known in radio as "noise." Whitford conceived the idea of cloistering the cell in an evacuated tank. He used a photocell in combination with an amplifying tube and enclosed the whole in a brass tank. When he evacuated the tank to a pressure of a thousandth of an atmosphere, he literally pumped out many of the difficulties. This single stratagem improved the performance of the instrument by a factor of 10; while the "signal" remained the same, the "noise" in the circuit was 10 times less. Besides this, the amplifying tube that was coupled to the cell added a fourfold gain in sensitivity.

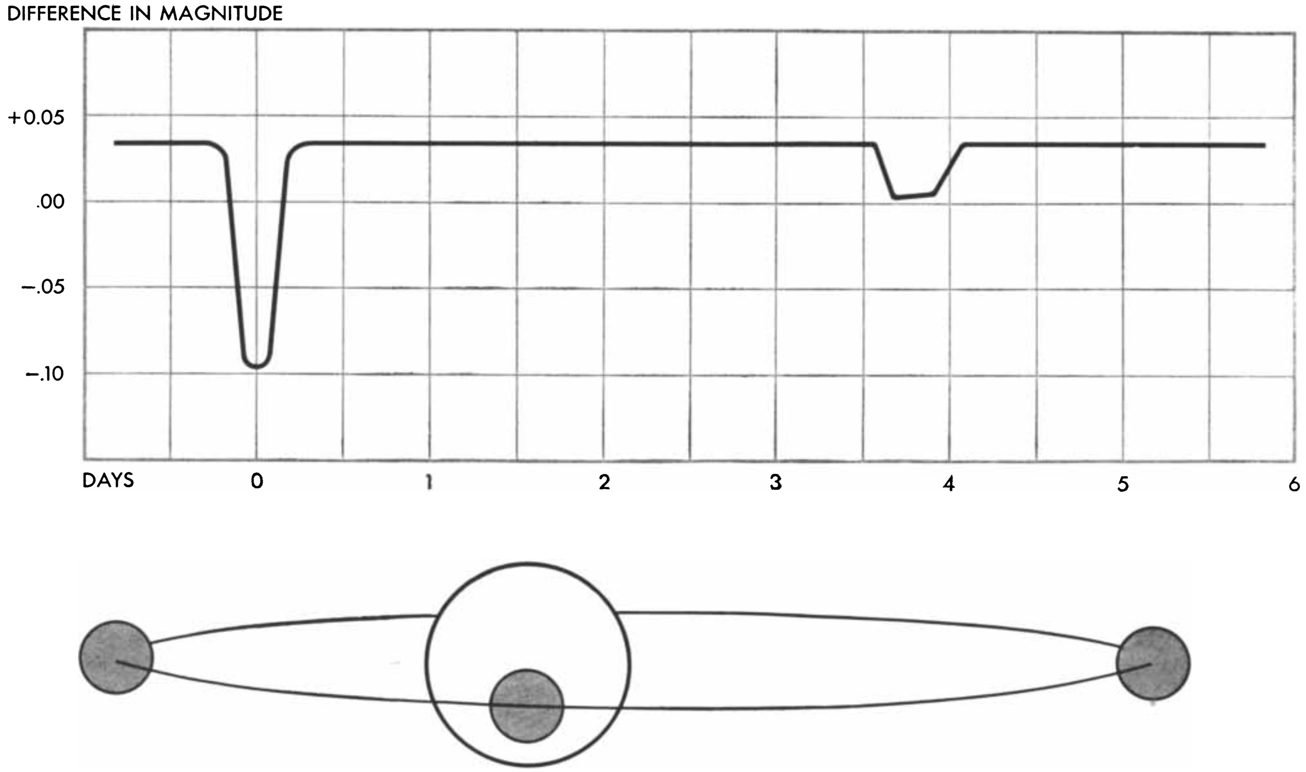
During World War II a new form of cell, called the multiplier phototube, was developed. This tube uses a series of sensitive surfaces, with electrons from the first bombarding the second to release "secondary" electrons, which in turn produce an additional yield of electrons from the third surface, and so on. The result is an amplification of a million times within the tube itself. A still further improvement is obtained by cooling a photocell or multiplier with dry ice. A photosensitive surface will emit electrons because of heat as well as light, and it produces a little current even in the dark. Cooling it to 80 degrees below zero Centigrade reduces the unwanted thermal emission to a negligible level.

FROM this brief description of the instruments we turn to their application in astronomy. One of the principal uses of the photocell has been to detect and measure changes in brightness of the so-called variable stars, where the variations are too slight to be observed directly by the eye or on photographic film. The eye cannot detect brightness variations in stars of less than about 25 per cent; the photocell records changes of 5 per cent and even less.

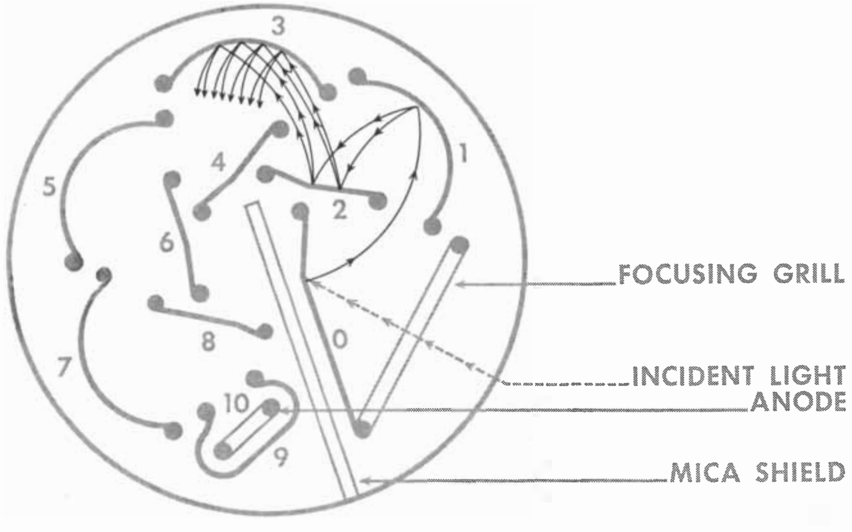
Eclipsing stars make up one important class of the variables. These are pairs of stars which rotate around each other in such a way that, on our line of sight, each member periodically gets behind the other. During the partial or total eclipse of one star by the other we get less light from the pair. One system that has been studied with a photocell is the faint star known as AR Cassiopeiae. Observations of shifts in its spectrum had shown that it consisted of a main body with a massive companion that revolved around it in a period of 6.1 days. The photometer, attached to a 12-inch telescope, was called into use to see what it could tell about the sizes and paths of the two stars. Its measurements showed that when the smaller member of the pair was in front of the other, it cut off some 13 per cent of the total light of the pair. When the larger member eclipsed its companion, the reduction in light was 3 per cent. This indicates that the companion is 3/13 (*i.e.*, about one-fourth) as bright as the main star. The eclipses do not come at equal intervals: the primary eclipse (of the main star by its companion) comes 2.3 days after the secondary one, and the secondary eclipse 3.8 days after the primary. The inequality of intervals of course means that the orbit of the companion is an ellipse, not a circle. From the relative duration of the two eclipses, compared with the total period of revolution, it is possible to calculate the dimensions of the stars in terms of the distance between them. Since we know this distance from other data, we can determine their absolute size. Previous studies of the spectrum had indicated that the main star in AR Cassiopeiae is probably about 600 times as bright as the sun; according to the photocell measurements the smaller companion is about 20 times as bright as the sun. Truly this is a giant pair system.

The Cepheid variables are another important class of variable stars. They are thought to be supergiant, gaseous stars which actually change size, swelling and shrinking in diameter by as much as 5 or 10 per cent in regular pulsations. Some of them are twice as bright at their light maximum as at the minimum. Many of the Cepheids have been studied with the photocell, and information on their temperature, as well as their changes of brightness, has been obtained.

A STAR'S temperature is indicated by its color. The hotter it is, the bluer its light. We can tell its temperature from its spectrum, but photoelectric measurements give another and more accurate method. If we place a filter glass which passes light of only one color over a photocell, we can measure the brightness of that color in a star's light. By measuring two colors and comparing their strength, we can obtain an indication of the star's temperature. Suppose we select two colors, a yellow and a blue, in which the sun is about equally bright when measured with a certain photocell. The sun's temperature is known to be about 6,000 degrees Cen-



ECLIPSING STARS have been intensively studied by photocell. At the top of this illustration is a curve based on numerous measurements of the light from the double star AR Cassiopeiae. At the bottom is a schematic drawing of this stellar system. When the smaller and dimmer member of the system passes in front of its larger and brighter companion, the light from both dims as shown by the dip in the curve at the left. When the smaller star passes behind the larger, however, the light dims as shown by the smaller dip in the curve at the right.



MULTIPLIER PHOTOTUBE allows light to fall on a photosensitive cathode, which then emits electrons. In traveling toward the anode these electrons strike a series of plates, causing them to emit more electrons. By this means the original electron can be multiplied by a factor of 1,000,000.

tigrade. Now if we measure a hotter star like Sirius (11,000 degrees) with the same two filters, we would expect it to be much brighter in the blue than in the yellow, while a cooler star than the sun will be stronger in the yellow. In this way we can build up a definite scale of stellar temperatures.

The scale of brightness for the stars is based on their comparative luminosity rather than on a terrestrial standard of light. It is measured in "magnitudes," and the numbers increase not in order of brightness but of faintness: thus a star of the second magnitude is fainter than one of the first magnitude. In these units each level of magnitude is approximately 2.5 times fainter than the one next higher on the scale. The magnitude of the North Star is 2; a star of magnitude 6, the faintest that can be seen by the unaided eye, is nearly 40 times as faint as the North Star. A 19th-magnitude star is something like six million times as faint as the North Star.

The faintest star yet recorded with a photocell was one of the 19th magnitude. Whitford and H. L. Johnson measured such a star in two colors with the aid of the 100-inch telescope on Mount Wilson. They centered the star in a tiny opening 200 times smaller than the diameter of the moon's image. Yet even through this small hole the dark sky gave 15 times the light of the star itself. In other words, the background of the night sky sets a limit on photoelectric measurement. To get the effect of the star's light Whitford and Johnson had to make a series of on-off readings—star plus sky, then sky alone, star plus sky, sky alone, and so on. The average net difference was taken to be the response from the star alone. The difference was enough greater than the random variations in the record to be measurable. The two-color measurement of this star showed the yellow response to be slightly greater than the blue, indicating that the star is appreciably redder, and cooler, than the sun.

PRECISE determination of the colors of stars has helped us to detect dark material in interstellar space. Just as the sun is reddened at sunset, when we see it through an extensive layer of air, a cloud of gas or dust in outer space reddens the light of a star. When a white-hot star like Sirius appears yellow, a plausible explanation is that its light has been absorbed more in the blue than in the yellow or red. If also the star is in a dark (*i.e.*, dusty) patch in the bright Milky Way, we have strong confirmation that the reddening is an absorption.

On a clear day 10 or 20 miles of ordinary air in the earth's atmosphere will dim a distant landscape, and a little dust or haze will blot it out. In interstellar space, however, the dust and gas are so thin that light must travel fantastic distances to show any perceptible effect of absorption. We can observe reddening only in stars that are many light-years away from us.

The best individual objects for studying absorption are certain high-luminosity, blue-hot stars of the type called Class B. These stars have temperatures of the order of 20,000 degrees. They are generally hundreds or even thousands of times as bright as the sun. Their spectra are simple and their individual colors are contained within a small range. Examples of Class B stars in the winter sky are those in the Belt of Orion, about 600 light-years away. These are close enough to be seen in their true colors. But in the summer all of the hottest B stars in the more distant region near the main line of the Milky Way are reddened, undoubtedly because of absorption of part of their light by interstellar matter.

Color measurements made with a photocell on Class B stars in all directions in the Milky Way show that most of the absorbing material which reddens the stars is concentrated in a relatively thin layer near the middle plane of our disk-shaped galaxy. The layer is not uniform; the material is probably bunched in clouds, each several light-years in extent. The clouds must be made mainly of dust, because dust, of course, is a far better absorber of light than chunks of matter or gas.

For studies of absorption at great distances, the globular clusters in our galaxy, of which about 100 are known, are even better objects than B stars. A globular cluster is a gigantic group of tens of thousands of stars. The photocell can record the total light of a cluster as if it were a single star. Measuring the light in different colors, it can indicate how much of the light is being absorbed by dust in the surrounding space. Let us take the case of the globular cluster called NGC 6553. When this cluster is photographed in blue and in red light, the two pictures are very different: in red light the cluster looks almost like a solid mass of stars, while in blue light it is thin and faint. If the cluster were out in clear space, the two pictures would be nearly the same. Measurements with a photocell show that only one or two per cent of the blue light comes through; the rest is absorbed in the clouds of interstellar dust through which the cluster's light travels to us.

IN THE RED picture the center of the picture is a solid blaze of light, but this is only an appearance; the telescope cannot resolve the light of such a distant object into individual stars. With the photocell it is possible to prove that there is plenty of room between the stars of a globular cluster. If there were no dark spaces between the stars as we see them on our line of sight, the central area of this cluster would have a surface brightness equal to that of our sun. Actually photocell measurements show that it is only about one 10-billionth as bright as the sun's surface, which indicates that in the picture the cluster presents to us the area of dark space is 10 billion times that of the stars themselves. Of course the total light from such a system is immensely greater than the light of a single star such as the sun: a globular cluster may have a diameter of 100 light-years and more light than 100,000 suns.

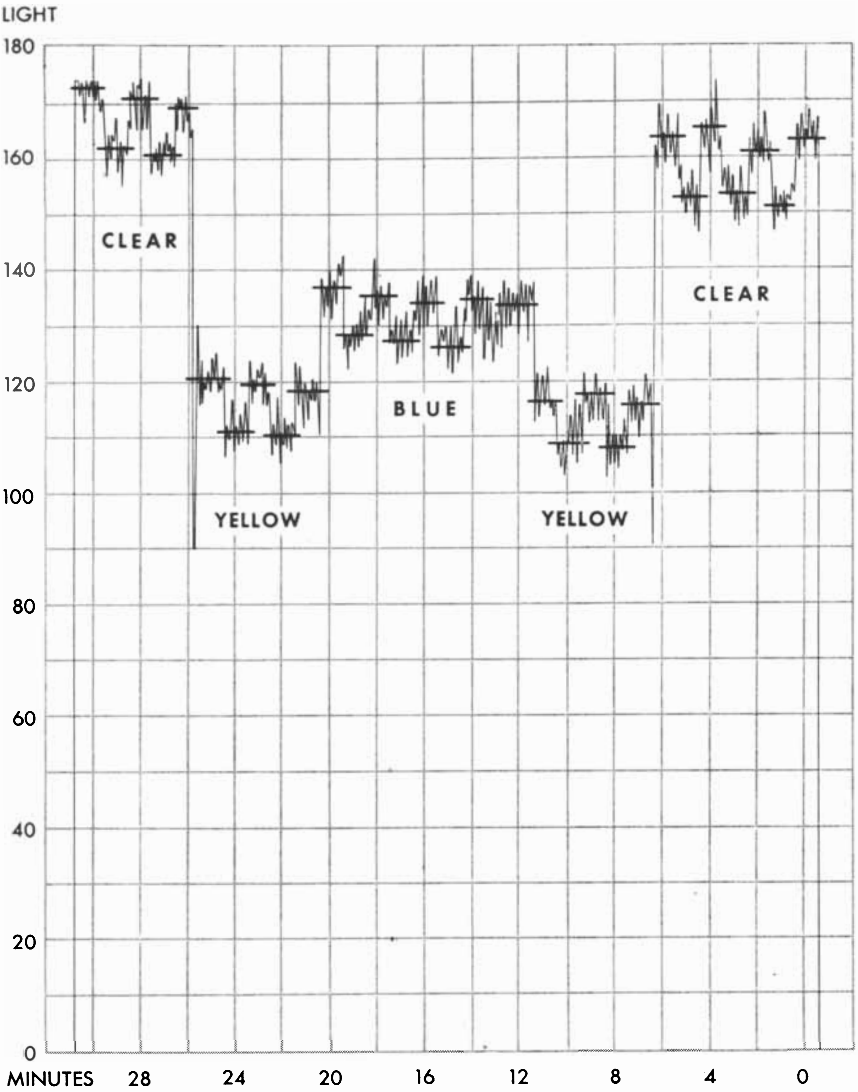
The far-off nebulae, systems of stars outside our own galaxy, are much more difficult to measure with a photocell.

These faint, diffuse objects are only slightly brighter than the sky. They must be measured by on-off readings, as faint single stars are, and it is sometimes a problem to find an area of nearby sky sufficiently blank and dark for the comparative "off" reading. Moreover, there may be stars in the line of sight between us and the nebula, so we must measure and subtract their light to find that of the nebula itself.

One of the main reasons for studying the colors of nebulae with the photocell is to investigate further the famous red-shift—perhaps the most striking discovery in astronomy in the past half-century. This phenomenon, the shift of all wavelengths of the light of distant nebulae toward the red end of the spectrum (the greater the distance, the greater the shift), is generally interpreted to mean that all the nebulae are racing away from us and from one another—*i.e.*, that the universe is expanding.

FROM the estimated velocity of a nebula and the consequent shift of its colors toward longer wavelengths, it is possible to calculate what the color composition of its light should be when it reaches us; for example, how much it should be reddened. Such a calculation has been made for the Boötes nebula, a star system estimated to be 220 million light-years away from us and receding with a velocity of 24,000 miles per second. According to this calculation its reddening, as measured on a two-color scale, should be 23 per cent. But when the Boötes nebula's light was measured with a photocell, it turned out that the reddening was 61 per cent—nearly three times the predicted value.

This discrepancy may call for some radical changes in our ideas about the universe. Two different explanations of the discrepancy have been advanced. The first suggests that the great reaches of space between galaxies may contain clouds of dust, just as the galaxies themselves do. Astronomers have supposed that intergalactic space is absolutely empty and transparent, but this is pure assumption. The density of matter in space between the nebulae would need to be no more than one 100,000th of that in the dust clouds of our galaxy to account for the unexpected extra reddening of Boötes. But if all space is indeed dusty, then we must revise our estimates of the distances of nebulae, for the intergalactic dust would absorb some of their light and make them seem farther than they really are. Boötes, for example, would be only 130 million light-years away, not 220 million. It would follow also that as we look farther and farther into space, we reach a point where it becomes practically impenetrable; in other words, that the 200-inch telescope cannot look a billion light-years into space, as it was designed to do, because of the interfering haze.



VERY FAINT LIGHT from a star was analyzed by the on-off technique and filters. The "dark" sky itself gives considerable light. The measurements in each section of chart show the small differences between skylight itself and the star plus sky, as measured without a filter (clear) and yellow or blue filter.

The other suggested explanation of Boötes' unexpected redness is that when the light left it, 220 million years ago, nebulae were in fact redder than they are now. The fact that distant nebulae are much redder than those near us may simply be a sign of their greater youth. (Redness of color, incidentally, should not be confused with the red-shift of the spectrum as a whole due to recession of the nebulae.) It may be that the red stars in all nebulae have faded in the time since light left the far ones, and that the nebulae have therefore become bluer. The time involved—only about 220 million years—may seem too short for any such change in a nebula, but many giant red stars are known to be radiating, hence fading, rapidly—1,000 times as fast as the sun.

The redness anomaly may be due to space-absorption or time or a combination of both; if it is the latter, the problem of disentangling the two effects from each other seems at present insoluble. In any case, the question as to what lies in space between the nebulae and how far our telescopes can reach will presumably be with us for a long time.

Step by step the use of the photocell has been extended to explore the whole range of objects in the sky, from the sun and moon to stars and finally to the distant nebulae and the spaces between them. In astronomy, as in other fields, the applications of the photoelectric cell are limited only by the imagination of the experimenter.

Joel Stebbins, director emeritus of the Washburn Observatory of the University of Wisconsin, is now research associate at the Lick Observatory of the University of California.

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SINCLAIR—for Progress

Maxwell's Poetry

The great English physicist wrote some amusing light verse. Herewith a small sample of it, written mostly at the expense of the British Association for the Advancement of Science

by I. Bernard Cohen

JAMES CLERK MAXWELL, the great 19th-century physicist, had a lighter side not commonly known. He liked to write humorous verses. They were generally Ogden-Nashish parodies of serious writings of his time, and some of them were in a vein and of a quality that would have made them eminently publishable in The New Yorker, *if that journal had existed in his day. Maxwell did not, however, write them for publication; he composed many of them simply as letters to his good friend and fellow physicist Peter Guthrie Tait. Fortunately Tait kept them and saw that they were published. Several were printed in* Nature *and* Blackwood's Magazine.

In the well-established tradition of satirists, Maxwell used a pen-name. He signed his verses "dp/dt," which came from an equation Tait had written to express the second law of thermodynamics, to wit:

$$\frac{dp}{dt}/M = JC$$

J stands for Joule's equivalent, C for Carnot's function and M for the rate at which heat must be supplied to increase the volume of a gas per unit while its temperature is kept constant. When M is transposed, the equation yields Maxwell's initials:

$$\frac{dp}{dt} = JCM$$

Maxwell was especially fond of ribbing the British Association for the Advancement of Science, which he often referred to as the "British Ass." The Association's meeting in 1874, held in Belfast, provoked several comments from him in rhyme. He wrote the following "epitome" of the president's address at this meeting:

In the very beginnings of science, the parsons, who managed things then,
Being handy with hammer and chisel, made gods in the likeness of men;
Till Commerce arose, and at length some men of exceptional power
Supplanted both demons and gods by the atoms, which last to this hour. . . .
From nothing comes nothing, they told us, nought happens by chance, but by fate;
There is nothing but atoms and void, all else is mere whims out of date!
Then why should a man curry favour with beings who cannot exist,
To compass some petty promotion in nebulous kingdoms of mist?
So treading a path all untrod, the poet-philosopher sings
Of the seeds of the mighty world—the first-beginnings of things;
How freely he scatters his atoms before the beginning of years;
How he clothes them with force as a garment, those small incompressible spheres!
Nor yet does he leave them hard-hearted—he dowers them with love and with hate,
Like spherical small British Asses in infinitesimal state;
Till just as that living Plato, whom foreigners nickname Plateau,
Drops oil in his whiskey-and-water (for foreigners sweeten it so),
Each drop keeps apart from the other, enclosed in a flexible skin,
Till touched by the gentle emotion evolved by the prick of a pin:
Thus in atoms a simple collision excites a sensational thrill,
Evolved through all sorts of emotion, as sense, understanding, and will. . . .
Thus the pure elementary atom, the unit of mass and of thought,
By force of mere juxtaposition to life and sensation is brought;
So, down through untold generations, transmission of structureless germs
Enables our race to inherit the thoughts of beasts, fishes, and worms. . . .
First, then, let us honour the atom, so lively, so wise, and so small;
The atomists next let us praise, Epicurus, Lucretius, and all;
Let us damn with faint praise Bishop Butler, in whom many atoms combined
To form that remarkable structure, it pleased him to call—his mind.
Last, praise we the noble body to which, for the time, we belong,
Ere yet the swift whirl of the atoms has hurried us, ruthless, along,
The British Association—like Leviathan worshipped by Hobbes,
The incarnation of wisdom, built up of our witless nobs,
Which will carry on endless discussions, when I, and probably you,
Have melted in infinite azure—in English, till all is blue.

AT THE 1876 meeting of the Association in Glasgow, Maxwell's friend Tait gave a lecture on force in which he demanded accuracy in scientific language and went on to give a demonstration that "force in the strictly Newtonian sense of the word has no real objective existence but is a mere space-variation of energy." Maxwell promptly wrote to Tait:

Ye British Asses, who expect to hear
Ever some new thing,
I've nothing new to tell, but what, I fear,
May be a true thing.
For Tait comes with his plummet and his line,
Quick to detect your
Old bosh new dressed in what you call a fine
Popular lecture.

Whence comes that most peculiar smattering,
Heard in our section?
Pure nonsense, to a scientific swing
Drilled to perfection?
That small word "Force," they make a barber's block,
Ready to put on
Meanings most strange and various, fit to shock
Pupils of Newton.

Ancient and foreign ignorance they throw
Into the bargain;
The shade of Leibnitz mutters from below
Horrible jargon.
The phrases of last century in this
Linger to play tricks—
Vis Viva and *Vis Mortua* and *Vis Acceleratrix*—

Those long-nebbed words that to our text books still
Cling by their titles,
And from them creep, as entozoa will,
Into our vitals.
But see! Tait writes in lucid symbols clear
One small equation;
And Force becomes of Energy a mere
Space-variation.

Force, then, is Force, but mark you! not a thing,
Only a Vector;
Thy barbèd arrows now have lost their sting,
Impotent spectre!
Thy reign, O Force! is over. Now no more
Heed we thine action;
Repulsion leaves us where we were before,
So does attraction.

Both Action and Reaction now are gone.
Just ere they vanished,
Stress joined their hands in peace, and made them one;
Then they were banished.
The Universe is free from pole to pole,
Free from all forces.
Rejoice! ye stars—like blessed gods ye roll
On in your courses.

No more the arrows of the Wrangler race,
Piercing, shall wound you.
Forces no more, those symbols of disgrace
Dare to surround you:
But those whose statements baffle all attacks,
Safe by evasion—
Whose definitions, like a nose of wax,
Suit each occasion—

Whose unreflected rainbow far surpassed
All our inventions,
Whose very energy appears at last
Scant of dimensions:—
Are these the gods in whom ye put your trust,
Lordlings and ladies?
The hidden potency of cosmic dust
Drives them to Hades.

While you, brave Tait! who knows so well the way
Forces to scatter,
Calmly await the slow but sure decay,
Even of Matter.

MAXWELL also rhymed about many subjects not strictly physical. One of his poems was called "A Vision of a Wrangler, of a University, of Pedantry, and of Philosophy," and another was titled "Lines written under the conviction that it is not wise to read Mathematics in November after one's fire is out." He composed a "Valentine by a Telegraph Clerk ♂ to a Telegraph Clerk ♀" which ended with this exchange of messages:

"O tell me, when along the line
From my full heart the message flows,
What currents are induced in thine?
One click from thee will end my woes."

Through many an Ohm the Weber flew,
And clicked this answer back to me—
"I am thy Farad, staunch and true,
Charged to a Volt with love for thee."

THERE is also a pair of poems which Maxwell called "Lectures to Women on Physical Science." The second, purporting to be a student's reply to "Professor Chrschtschonovitsch" after his lecture on the C.G.S. system of units, goes:

Prim Doctor of Philosophy
From academic Heidelberg!
Your sum of vital energy
Is not the millionth of an erg.
Your liveliest motion might be reckoned
At one-tenth metre in a second.

"The air," you said, in language fine,
Which scientific thought expresses,
"The air—which with a megadyne,
On each square centimetre presses—
The air, and I may add the ocean,
Are nought but molecules in motion."

Atoms, you told me, were discrete,
Than you they could not be discreter,
Who know how many Millions meet
Within a cubic millimetre.
They clash together as they fly,
But *you!*—you cannot tell me why.

And when in tuning my guitar
The interval would *not* come right,
"This string," you said, "is strained too far,
'Tis forty dynes, at least too tight!"
And then you told me, as I sang,
What overtones were in my clang.

You gabbled on, but every phrase
Was stiff with scientific shoddy,
The only song you deigned to praise
Was "Gin a body meet a body,"
"And even there," you said, "collision
Was not described with due precision."

In the invariable plane,"
You told me, "lay the impulsive couple."
You seized my hand—you gave me pain,
By torsion of a wrist so supple;
You told me what that wrench would do—
" 'Twould set me twisting round a screw."

Were every hair of every tress
(Which you, no doubt, imagine mine),
Drawn towards you with its breaking stress—
A stress, say, of a megadyne,
That tension I would sooner suffer
Than meet again with such a duffer!

I. Bernard Cohen is assistant professor of general education and of the history of science at Harvard University.

How Animals Change Color

The chameleon is only one of many creatures that possess special cells for this purpose. Notable among the others: the catfish, the flounder, the tree toad, the squid and man

by Lorus J. and Margery J. Milne

WHEN YOU MEET a friend just back from a vacation at the beach, you are expected to exclaim: "What a beautiful tan!" This is no more than a proper reward for his many uncomfortable hours of baking in the sun. In a way it is also a tribute to a remarkable property of human skin—highly useful as well as ornamental. The darkening of the skin is an automatic means by which we defend ourselves against the harmful rays in intense sunlight; when the sunlight is weaker, as in winter, we conveniently lose the tan and our skin can admit the available ultraviolet rays to manufacture vitamin D. In other words, our changes of skin color are one of our devices for adapting to the environment, just as we shiver in defense against cold.

The animal kingdom abounds in examples of color changing much more spectacular than the human one. The animals that can change hue do so for diverse reasons and in diverse ways; the tanning of human skin itself is a rather special case, as we shall see.

Proverbial among the color-shifty animals, of course, is the chameleon. This native of Africa, rarely seen in the U. S. because it is hard to keep in captivity, is a slim creature with independently roving eyes, a long coiled tail, a remarkable snatching tongue and extremely sluggish habits. Normally leaf-green, it can ring the color changes from green through various shades of brown or red to black. There is a so-called "American chameleon," the Carolina lizard, which is just about as versatile; this alert-eyed little animal can change within a few minutes from bright green through chocolate-brown to grayish black, or through tan to a dirty white. The male, when courting a mate, puffs out a scarlet dewlap under its throat.

Popular superstition pictures the chameleon as the prime example of an animal that changes color to camouflage itself against its background. The truth is that its color shifts are due to temperature changes or the creature's nervous instability, and only accidentally do they ever match the background. The chameleon's color changeability is probably no more a protective mechanism than a human blush. In fact, the "protective coloration" of land animals in general is greatly overrated. Much sentimental writing has been done on the "perfect camouflage" of gray underwing moths on birch bark, yellow spiders on black-eyed Susans and green caterpillars on foliage. This overlooks the fact that the animals in question spend only portions of their time against these sheltering backgrounds!

WITH FISH it is a different story. The late F. B. Sumner found in experiments at the Scripps Institution of Oceanography in California that some fish possess remarkable ability to blend with their backgrounds. For instance, a medium-gray catfish placed in an aquarium with black walls and a black bottom becomes completely black in a matter of days. Transferred to a white pan, it bleaches out in a week to so pale a color that the pink of its blood shows through its translucent skin.

Blinded fish do not respond to alterations in the background; obviously the fish's change of color depends on visual cues. But the tank background is not the sole cue. Sumner proved this in the following way: Fish kept in a white tank bleached out to the maximum possible whiteness even under dim light. On the

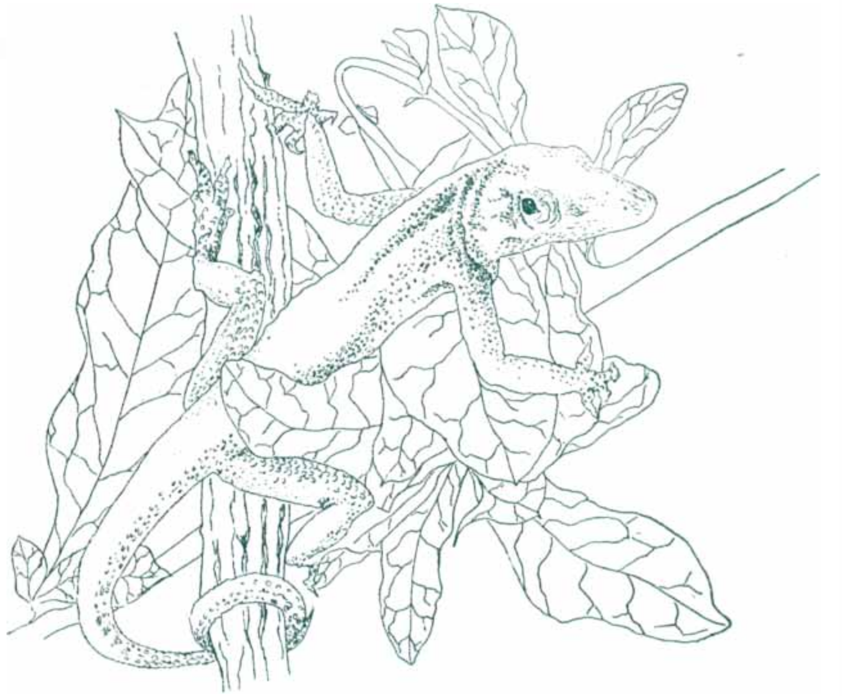
THE TREE TOAD HYLA can turn black, brown, gray, tan, green, white, yellow or light pink by means of cells containing three basic pigments.

other hand, in a dark-gray tank they turned dark gray or black even when the tank bottom and sides, under bright sunlight, reflected more light than those of the dimly lit white tank. This meant, of course, that their coloring was determined not by the absolute amount of reflected light but by the relation between the incident light (from the sky) and the reflected light (from the tank). Sumner showed that the amount of dark pigment in the skins of the fish was directly proportional to the ratio of direct to reflected light. He demonstrated also that the upper and lower parts of the eyes played different roles in controlling the fish's color reactions. He devised "false corneas" (celluloid goggles) which could be fitted over the eyes of anesthetized fish. When he attached goggles that blacked out the lower half of the visual field, hiding the bottom and walls of the aquarium, the fish became dark even when kept on a white background. When the goggles blacked out the upper half of the eyes, concealing the sky, the fish remained pale even on black backgrounds.

Sumner went on to investigate the protective value of fishes' ability to change color. In a large shallow black tank he mixed two groups of killifish, one of which had been bleached by being kept for two months in a white tank and the other of which had been similarly conditioned to have a black color. The black and white fish mingled together and swam in a single school, but against the black background of the tank the bleached fish of course were much more conspicuous. Sumner then put a penguin in the tank. It ducked its head under water and began to hunt the fish, pausing only for occasional breaths of air. By the end of the experiment it had eaten 293 fish, and it turned out that 74 per cent of the penguin's catch were bleached fish. In a counterpart experiment in a white tank, where the black fish were a little easier to see than the bleached ones, 61 per cent of the fish caught were black.

Most remarkable of the background-matching fishes are the flounders and their flatfish relatives. Sumner made many studies of these fish at the marine biological laboratories in Naples, Italy, and Woods Hole, Mass. He first noticed that on gravel bottoms with a mixture of dark and pale stones flatfish showed bold white patches on their backs. To find out how accurately they could match the background, he put flounder in a tank with a black and white checkerboard floor. The fish neatly matched the checkered pattern. What was more, when he varied the size of the squares in the checkerboard, the fish followed suit: they could match the coarseness or fineness of the pattern to an amazing degree. They also matched, more or less successfully, patterns of stripes, herringbones, polka dots, even quartz pebbles scattered on black lava sand.

The color changes in these fishes, then, depend on what they see. Land



THE CAROLINA LIZARD ANOLIS, sometimes called the American chameleon, commonly adopts a leafy green that matches surrounding foliage.

animals may be prompted to change color by various other stimulants—a change in temperature, an emotional disturbance. The tanning of human skin is a special case; this change is purely local and has nothing to do with the nervous system or vision. Indeed, it is induced by ultraviolet rays that are invisible to the human eye. But in all animals—fish, beast or man—the basic event is the same: a change in skin color is due to a reversible change in the distribution of certain skin pigments.

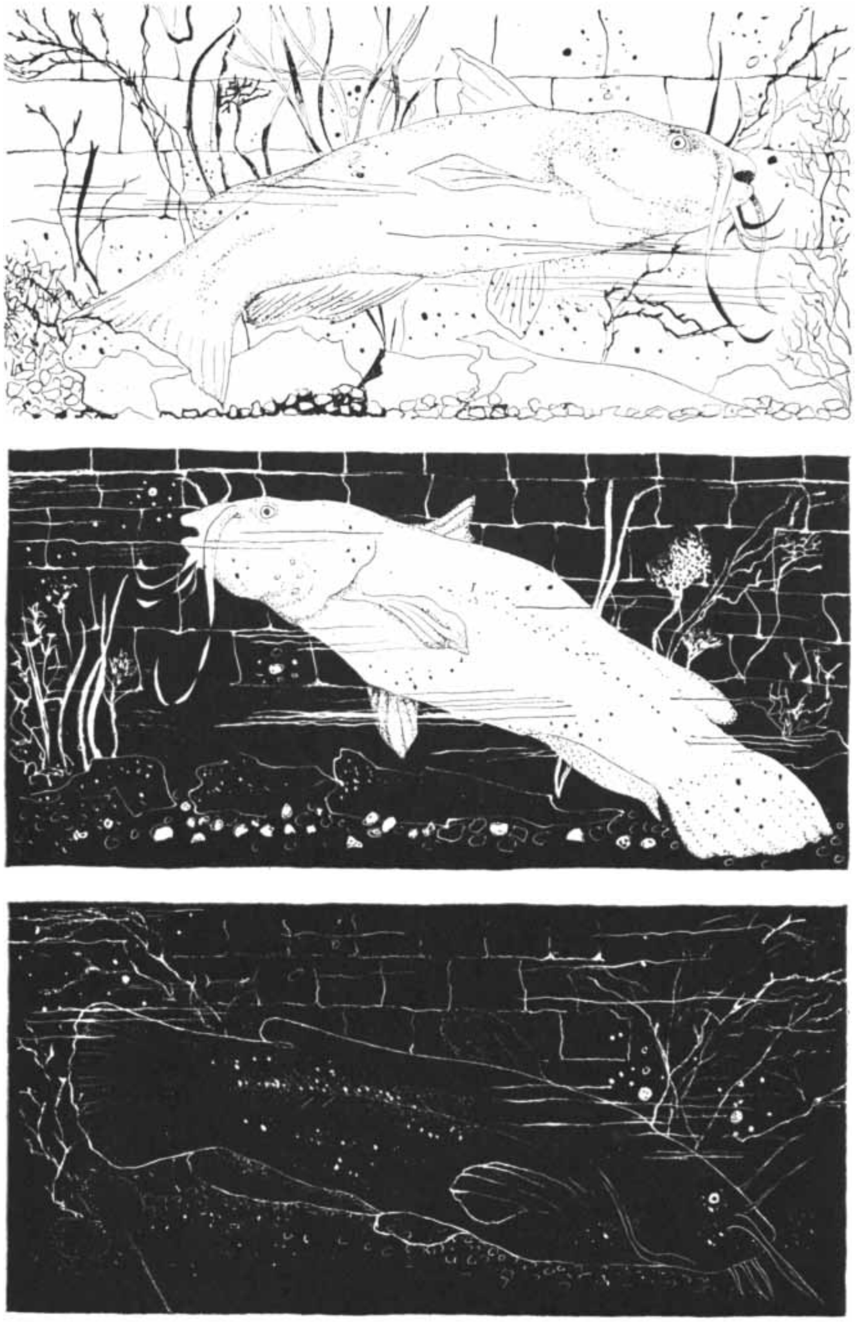
SKIN COLOR depends on pigment-bearing cells called chromatophores, located in the lower levels of the skin. A chromatophore usually is star-shaped, with long arms radiating from a central body. Its pigment is in the form of extremely tiny granules, and the granules may be distributed throughout the cell or concentrated in one spot in the center. The granules of pigment in a chromatophore are all of the same color—black or yellow or blue or red. There are many kinds of chromatophores, each named for the pigment it carries. The chromatophore involved in darkening of the skin is called a melanophore, from its brown or black pigment, melanin. When the melanin particles are dispersed throughout the body and arms of the melanophore cells, they darken the color of the skin; when they collect in a tiny dot in the center of the cell, light passes through these cells and is reflected from the lighter underlying tissues, so the skin becomes pale. Progressive darkening of the skin is the result not only of dispersion of the pigment through the cell but also of the manufacture of additional melanophores in the skin. This is the way the human skin develops a steadily deeper tan or a fish becomes darker and darker in a black tank. A black fish can bleach to gray in a few hours, merely by contracting the melanin granules into the centers of the melanophore cells. If it is kept on a light background for a long period, the melanophores themselves gradually disappear and the fish grows progressively paler. Similarly the human skin loses many of its melanophores when its exposure to ultraviolet rays is reduced.

Another important skin pigment is xanthophyll—the same xanthophyll that is largely responsible for the yellow color of autumn leaves. Unlike melanophores, the cells that carry the yellow pigment (xanthophores) do not increase or decrease in number in response to outside stimulation; the supply of xanthophores stays constant, and they produce changes in hue only by dispersing or contracting their pigment particles. The xanthophores, in combination with melanophores, extend the color repertoire of a fish or animal to various shades of yellow, tan and brown.

A third common skin pigment is guanine, whose color is silvery white. This is the pigment that enables flounders to match a mixed background so skillfully; apparently the flatfish reproduce white stripes or a checkerboard pattern solely by bringing into play the guanophores in the skin of their backs. Guanine also plays a part in the rapid color changes of the chameleon. Like the basic color on an artist's canvas, it serves as a background for other pigments. The guanophores are densely packed at an intermediate level of skin below the surface, and above them is a layer of yellow xanthophores. Apparently the guanophores do not change but form a steady reflecting background. Deep in the skin, their white color appears sky-blue, and this hue, filtered through the overlying yellow, is what gives the chameleon its usual leaf-green color. At deeper levels below the guanine layer the animal has melanophores of several shades—black, brown and reddish. These cells possess long arms that extend to the skin surface. The chameleon produces its changes of color by dispersing the various shades of melanin, one at a time or in combinations, into these arms. When the dark melanin spreads far enough into the arms to cover the guanophores but not far enough to hide the yellow, the animal's skin turns brown; when it covers the yellow as well, the chameleon takes on the hue of the red or black melanin. The change seldom occurs uniformly over the whole body; hence the colors sweep slowly over the chameleon in spots or waves.

Although the chameleon has been the favorite of authors and poets from Plutarch to Shelley, it is at least equaled by some other animals, so far as color versatility is concerned. Notable among these is the American tree toad named *Hyla.* Using the same three pigments—melanin, guanine and a yellow which may be xanthophyll—the tree toads can turn black, brown, gray, tan, green, white, yellow or light pink. (Curiously, one species of the toads is named *H. coerulea,* meaning sky-blue, although it never has that color in nature; it becomes blue only after it has been preserved in alcohol, which dissolves the yellow pigment and exposes the bluish guanine underneath.)

WHAT SORT of directing system controls all this color staging in animals? As we have seen, the initial cue may come from vision, emotion or temperature, which sends the message to the central switchboard—the nervous system. (Skin-tanning is an exception; here the light stimulates the chromatophores locally.) Usually the nerves send directions to the chromatophores by way of hormones, the chemical messengers that travel in the blood. But there is one group of animals in which the switchboard operates the pigment cells by direct control. These are the mollusks that have tentacles reaching from the head—



THE CATFISH will change color according to its surroundings. In one experiment a white catfish that had been in a white tank (*top*) was removed and placed in a black tank (*middle*). The fish then turned black (*bottom*).

the octopus, the squid, the cuttlefish and the like. The chromatophores in the skins of these animals consist in flexible bags containing a colored liquid—red, blue, yellow, black or white. Each bag has a ring of threadlike contractile elements which can pull the bag out into a flat disk, showing the color, or let it collapse into a tiny sphere. A separate nerve fiber controls each bag. Cephalopods are high-strung animals, and the state of their emotions can be read in the twinkling of their thousands of chromatophores. An octopus, disturbed during its daytime rest, may blush a deep maroon or blanch to a ghastly white, or it may display a swift succession of yellow, tan, green and blue spots as it agitates its chromatophores in protest.

Although we usually think of the plant world as furnishing most of nature's color, animals, too, contribute to the canvas, and their chromatic shifts are even more dramatic.

Lorus J. and Margery J. Milne, biologists at the University of New Hampshire, were the authors of The Eelgrass Catastrophy *and other articles that have appeared in this magazine.*

Logic Machines

The ancient idea of a device which would test the validity of a system of thought has recently made progress. A very simple machine can be made from page 71 of this magazine

by Martin Gardner

THE most powerful intellects have always agreed that thinking is hard work, and many have attempted to create labor-saving devices to lighten the burden. Systems of logic are, in a sense, instruments for more efficient solving of problems. One of the oldest and most elementary devices is the syllogism, invented by Aristotle (*e.g.*, All Texans are Americans; no American wears a monocle; therefore no Texan wears a monocle). The great 17th-century mathematician Gottfried Wilhelm Leibnitz dreamed of a "universal calculus" by which logical problems might be solved. His dream has been partly realized in the modern system of symbolic logic, a labor-saving method which uses symbols to represent ideas and solves problems in reasoning by a kind of algebraic process. First formulated in the 19th century by the English mathematician George Boole, the system has been developed into a powerful tool for dealing with complex problems in mathematics and in business ("Symbolic Logic," by John E. Pfeiffer; SCIENTIFIC AMERICAN, December, 1950).

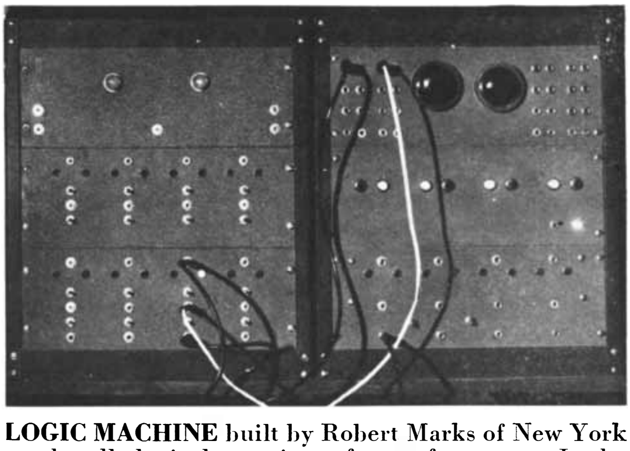
But the great dream, of course, has been to create a thinking machine—a physical "brain" that could carry out the mechanical processes of reasoning automatically. So far as anyone knows, the first man to tackle logical problems with mechanical aids was a 13th-century Spanish mystic named Raimon Lull. Almost forgotten today, in his time Lull was a widely influential and controversial figure. His consuming ambition was to convert the Saracens to Christianity. In this endeavor he used a system of "proof" intended to lead them to the truth. It involved translating logical problems into geometrical figures of various shapes and colors, which were made to intersect and overlap in different ways. Lull applied his *Ars Magna*, as he called it, to every branch of science and philosophy—even to military tactics—and was firmly convinced that every truth in Christian revelation could be given a definitive proof by his multicolored designs. (The Moslems remained skeptical, and in 1315 they stoned Lull to death.)

ONE OF Lull's devices used movable parts and can therefore be considered a primitive logic machine. It consisted of a set of metal disks which rotated about a common center. On each disk were letters representing various ideas. For example, around the circumference of one disk would be 16 letters symbolizing 16 attributes of God, and the same letters were repeated on a second circle outside the first. By rotating the inner wheel one could explore all the possible combinations of attributes on the two wheels (a total of 256 in this case). In this way Lull "demonstrated" that God is "gloriously wise," "gloriously glorious," and so on.

Since his wheels were a handy mechanical means of exhausting the possible combinations of given sets of terms—a principle used today in the construction of tables listing all possible combinations of true and false for a given set of propositions—it is not unreasonable to regard Lull as the first inventor of a logic machine. As a matter of fact, in many of his figures he employed the symbol Y for "truth" and Z for "falsehood," to indicate which combinations of ideas were to be rejected and which retained—a process analogous in a dim way to the operation of later and more legitimate logic machines.

But most of Lull's devices were completely valueless, and his *Ars Magna* fully deserved the epithet of *Methodus Imposturae* that Francis Bacon later bestowed on it. Jonathan Swift may have had Lull's circles in mind in his satirical description of the logic machine that Gulliver found in the voyage to Laputa. This contrivance was a big square frame with hundreds of small cubes strung together by wires, each cube having various words in the Laputan language on its several faces. A Laputan professor and his pupils were turning cranks that rotated the cube faces, and whenever the faces combined a few words that made sense, the scholars copied the phrases down. From the broken phrases the professor was composing erudite treatises. "By his contrivance," writes Swift, "the most ignorant person . . . may write books in philosophy, poetry, politics, law, mathematics, and theology, without the least assistance from genius or study."

LATE in the 18th century Charles Stanhope, third Earl, a British statesman and inventor, built the first true logic machine, the Stanhope Demonstrator.



LOGIC MACHINE built by Robert Marks of New York can handle logical equations of up to four terms. In the first photograph the jacks have been inserted in such

The Demonstrator was a crude gadget for solving syllogisms. A syllogism consists of a major premise and a minor premise, the first making a statement about a "predicate term" and a "middle term," the second about the same middle term and a "subject term." By eliminating the middle term one arrives at the correct conclusion as to the relation of subject to predicate. In Stanhope's Demonstrator the middle term was represented by a small wooden panel called the "holon." It had a frame through which other panels could be slid to cover all or part of the holon. A panel of gray wood, representing the subject, was pushed in from the left, and one of red glass, representing the predicate, was pushed in over this from the right.

To solve a syllogism the machine required that the premises be stated in affirmative form. To illustrate how it was used let us take the syllogism given at the beginning of this article: "All Texans are Americans," and "No American wears a monocle." We will let M stand for "American" (the middle term), S for "wears a monocle" (the subject term) and P for "Texans" (the predicate term). Now the minor premise can be stated "No M is S," but this must be translated into the affirmative "All M is some not-S" (all Americans are part of the class which does not wear monocles). The holon stands for M, the middle term. We push the gray slide, representing "some not-S," into the frame so it covers the entire holon ("all" of M). The major premise is "All P is some M," (all Texans are part of the group called Americans). We slide the red glass ("all P") part way into the frame to cover "some" M. The two slides overlap, with the gray panel (S) showing through the glass. Hence an identity is established between S and P, and we have proved that "All P is some not-S," meaning that all Texans are part of the class that does not wear monocles—in other words, no Texan wears a monocle.

Stanhope scaled the sides of the holon and of the two slides from 1 to 10, and thus made it possible for the machine to solve syllogisms in which the subject and predicate have numerical values. For example, if you are told that 8 of 10 pictures are abstractions, and 4 of the 10 are by Picasso, the Demonstrator will show that at least 2 and no more than 4 abstractions are by Picasso. Stanhope's device also can solve some elementary problems in probability.

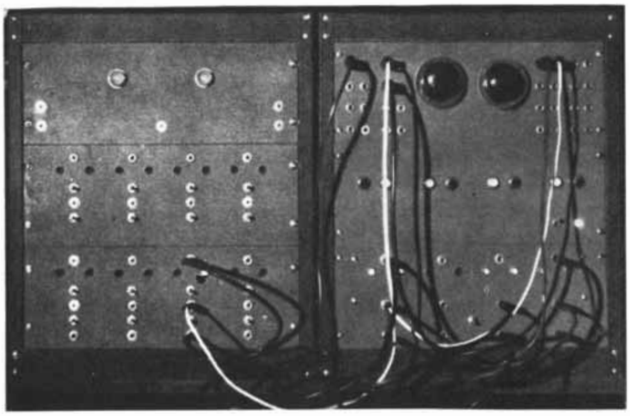
IT WAS in 1854 that Boole published his epoch-making little book, called *An Investigation of the Laws of Thought,* outlining a system of symbolic logic. Logicians generally ignored it, but William Stanley Jevons, a British economist and logician, recognized the revolutionary character of the Boolian algebra. With remarkable insight he wrote that Boole had "put the science [of logic] substantially into the form which it must hold forevermore."

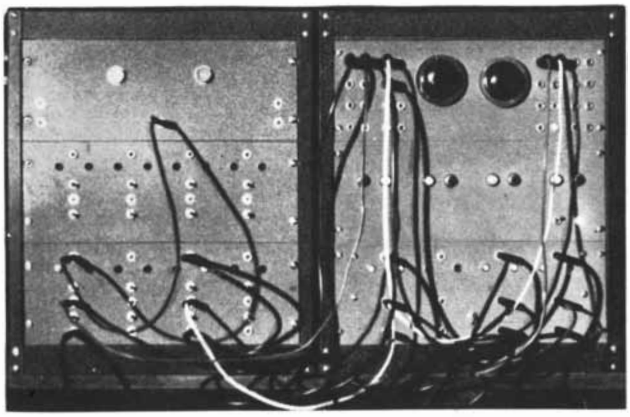
Jevons promptly began to work out methods of applying Boole's approach. One of these, which he called the "abecedarium," operates as follows: A list is made of all possible combinations of terms in their positive and negative forms. If it is a syllogism we are considering, three terms are involved. They may be called A, B and C, and the negatives of these terms (not-A, not-B and not-C) can be represented by a, b and c. There are eight ways in which the three letters, in upper- and lower-case forms, can be combined—each combination representing a possible class: ABC, ABc, AbC, Abc, aBC, aBc, abC, and abc. We now cross out all classes inconsistent with the premises. For example, if the major premise is "All A is B," then combinations containing A and b (not-B) cannot be true, so we cross out AbC and Abc. If the second premise is "All B is C," we eliminate ABc and aBc. The remaining combinations (ABC, aBC, abC and abc) are consistent with the premises and therefore true. We now examine them to determine the relation between A and C. We find that A appears in combination only with C, not with its negative, so we correctly conclude that "All A is C." If it had also been combined with c, no conclusion would have been possible, because the combinations would contradict each other.

Jevons went on to construct a device to solve the Boolian algebraic equations mechanically. This instrument, which he called the "logical piano," was the first logic machine efficient enough to solve problems more rapidly than they could be solved by the human brain.

Jevons' famous logical piano works on exactly the same principle as the "abecedarium." The machine looks like a miniature upright piano about three feet high. On its front are openings through which can be seen letters representing the 16 possible combinations of four terms and their negatives. It has a keyboard with 21 keys, one for each of the 16 combinations and five others for certain necessary operations. To use the piano it is necessary to translate each premise into the form of an equation along lines proposed by Boole. Then the proper keys are pressed to feed each premise into the machine. A system of connecting levers automatically eliminates from the face whatever combinations of terms are eliminated by each premise. When all the premises have been given to the machine, the face is inspected to determine what conclusions can be reached.

IN ADDITION to solving syllogisms—or problems in the logic of class inclusion—the machine also handles problems involving truth relations between propositions. In fact, it solves them with greater ease, because syllogisms are far from the simplest forms of logic. The assertion "Either A or B is true" (meaning one must be false) is an example of a truth-value relation between two propositions. In this case, if we let upper-case letters stand for "true" and lower-case for "false," only two combi-





a way as to set up a proposition. In the second they have been rearranged to express a related proposition. In the third they have been rearranged again to establish another related proposition. The light at the upper left-hand corner of the machine now comes on to indicate that the three propositions form a logically valid system.

nations will be possible, namely: Ab and aB. Assertions of a similar kind, such as "If, and only if, A is true, then B is true," or "Not both A and B are true," can be fed into the logical piano by pressing keys which eliminate the invalid combinations. The assertion "A is true" is fed to the machine simply by eliminating all combinations containing a. After the given premises are in the machine, the face shows at a glance the valid truth-relations between the terms.

A sample problem of this sort, solved quickly by the piano, is the following: Four clerks work in the same office—Amy, Bill, Charlie and Doris. When Amy goes out for a cup of coffee, Doris always goes with her. When Bill goes out for coffee, and only when he goes out, Charlie goes along. Bill and Doris, however, are never permitted out of the office at the same time. If I pass a restaurant during working hours and see Charlie enjoying a cup of coffee, what can I deduce about the others? Since "out" and "in" are mutually exclusive, we can equate "out" with "true" and "in" with "false." The initial letters of the names are our four terms. After feeding the assertions into the machine, we discover that all combinations vanish from the face except one: aBCd. This tells us immediately that Bill is having coffee with Charlie, and Amy and Doris are at the office.

In 1881 Allan Marquand, another British logician, constructed a much-improved version of Jevons' machine. He eliminated the awkward translation of premises into equations and simplified the keyboard to 10 keys.

Since 1900 many odd devices for solving syllogisms have been invented. An Italian logician named Annibale Pastore built a Rube Goldberg contraption of rotating gears, pendulum-like weights and wheels connected in various ways by endless belts. The U. S. psychologist Clark L. Hull created a syllogism-solving machine involving metal disks. Other inventions include slide rules, in both straight and circular forms, and sets of cards with openings cut at various places. On the opposite page is a set of syllogism "window" cards I worked out recently.

The first to use electrical circuits for solving syllogisms appears to have been Benjamin Burack, professor of psychology at Roosevelt College in Chicago. His machine, built in 1935, consists of three compartments into which wooden blocks can be fitted. There are 20 blocks in all, representing the 16 different premises and the four conclusions. On each block are contact points at certain spots. If the syllogism is valid, a circuit is completed and a bulb lights up next to the word "true." If it is invalid, one or more other bulbs light to indicate the fallacies.

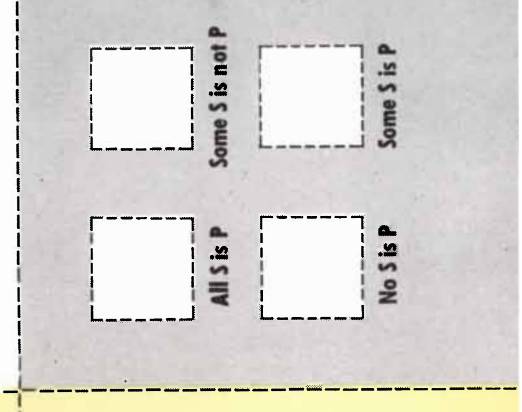
In 1938 Claude E. Shannon, research assistant in the department of electrical engineering at M.I.T., published a historic article titled "A Symbolic Analysis of Relay and Switching Circuits." The article called attention to the fact that "true" and "false," the two truth-values of symbolic logic, translated exactly into the binary system of 1 and 0, which is used in the construction of electrical calculating machines. Shannon proved it was a simple matter to construct circuits in series and parallel, with switches properly placed, so that the network corresponded to basic relations between propositions in the Boolian algebra. For example, the assertion, "If, and only if, A is true, then B is true," can be translated into A and B circuits which open and close simultaneously, showing the truth-identity.

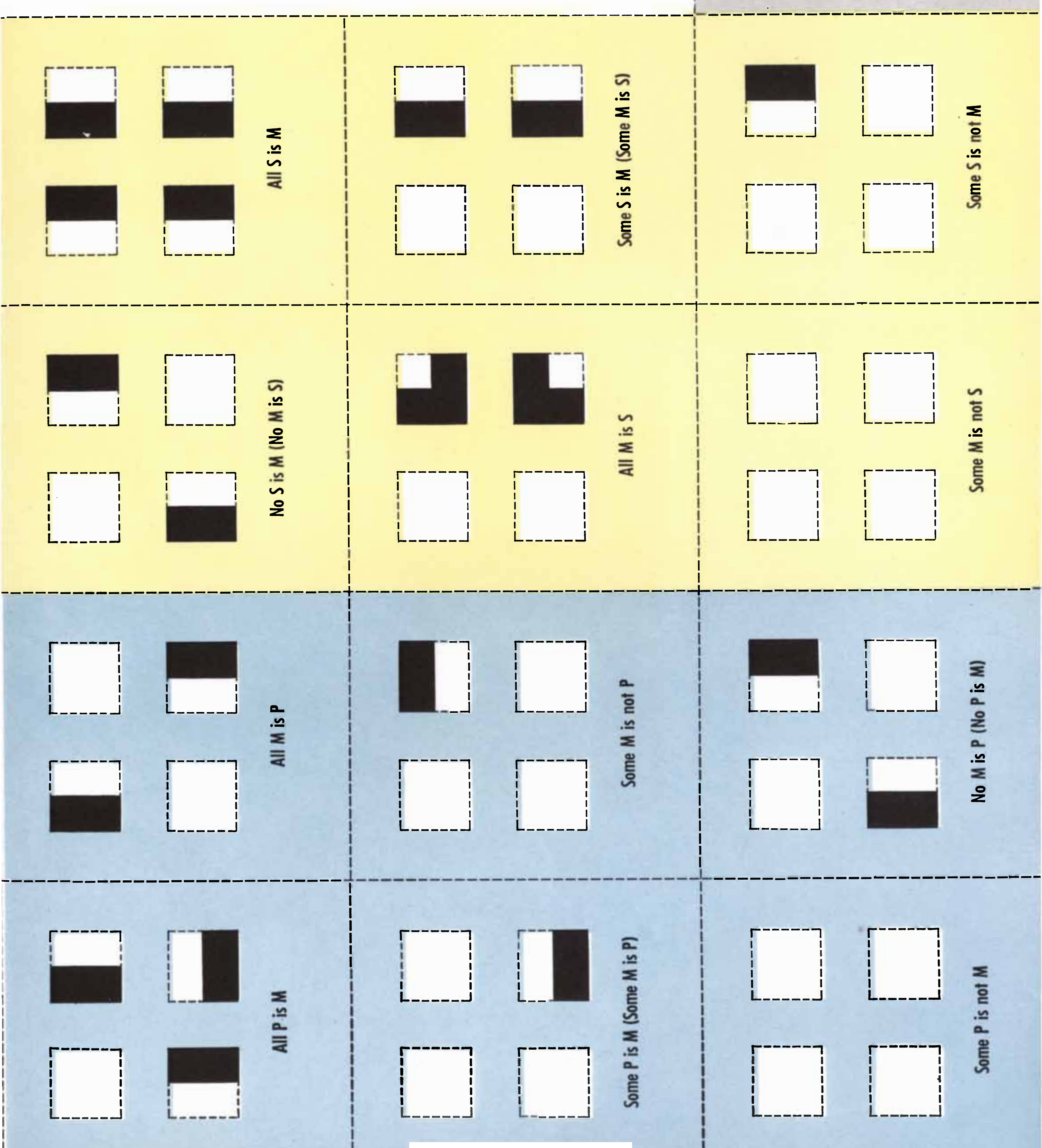
In 1947 two Harvard undergraduates,

A PRIMITIVE LOGIC MACHINE that will test the validity of syllogisms is printed on the opposite page; the reader is invited to cut out the 13 cards and operate it. A sample syllogism: "All potatoes are tubers; all tubers contain starch; therefore all potatoes contain starch." In the conclusion of this syllogism the word potatoes is the subject (S) and starch is the predicate (P). Thus the conclusion may be stated: "All S is P." The problem is to determine whether this conclusion can be validly deduced from the premises, which relate S and P to a middle term (M). The premise containing P is called the major premise; in this case it is "All tubers contain starch," or "All M is P." The premise containing S is the minor premise; in this case it is "All potatoes are tubers," or "All S is M." Now the blue cards on the opposite page are labeled with major premises and the yellow cards with minor premises. All the possible conclusions of a syllogism are on the single gray card. If we take the blue card labeled "All M is P," place it on top of the yellow card labeled "All S is M" and place the gray card on top of both, we find that the window on the gray card labeled "All S is P" is filled with black. This indicates that the syllogism is valid, which is hardly surprising. To go one step further the reader may try a syllogism adapted from Lewis Carroll: "No fossil can be crossed in love; some oysters can be crossed in love; therefore no oyster is a fossil." If the appropriate blue and yellow cards are placed under the gray card, and if the properly labeled window in the gray card is filled with black, the syllogism is valid. If the window in the gray card is only partly filled or empty, however, the syllogism is invalid.

DIRECTIONS FOR PREPARING CARDS:

1. CUT ALONG DOTTED LINE AT LEFT
2. MAKE 13 CARDS BY CUTTING ALONG REMAINING DOTTED LINES
3. CUT WHITE AREAS FROM EACH CARD





Theodore A. Kalin and William Burkhart, who were taking an elementary course in symbolic logic and found the elaborate computations tiresome, read Shannon's paper. They decided to build an electrical machine along the lines he suggested, to do the work for them. Using about $150 worth of material, they built a machine of less than four cubic feet which solved complex problems in logic with great speed and efficiency. Their device, the first in history to use electrical circuits for solving problems in symbolic logic, is now well known as the Kalin-Burkhart Calculator.

The calculator takes care of 12 terms and 12 assertions about their truth-relations. Its method of operation is basically the same as in Jevons' piano, except that electrical circuits rather than levers are used for eliminating invalid combinations. Instead of showing immediately which combinations of true and false terms are valid, however, the calculator considers each combination separately, one after the other. If the combination is consistent with the premises, a yellow light glows and a row of 12 red bulbs, each representing a term, indicates which terms are true and which false. Since each combination corresponds to a row on a truth-table, the Kalin-Burkhart machine is simply an electrical device for scanning rapidly the successive rows of a truth-table. It can be set to stop automatically whenever the yellow light flashes, so the operator may copy down each valid row of the truth-table as indicated by the red bulbs. The results can then be inspected to answer any desired question. The advantage over the Jevons piano is that the calculator can handle many more terms, and complex premises can be fed to it with greater ease.

An electrical logic machine with slightly different abilities was built in 1949 at the University of Manchester, where 80 years before Jevons had built his logical piano. The Manchester machine handles only three terms, but a more elaborate, multitermed calculator is currently under construction there.

At the moment, logic machines have very limited value, due to the fact that science is seldom confronted with problems of a strictly logical nature which are complex enough to require mechanical aid. In business procedures, however, fairly intricate logical questions may arise, and a number of large corporations have been considering ways of making use of the Kalin-Burkhart machine. It would be particularly useful, for example, on complex problems such as arise in insurance.

Another field in which logic networks may become increasingly useful is in the operation of the giant electronic computers. Problems frequently arise in deciding the best way to set the machine for a given task, and often these problems are purely logical in character. Computers of the future may have logic circuits built into them so that such decisions will be made automatically.

LOOKING far into the future, the most fascinating speculations concern the possibility of combining reasoning and memory in a machine. A machine of this sort, using mechanical means, was actually proposed as early as 1851 by a prominent British surgeon, Alfred Smee, in a curious little book called *The Process of Thought*. The doctor admitted that his machine would "cover an area exceeding probably all London." A few years ago Vannevar Bush, inventor of M.I.T.'s first differential analyzer, described a similar imaginary machine called the "Memex," which would store factual data on microfilm and connect it logically by means of electrical circuits. You could, for example, ask such a machine, "At what temperature would water boil on the moon?" The machine would collate all the relevant data and give you the answer. As Dr. Smee suggested, probability values also could be built into such a contrivance. You might give the machine a set of premises about the geological conditions known to prevail in an area where a wildcat oil well was being drilled. The machine would integrate all the known facts about the relation of oil pools to various types of geological structures, and tell you the probability of finding a profitable well at this site.

In principle it is not impossible that such a machine might even invade the field of philosophy, indicating precisely what philosophical questions are capable of solution on the basis of known data. It might also be possible to build into a machine all the basic axioms of a system of thought, such as that of Spinoza. We could ask the machine to detect any contradictions in the system and answer philosophic questions in terms consistent with the axioms. A machine might also be built to translate from one system into another.

The question of whether philosophical machines could be constructed to think creatively leads into many tangled matters. Outside of science fiction no calculator—logical or mathematical—has yet betrayed the slightest spark of originality. Perhaps it is just as well. Samuel Butler's *Erewhon* paints a horrifying picture of what might happen if machines became intelligent enough to think and act for themselves; there is also the Ambrose Bierce story of the robot chess-player which, after being beaten by its inventor, strangled him. As the logician Charles Peirce has pointed out: "We do not want it [a logic machine] to do its own business but ours."

Martin Gardner is the author of numerous articles on mathematical subjects.

What GENERAL ELECTRIC People Are Saying

I. LANGMUIR

Research Laboratory

PLANNING UNPLANNED RESEARCH: You can't plan to make discoveries. But you can plan work that will probably lead to discoveries.

Dr. Willis Whitney discovered a word which is in the dictionary—serendipity—and I don't like the definition that is given. Let me suggest this one: "The art of profiting from unexpected occurrences." Now, it seems to me a large part of the Laboratory work is based on that. You don't know all the things that are going to happen; too many of them are unexpected. But it is these unexpected things that are going to be the most profitable—the most useful—things you do.

In 1942, when I was President of the American Association for the Advancement of Science, I broadcast a half-hour talk in which I said that physics nowadays is not like the physics of the past century. There is classical physics, and there is quantum mechanics. What's the main difference?

The old idea of physics was that everything was perfectly, definitely due to causality. There was a definite relation of cause and effect. And that worked perfectly well in classical physics. But, then, years later came the quantum theory and the uncertainty principle of Heisenberg. But Bohr, five or ten years before Heisenberg's uncertainty principle, had the idea of the correspondence and uncertainty principles very clearly in mind. I remember Bohr saying that if a thirteen inch shell is coming toward you, several thousand feet a second—headed right toward you—it may pass through you and produce no effect whatever. There is a certain definite chance that this will happen—very small.

Take another example. You can see the track of an alpha particle. It's one quantum effect—a radium atom exploded. Fundamentally, you can't find the cause for such things. In fact, as Bohr pointed out very clearly, if you could find out what it is that sets off a radium atom after 2000 years, then the whole of quantum mechanics would have to go by the board. It's basic that those must be the fundamental things, the probability, and not the cause of the definite action. All right, if an alpha particle can leave a track and a man can do something as a result of it—see it, for example—he may either get killed or not get killed because of timing. He may be run over by an automobile because he left his office a little later than he otherwise would have.

So single quantum effects can affect the lives of individuals. Now, the moment you prove that in principle, the whole basic idea of cause and effect is gone for all those phenomena that can be started from small beginnings and grow up to large things.

Take heredity, for instance. A single gene cell can be affected by a cosmic ray or by x-rays. Single quantum phenomena. They're absolutely interminable. And, therefore, basically the whole development of the human race has not been the result of cause and effect—only probabilities.

Come down to human affairs—an idea, for instance. How did it begin? Why, with something as small as a quantum, or the actions of a lot of separate quantums, of course. You have the dividing of the ways. Either you do one thing or the other. You continue to have alternatives. Those alternatives may determine things of tremendous importance.

If you can't predict ideas, you can't plan things in a laboratory. But you can organize a laboratory so as to increase the probabilities that useful things will happen there. And, in so doing, keep the flexibility, keep the freedom. That's what freedom is for. All of us in this Research Laboratory are interested in freedom. We know from our own experience that in true freedom we can do things that could never be done through planning. That's why we are going to beat out Russia in the long run.

Stalin believes that everything can be planned. Marx believed that everything could be planned. That's the trouble with all dictators. They think that they can run the world by planning from above. And that is an utter impossibility, basically and fundamentally, because of the existence of divergent phenomena.

The moment that you see that the world isn't a kind of place where complete planning is possible, then you believe in democracy, you believe in freedom and initiative—in all the kinds of things that can be planned only in very general ways, not in detail.

What did Mussolini try to do? What did Hitler try to do? They had plans for conquering the world, and they knew just how to do it. They failed. They failed for many reasons, but one of the reasons is that you can't run things that way. And I think, no matter how far you may go in dictatorship, no matter how far it may succeed, it will ultimately fail because of the impossibility of planning on a world-wide scale.

Now, in this Laboratory we have a good example. I think most of us here have ideas of freedom and of the importance of thinking things out in our own way. Human virtues such as curiosity, initiative, interest in things, and just doing things for the fun of it, add up to me as just one of the things you realize in this Laboratory. And if only it could be that way on a world-wide scale, we would be much better off than we are now.

Colloquium
General Electric Research Laboratory
December 12, 1951

You can put your confidence in—

GENERAL ELECTRIC

BOOKS

Concerning the brain of man and its biological and mechanical analogues

by James R. Newman

Doubt and Certainty in Science, by J. Z. Young. Oxford University Press ($2.50).

"OF ALL the wonders," wrote Sophocles, "none is more wonderful than man—who has learned the arts of speech, of windswift thought, and of living in neighbourliness." As to the cultivation of neighborliness there may in our age be some doubt, but of man's distinctive proficiency in speech and thought there can be none. The subject of this brilliant book is the relation between man's behavior as a communicating and cooperating animal and the processes of the human brain. Biologists have suggested that we are what we eat; Professor Young proposes that we are what we observe and communicate. The biologists, studying man's habits of eating, digestion, locomotion, mating and so on, have concentrated on the features of man that resemble those of other animals and have not sufficiently considered the "traits of what we commonly call man's mind that are also his most peculiar and important *biological* characteristics." Professor Young, a leading British anatomist, takes the latter approach and examines the working of the brain, how we learn and tell one another, how man's "higher activities" depend on the operations of the marvelously compact engine built into his skull. While his book (the 1950 Reith Lectures of the British Broadcasting Corporation) suffers to some extent from oversimplification, I cannot remember reading a more stimulating popularization of science.

What is known about the brain as a machine? Sir Charles Sherrington, E. D. Adrian, D. O. Hebb and other outstanding investigators have written lucidly on the frontiers of knowledge in this field. Research on the physiology of the nervous system is a most difficult endeavor, the details being of "hardly imaginable complexity." Despite significant advances, we have not yet accumulated more than fragmentary insights into what goes on in the brain. This fact, Young points out, should make educators and psychologists cautious in acting on their theories of how we think and learn, and might be expected to restrain the intrepid little band of surgeons who cut pieces out of an organ about whose processes they are essentially ignorant.

Young's method of explaining the brain rests almost entirely upon analogy. We enlarge our knowledge by making new comparisons, by looking about, as one might say, with an innocent eye. "A polyp," William James wrote in his *Principles of Psychology*, "would be a conceptual thinker if a feeling of 'Hollo! thingumbob again!' ever flitted through his mind." In science and art, in philosophy, statecraft and shoemaking, it is surprising how much progress results from merely cocking the head, changing the angle of view and uncovering unsuspected similarities. "The brain is continually searching for fresh information about the rhythm and regularity of what goes on around us." This quest Young calls "doubting." When, for the moment, the brain is satisfied by the discovery of analogies and significant resemblances, a new "system of law" is created and we are comfortable in a new "certainty." Sooner or later our dogmatic ease is disturbed by fresh doubts, provoking more fruitful comparisons and requiring us therefore to change our notions about the world and to talk about it differently.

Young traces the fashions in analogies—how man has alternated in the use of words to describe his own actions and those of the tools he produces. Fire was first spoken of as "a living thing"; as men learned to use it for cooking and other purposes, they came to speak of "vital fires and vital cookings within them." Classical physics borrowed from ordinary language such words as "force" and "work," made their meaning more exact so that they could be used in mathematical discourse, and then returned them to biology for use in studying problems of the "interchanges of work and energy in the body." New concepts, tools and techniques not only enrich the field in which they were first developed but by a wider absorption in thought and language may produce profound changes throughout the sphere of human activities. The physics that postulated the world as a machine was tutor to biology and medicine, enabling them to cast off a good deal of medieval hocus-pocus and to make fruitful studies of the body by also viewing it as a machine.

Modern physics has discarded the simple clockwork interpretation, recognizing at once the imperfections in our knowledge of present states and the impossibility of forecasting exactly future states. Statistical methods have been developed to deal with the slippery essence around us: the physicist now knows that his theories and experiments deal not with simple entities but always with complex and uncertain organizations, and thus finds himself working at the same bench with the biologist, who has known for a long time that the entities he is studying are not simple. With biology and physics sharing this powerful technique, it follows that innovations in physics may almost immediately suggest new ways in biology. Physics uses new words to describe the physical universe, biology new words to describe the organism. "We are gradually coming to speak in new ways about ourselves."

In the light of this discussion, we may return to the question about the working of the brain. In the branch of applied physics sometimes called "small-current engineering," a good deal of work has been done on control and communication in machines. Engineers in this field, to which popular attention has been drawn by achievements in the design of electronic computers, have found it convenient to borrow terms "previously used to describe human communication." They have redefined and sharpened the meaning of words such as "information," and have concocted their own jargon, *e.g.*, "feed-back." They have built machines that can "receive and react to information," exert control, "remember" and perform other acts which until recently only living things could perform. Indeed, these machines possess some talents that no man can match. Physiologists studying the nervous system have been able to make use of the general ideas and terminology developed by the small-current engineers, even though a "detailed application of their techniques" has not yet been possible.

In his summary of what is known about the functioning of the brain Young avails himself fully of the research on nonliving feedback systems. Descartes compared the body with a clock; Young draws analogies from a wide range of mechanical self-regulating devices to show how the brain, acting on information from its receptors, adjusts the responses of the body to outer changes and keeps it in a "steady state."

He draws an interesting comparison, for example, between the nervous system of an octopus and the elaborate calculating machine installed in a guided missile. The octopus—a slave in one of Young's experiments—had a rough time trying to snatch a crab placed in the same tank. It had been arranged that whenever the octopus reached out a tentacle, it would get an electric shock from a small white metal plate placed next to the bait. After two or three painful attempts the octopus quit and went into a sulk; its frustration was manifested in marked changes of body color and in the darkening of its eyes. A guided missile can be designed which will react to danger signals in similar fashion. It will have a receiver corresponding to the retina of the octopus' eye. Upon the appearance of certain signals, it will send electrical warnings and instructions to its steering apparatus, just as the octopus' retina transmits electrical nerve-impulses to the optic areas in its brain. The missile will evaluate the information received, as does the octopus, and "decide" what to do—to run away, to change course, to take "evasive" action. Its eyes will not darken—but let us hope it will run away.

Is there a difference between the octopus and the guided missile? An enormous difference, to be sure. Louis Ridenour at a recent Harvard symposium quoted a psychiatrist to the effect that "the over-all complexity of the largest and most complicated computing machine now in existence or proposed is just about equivalent to the complexity of the nervous system of the flatworm"—and the flatworm is a Simple Simon compared to the octopus. Yet there are useful analogies between the missile and octopus. Both can "remember." The octopus that served as Young's assistant learned to reach for the crab immediately whenever the white plate was removed. The guided missile's "memory" is a set of stored instructions telling it what to do and what not to do under various conditions. There are many ways of storing information—photographs, books, punch cards, magnetic tape, vacuum tubes, to name only a few.

How the brain of the octopus (or, for that matter, of man) remembers is not certainly known, but Young believes that the artificial memory-aids man has devised, from hieroglyphs to electronic circuits, provide possible clues to the memory processes of the nervous system. There is evidence, as Hebb has suggested, that each experience leaves some physical trace in the brain tissue. Brain cells are known to grow bigger with use and atrophy with disuse; those who expect to keep their heads in vigorous shape by using them as little as possible may be mistaken. There is a basis for the more intriguing conjecture that information is stored in the brain by setting it up in a continuous electrical circuit where it is available for reference when needed, just as is done in certain computers. To appreciate how the brain might exploit this method one should note that while the largest computers have fewer than 25,000 tubes, the cortex of the brain has some 15 billion cells, each corresponding to a tube.

Young compares the brain also to a "gigantic government office, whose one aim and object is to preserve intact the country for which it is responsible. Ten million telegraph wires bring information to the office, coded in dots. These correspond to the sensory or input fibres reaching the brain." In this office 15 billion clerks sit in closely packed rows; each clerk has a telephone connecting him with receiving stations (sense organs) and with other departments (cell groups). Each spends "most of his time sending code messages on his telephone to some other group, which may be near or far. . . . But the clerks can also influence their neighbours by whispering 'silence'; obviously if a group of them starts doing this then a wave of quiet will pass over that area and it will send out no messages for a while. In this way most elaborate patterns of activity will grow up between the huge numbers of clerks throughout the building. There are circuits by which messages are sent from one department to another and then back to the first and so on indefinitely. Messages will go round and round, but be influenced by incoming messages and by the waves of silence. However, the whole office is so arranged that some of the telephones eventually transmit instructions to workers outside, directing them how to run the country and bring food, drink and other necessities to the government office."

How information fed into the brain is converted into responsive and sensible decisions is one of the grand enigmas. Young is again prompted to enlist the analogy of the computer. In certain calculators information received in the past may be coded and stored away for reference. "When asked a question [the machine] puts it into code, and, by a process that is essentially one of adding and subtracting very fast, the machine can then refer the question to the rules that are already stored in it, and so produce the right answer. Similarly, the brain is constantly relating the new impulses that reach it to the information already stored away in its tissues."

A television camera can translate visible events into dots and dashes; a computer can transact all its business in 0s and 1s. It is "not at all impossible" that the brain maintains its enormously involved communications by elaborate permutations and combinations of an on-off, yes-no, dot-dash, or 0-1 symbolism. The center for these operations is the great sheet of nerve cells at the top of the brain, the cerebral cortex, which is "the chief section of our great government office and employs 99 per cent of the clerks." Here the messages are sifted and decoded, decisions are made and orders relayed to appropriate stations. It staggers the imagination how efficiently this office—surely not an ordinary government bureau—does its job. With five or six times as many workers as there are people in the whole world, without supervisors, section heads or secretaries, it can handle equally well the information conveyed by the calls "Soup's on!", "Fire!" or "Play ball!", by the sight of a new hat in a store window or a page of differential equations or Rita Hayworth, by the "tiny spot of light on the retina" produced by a distant star, by the blinking of a traffic signal, by the slow movement of a Brahms symphony, by an unremembered scent that nevertheless reminds the brain of a train of experiences apparently long-forgotten. The reader begins to suspect, after all this, that Young has overworked his analogy. "It is a far cry," Sherrington reminds us, "from an electrical reaction in the brain to suddenly seeing the world around one, with all its distances, its colors and chiaroscuro." The analogy of the government office has its uses, but if I am to be swept away by an image I would prefer that it be by Sir Charles' "enchanted loom."

Among the most interesting of the topics touched on in this book is the discussion of perception as a creative act. The eye is a camera, but the brain is much more than a darkroom for developing the films. More than half a century ago William James stressed the discriminating and utilitarian aspects of sense perception. The uncertainty principle of modern physics, postulating that no sharp line can be drawn between the observer and what he observes, carries the thought to the threshold of a sweeping conceptual revolution. The trite saying that the world is what we make it conceals, one may suppose, a meaning which is only beginning to dawn upon us: that the brain is not merely a recording device—"we have to learn to see the world as we do." A. E. Housman's lines

I, a stranger and afraid,
In a world I never made

echo a poignant, wide-felt conviction which is nevertheless an illusion. The brain of each of us "does literally create his or her own world." One recalls Pascal's famous aphorism: "They say that habit is second nature. Who knows but nature is only first habit?"

The corollary to the principle that perception is an active process is that it must be learned. We must literally learn to see. Our understanding of the learning process is facilitated by reports of the experiences of persons who were born blind and received their sight by surgery. The sensation of such a patient on first opening his eyes is painful and confusing; "he reports only a spinning mass of lights and colours." He is unable to recognize objects—though he has learned by touch to speak of them and use them. He has "no conception of a space with objects in it," and it takes years to learn to see, to train his brain in the "rules of seeing." That seeing is part of the whole learning process is further illustrated by the remarkable fact that when children make drawings, "they tend to show only parts that they can name."

The translation of impressions from the idiom of one sense to the idiom of another requires great effort and skill. "One man, when shown an orange a week after beginning to see, said that it was gold. When asked, 'What shape is it?' he said, 'Let me touch it and I will tell you!' After doing so, he said that it was an orange. Then he looked long at it and said, 'Yes, I can see that it is round.'" But the effort involved in the new exercise of seeing may not seem to the person worth while or meaningful, and he is apt to disregard visual distinctions because they do not impress him as significant. A slight alteration in a group of objects set before him may perplex him hopelessly: "One man, having learned to name an egg, a potato and a cube of sugar when he saw them, could not do it when they were put in yellow light." An amusing but not unimportant aspect of learning and the process of association comes to light in Young's sad tale of a goose. "A German scientist, Dr. Heinroth, found that a young goose, freshly hatched, who saw the doctor before it saw any other goose, thereafter acted in every way as if Dr. Heinroth was a goose, following him around and so on." (Whether German scientists alone possess this strange power over geese is not clear.)

Evidently learning itself must be learned. Most of us have never learned to learn, and have a hard time, therefore, ascending to the next rung of knowledge. It is astonishing, for instance, how poorly reading is taught, and few persons realize how much better and faster they could read had they been properly trained. The same is true of the use of mathematical symbolism—an invaluable and comparatively simple skill, yet quite beyond the capacity even of many who pass as deep thinkers. It may well be, as Young believes, that the study of new methods of training the brain to learn, to think and to communicate more effectively holds the best hope "for improvement in the welfare of the human race."

The second half of this book attempts to explain the more complicated things we do in terms of what is known about the working of the brain. Young touches on a wide range of topics, including the growth of communication in childhood, the evolution of language, the development of scientific thought, the role of man's "habit of assembly" in overcoming the tendency of animals "to repel each other," the choice of natural hills (and later the building of artificial hills) for meeting places where men may talk, plan, feast, worship, sacrifice or scream themselves blue in the face watching sporting events. However precarious his speculations, Young is unfailingly fresh in outlook, and it is impossible not to be stirred by what he says. Having reminded us that discovery stems from new ways of seeing, he launches us on our journeys and bids us only to be gallant and unafraid.

Reviewing this book in the British scientific journal *Nature,* the anatomist Solly Zuckerman, of the University of Birmingham, objected to its "excessive emphasis" on analogies. He pointed out that Young's comparison of brain and machine obscures essential points of difference, such as the brain's active learning processes and the complete predictability of the machine's sphere of action. "It begs the question," observed Zuckerman, "to imply that the reason why the analogy between them is not more complete is, on one hand, ignorance, and, on the other, the immensely greater complexity of the brain relative to the machine." He also made the even more telling point that while cybernetic models make us feel somehow that at any moment they will reveal to us epoch-making secrets about the brain, they "scarcely help us to understand" such fundamental questions as "how the 'output' of the cortex is controlled or how the 'input' fibres are related to the cortical cells."

We are a long way still from understanding the brain. Progress will depend not alone upon research but upon the ability to extricate ourselves from certain ancient verbal and metaphysical swamps. " 'Mind' and 'Matter,' " remarked the English philosopher Gilbert Ryle, "are echoes from the hustings of philosophy and prejudice the solutions of all problems posed in terms of them." Young is not bemused by such echoes. His admirable book, rich in scientific ideas and imbued with a sense of social responsibility, is no less notable for its emancipation from venerable prejudices. I am obliged also to pay tribute to Young's persuasiveness by reporting a vision that has haunted me since reading his lectures: The last surviving man, a cybernetician, discovers the final clue to his brain just as the last guided missile dips down to meet him. A vision of doubt, I trust.

PAWNEE INDIANS, by George E. Hyde. The University of Denver Press ($7.50). A history of the Pawnees from the 16th century to the present, in the course of which time the tribe, never large, was almost entirely wiped out by the combined effects of war, disease and the dishonesty, greed and incompetence of the Government. Since 1933, however, some of the benefits of civilization have been conferred upon the Pawnees; now, says Mr. Hyde, they are better cared for than ever before, and their number has steadily increased. Photographs and maps.

A DICTIONARY OF ANTIBIOSIS, compiled by Leonard Karel and Elizabeth Spencer Roach. Columbia University Press ($8.50). A reference manual for research workers presenting data on antibiotic substances (source, method of extraction, chemical and physical properties, clinical and experimental results), and enumerating organisms "against which substances have been tested for antibiotic activity." There is also a 50-page bibliography of principal papers in the field.

MATHEMATICS FOR THE MILLION, by Lancelot Hogben. W. W. Norton & Company, Inc. ($5.95). Third edition of an immensely, and deservedly, successful popularization of mathematics, with a new chapter on the "algebra of the chessboard and the card pack." The information contained in the additional chapter, while both instructive and interesting, will not, it should be noted, improve the reader's mastery of the Queen's Gambit Declined, Pinochle, Bridge or Old Maid.

FIFTY YEARS OF POPULAR MECHANICS: 1902-1952, edited by Edward L. Throm. Simon & Schuster ($5.00). Selections from the pages of the magazine *Popular Mechanics,* illustrating scientific and technical progress, as well as some of the outstanding zany ideas, inventions and predictions of the past half-century. All play and no work, an ideal alternative to brooding or gazing into space.

THE ROAD IS YOURS, by Reginald M. Cleveland and S. T. Williamson. The Greystone Press ($3.75). An entertaining, nostalgic history of the automobile from Winton's Red Devil, Olds' two-seater, the Columbia Electric Hansom, the Searchmont Wagonette, the Duryea brothers' motor buggy, the Stanley brothers' (identical twins) Steamer, the Apperson brothers' Jack Rabbit and the Packard brothers' Model L (where would the industry have been without brothers?) to the luxurious inverted bathtub of the glorious year 1950, when we produced 8,002,782 of these devices.

FLORENCE NIGHTINGALE, by Cecil Woodham-Smith. McGraw-Hill Book Company, Inc. ($4.50). A brilliant biography of an extraordinary personality. Mrs. Woodham-Smith is a discerning, witty, sympathetic critic; her historical sense is sure; her style felicitous. This is a first-rate piece of work which no discriminating reader will want to miss.

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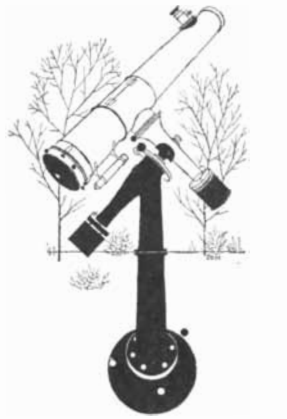

Conducted by Albert G. Ingalls

IN 1913 William Brooks Cabot and Russell W. Porter together explored the St. Augustine River in Labrador, east of the route up which a railroad is now being pushed toward the great new iron-ore deposits. In later years they discussed the question whether an explorer could determine his latitude in the field without a precision instrument. Porter tried it and described the experiment in the journal *Popular Astronomy*.

Cabot, he wrote, "deplored even the addition of a pocket sextant and horizon to a camper's pack where dead weights must be shaved to a minimum, and argued that the tools irreducible to the explorer—a knife, hatchet and fish line—together with Nature's available materials, would suffice to obtain latitude within a mile" by measuring the sun's altitude. Porter doubted this, but made the experiment at Springfield, Vt., and was greatly surprised to find that the specified precision could be reached if he used a steel tape instead of a stretching fish-line. By various refinements he found the latitude within a fifth of a mile. The method should interest explorers, Robinson Crusoes, escaped prisoners, amateur astronomers and others with intellectual curiosity.

Roger Hayward's drawings on the opposite page describe the simple principle of the method. At *C* in the lower right-hand corner is a nail driven into a small log exactly opposite a chosen mark on the plumb line *BC*. The distance *BC* is known, and attached to the nail at *C* is a steel tape with a sliding sight. Always keeping *BAC* a right angle, the observer sights the sun at its culmination or highest angle (local apparent noon) and measures *AC*. In the right triangle *ABC* the distance *BC* divided by the distance *AC* will give a decimal fraction which is the sine of the angle *ABC*. The same decimal is then found in a table of sines, and on certain dates in March and September when the sun is over the Equator the angle shown opposite will be the observer's latitude.

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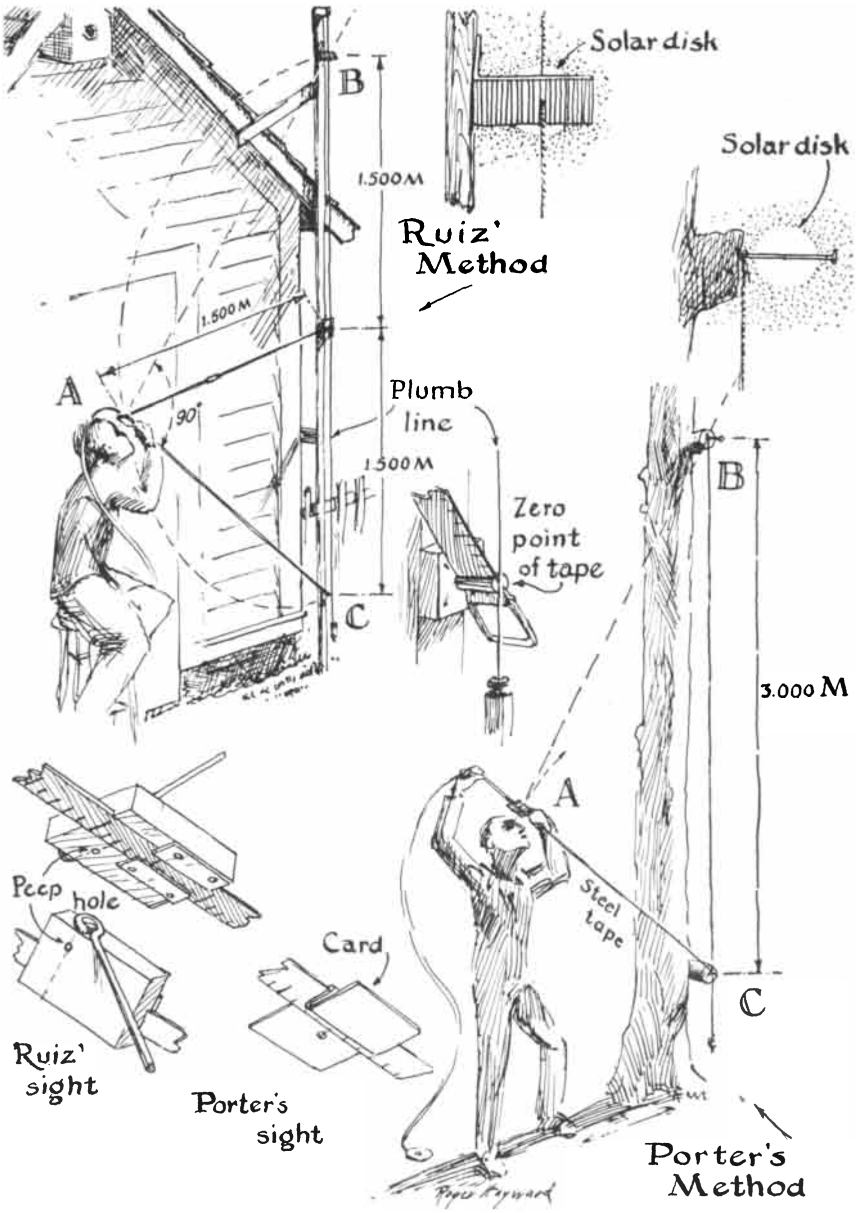
On all other dates, corrections given in tables in the ephemeris of the sun must be added or subtracted. In either case a small correction, given by Porter as about one minute of arc in summer and two in winter, must be added for atmospheric refraction.

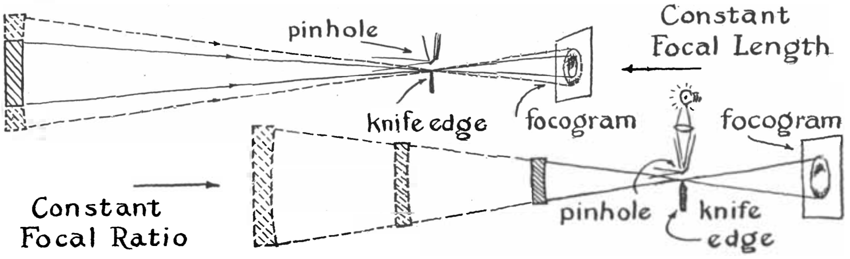
For convenience in calculation Porter used a tape with feet divided into tenths and hundredths, and interpolated to thousandths of a foot. A metric tape is just as convenient, and Hayward points out that an ordinary tape with 96 subdivisions per foot may not introduce significant error. An error of one thousandth of a foot affects the result about half a mile in latitude.

For a sight Porter used a tiny hole in the sliding sight shown in the drawing, covered with colored glass to protect his eye. He found it possible to bisect the sun's disk with the nail at *B* reliably within less than one minute of arc.

In a test of the method Porter made six sights between 11:41 a.m. and 12:08 p.m. on the same day, obtaining latitudes for Springfield varying from 43 degrees 17.2 minutes to 43 degrees 19.8 minutes. The mean of the six sights was 43 degrees 18.5 minutes. As a check he



Finding the latitude without a precision instrument



The philosophy of exposure time in making a focogram

next determined the latitude with his theodolite and found it 43 degrees 18.3 minutes. Thus he had determined his latitude within .2 minute, or only 1,200 feet, without an instrument.

Theoretically the tape is unnecessary. Fish lines at *AC* and *BC* could be measured with any arbitrary, unknown unit of length, such as a stick, provided the same unit was used on *AC* and *BC*, but precision would be difficult.

John J. Ruiz of Dannemora, N. Y., recently tried Porter's experiment with more refined accessories and a modification of his own. Exactly halfway between *B* and *C* he pivoted a rod and hooked it to the sight, as shown at the left in the same drawing. "If you remember your Euclid," he writes, "you will note that the angle *BAC* is always 90 degrees." (An angle inscribed in a semicircle is a right angle.) The purpose of the rod was to exclude a possible source of error in Porter's method: "The observer's head," Porter wrote, "must be moved and the target shifted until the sun is bisected with the minimum length of tape."

Ruiz used a slotted pivot in place of the lower nail, and a sight with a vernier and 1/25-inch peephole (No. 60 drill) protected by two thicknesses of deep-colored cellophane. To average out the accidental errors he too made six observations and, since each took time, and since Joshua was not present to make the sun stand still, these sights were made at intervals before and after apparent noon and then reduced to the meridian. He came out neither worse nor better than Porter, that is, within about 1,200 feet of the true latitude.

Since it is impossible to evaluate all the contributing factors in the two observers' experiments, with the hidden chance errors, it cannot be known without more meticulous repetition by a third person whether or not Porter had already exhausted the precision inherent in the method. If he had, added accuracy in technique might bring only fictitious improvement.

The ephemeris of the sun is in the *Observer's Handbook* of the Royal Astronomical Society of Canada, 3 Willcocks St., Toronto, Ont., Canada (price 40 cents). Ruiz provides refraction corrections which he says "are good enough for you and me." For 10-degree altitude of sun, add 5 minutes angle; for 20 degrees, 2.4 minutes; for 30 add 1.5; for 40 add 1; for 50 add .7; for 60 add .5; for 70 add .3; for 80 add .2, and for 90 add nothing.

ALAN R. KIRKHAM points out two omissions from the round-up on the modified or spherical-secondary Cassegrainian telescope (Dall-Kirkham) in the September, 1951, issue. He writes:

"The great difficulty in testing the hyperboloidal secondary of the straight Cassegrainian is almost eliminated by changing to the modified form with its spherical secondary, and using the King test or others. But the primary remains a bugaboo, with its zonal testing. No one seems aware that this, too, can be avoided. Since the primary is very nearly if not exactly an ellipsoid, it may be tested by the direct focal test (*Amateur Telescope Making*, page 271), which 'feels' just like figuring a spherical mirror by testing at the center of curvature. The problem is to find where to put the knife-edge and pinhole to make the desired ellipsoid look flat.

"The formula for finding their distances from the mirror is

$$\frac{R}{e}\,(1\pm\sqrt{1-e}),$$

in which *R* is the radius of curvature of the mirror and *e* its undercorrection found either from my original formula (Scientific American, June, 1938) or from the formula in the September, 1951, article in which *N* is the per cent correction. $e=1-N$; for example, a 70 per cent corrected paraboloid is .30 undercorrected, and it is the .30 that is used for *e*. By taking the ± sign first as plus, then as minus, and solving for each, both distances are obtained. It is theoretically immaterial which distance is used for the pinhole and which for the knife-edge, but better results are obtained with the pinhole distance the greater. A diagonal or prism is necessary for viewing the mirror.

"The second omission is the fact that the straight Cassegrainian is afflicted with coma, and the modified Cassegrainian is somewhat more so. If the telescope is to be used photographically, with the wide field of the plate, this will be damaging, but when we come to the visual instrument—and the majority of amateurs' telescopes are built for 'just lookin' '—the case is very different. The field of stars intercepted by, say, a one-inch eyepiece is less than 3/4-inch in diameter, and over that small area the coma will be undetectable in either telescope, probably covered up many times over by the faults of the eyepiece. The modified Cassegrainian may even outperform the other, since it will probably be a little better figured.

"Modified Cassegrainians rigorously investigated by ray tracing have been found to be within or very near the boundary of the coma tolerance for high-quality visual instruments such as microscopes and binoculars."

IS the focal ratio of a mirror a determining factor in the exposure required for a focogram? No, says Lieut. Col. A. E. Gee of the Frankford Arsenal, who was asked to answer the question as a referee.

He demonstrates this as follows (see the drawings on the opposite page): "Obviously, the same exposure that would give a focogram for an $f/4$ mirror would give an equally good focogram of the central half of the mirror if it were stopped down to $f/8$. *The mirror is the object being photographed, not the lens taking the photograph.*

"The 'lens' of the focogram camera is the image of the pinhole produced by the mirror. The light source is the pinhole itself. Ignoring for the moment the reflectivity and figure of the mirror and the presence of the knife-edge, the necessary exposure is solely dependent upon the intensity of the light source, size of the pinhole, sensitivity of the film and distance from the pinhole image to the film. If these factors are constant, all mirrors, whether large or small, long focal length or short, will require the same exposure. Increasing the focal ratio will simply mean a larger picture. Increasing the mirror size at the same focal ratio would make no change whatsoever.

"All other factors being the same, the diameter of the focogram will be directly proportional to the distance from the pinhole to the film. Exposures will vary as the square of this distance. If the pinhole image to film distance is left constant, the diameter of the image on the plate will be inversely proportional to the focal ratio of the mirror. That is, that of an $f/4$ would be twice as big as an $f/8$.

"The knife-edge has a tremendous effect on the exposures required, acting as a diaphragm to the pinhole 'lens.' In theory, the closer a mirror is to a true sphere, the longer the exposure that would be required to provide any given degree of contrast in the image detail. In practice, it is impossible to set the knife-edge in the same position from mirror to mirror, and its contribution to exposure time will outshadow that due to figure. This accounts for the different results with regard to comparative exposures of paraboloids and spheres."

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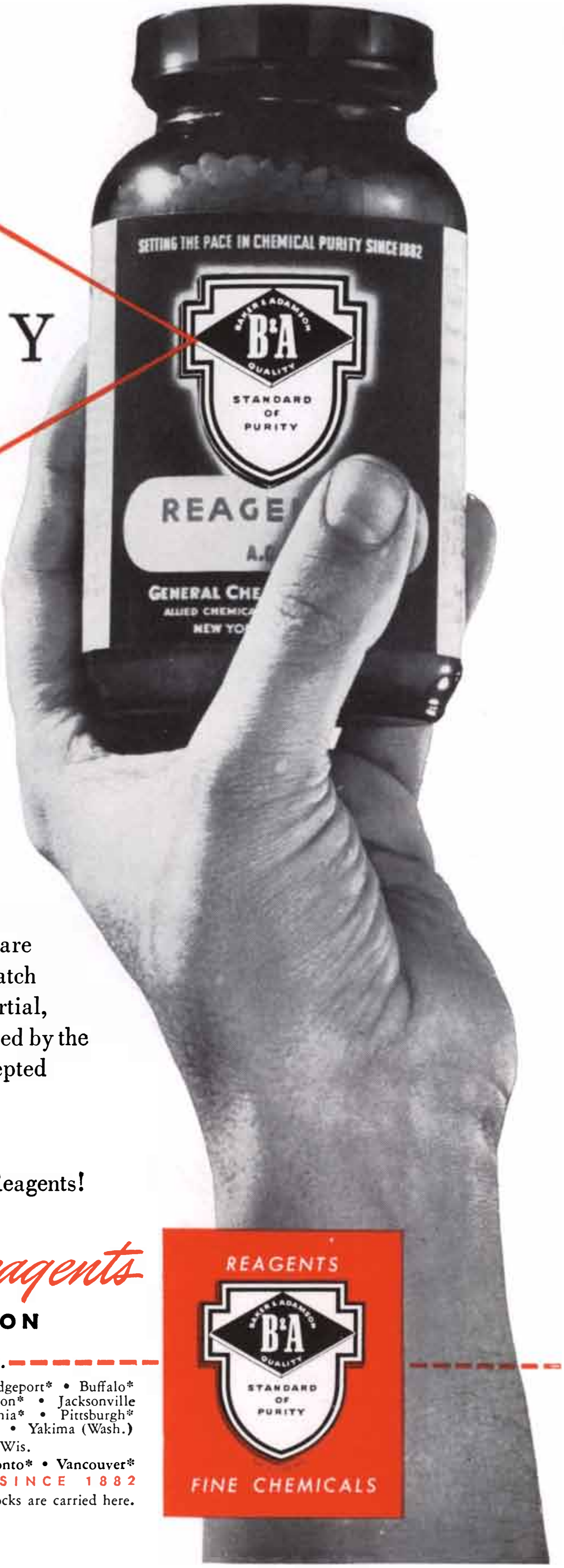

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