SCIENTIFIC AMERICAN

THE SUN FROM MERCURY (PAGE 26) FIFTY CENTS

November 1948

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Teamwork is simply working together to turn out more goods in fewer man-hours—making things at lower costs and paying higher wages to the people who make them and selling them at lower prices to the people who use them.

What we've already accomplished is just a foretaste of what we *can* do. It's just a start toward a goal we are all striving to reach: better housing, clothing, food, health, education, with ever greater opportunities for individual development. Sure, our American System has its faults. We all know that. We still have sharp ups and downs in prices and jobs. We'll have to change that—*and we will!*

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Sirs:

The sudden outburst of talk recently about population increasing faster than the food supply is one of the most curious paradoxes of our paradoxical times. Starvation in the midst of plenty characterizes the postwar period at the moment when potential productivity has grown beyond the possibility of accurate prediction. Yet at this moment economic man turns back to the old classics, instead of rising imaginatively to the new economics suitable to the new methods of production.

Malthus first enunciated the formula that population increases faster than means of subsistence. He lived in the years from 1766 to 1834, when the industrial revolution of steam, with capitalism as its economic system, was supplanting the older system of feudalism. The population was being driven from the land to cities. The land had to feed not only those who tilled the soil, but also city dwellers. Moreover, the new system of production was not yet as productive as it was destined to become.

Today we are witnessing a tremendous acceleration in potentialities of means of production. Science can now change the condition of the soil and produce vastly more food. Among many studies which might be cited is the paper prepared for the World Social Economic Congress held in August, 1931, at Amsterdam, Holland. Dr. Otto Neurath, sociologist of Vienna, presented in visual form the increase in productive capacity of the world, and concluded that "Malthus was wrong" and that in our day productive capacity has increased faster than population.

But war and the economics of war have burdened production with debt, besides wasting resources and imposing such severe shortages in many parts of the world that starvation, rather than abundance, characterizes the present decade, while unprecedented unemployment and depression were the experience in the 1930's. It is clear today that man's wastefulness is responsible for failure of means of subsistence to keep pace with population. Planned abundance, which is actually the objective of the peoples of the world today, can produce standards of living far beyond the possibility of imagination in Malthus' day. At the same time, raising of living standards, material and cultural, would certainly result in planned population. This does not necessarily mean a check to present rates of growth. It should be observed that *rate* of growth, as con-

LETTERS

trasted with actual growth, either of population or of production, tends to decline. There seems to be no scientific basis for indicating that a given rate of growth of population will continue into the future. Likewise, there is certainly no reason to assume a static condition in means of subsistence. It appears today that both population and production are destined to increase.

It is to be hoped that the new assertion of Malthusianism will be countered by carefully developed interpretation of social and technological data concerning population and world resources today. The purpose of this letter is merely to give expression to the widespread protest against these recent pronouncements, and to call attention to the evidence against them. The false doctrine which Malthus himself might have repudiated can certainly not win scientific adherence. It is merely one more indication that social and political thought lag behind technological development.

MARY VAN KLEECK

New York, N. Y.

Sirs:

The article in your July issue by Frederick A. Saunders on "Physics and Music" appealed to me very strongly, and was so full of interest that nothing additional seemed necessary. But the letter from Marie Mikova in your September issue, taking issue with Dr. Saunders' statement that the tone of a piano is the same whether the key is pressed by a great artist or the tip of an umbrella, prompts me to add a few words in defense of Dr. Saunders.

The performer at the piano is free to make two choices. and only two. He may determine the intensity of the sound by determining the velocity with which the hammer meets the wire. and he may determine its duration by determining the length of time he keeps the key depressed. Thus intensity and duration are directly under the performer's control, although if he strikes the key with an instrument other than his finger this control may be somewhat impaired. On the other hand, pitch and tone are not under the performer's control but are inherent in the instrument.

If the performer releases a key a perceptible time before depressing the next one, so that a hiatus of silence occurs between the two notes, he is said to be using a staccato touch; if he releases one key and depresses another simultaneously so that no hiatus of silence can occur, he is said to be using a legato touch. Judicious use of the damper pedal makes it possible to combine a staccato touch with a legato effect. If a long succession of otherwise legato notes be broken up by the insertion of judiciously placed staccato notes into a series of groups. the passage is said to be phrased. The older classical writers frequently did not indicate the phrasing very precisely, but left it to the judgment of the performer, with the result that modern editions of Bach, for instance, exhibit considerable divergence in their phrasing. Differences in phrasing produce different sound effects, especially in passages in which dissonances predominate. But these differences are not tonal; they are stylistic.

My own feeling is that Miss Mikova, being a pianist herself, is very sensitive to minute variations of phrasing and intensity, which she hears accurately, but which she mistakes for tonal differences.

There is one conceivable way in which a pianist might alter the tone of a piano while playing it. That is by the use of the so-called "soft pedal." On most grand pianos, but not all, this pedal shifts the keyboard laterally, so that the hammers strike only one wire, leaving the other two to vibrate sympathetically, and it is not impossible that a wire vibrating out of sympathy might produce a different tone from that produced by a wire that had been percussed, but if so this difference must be very slight. I cannot distinguish it myself, and I doubt if anyone else can do so.

But in any case, Dr. Saunders has not maintained that the pianist cannot alter the piano tone. but only that he cannot do so by means of varying his touch.

JOSHUA L. BAILY, JR.

San Diego. Calif.

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50 AND 100 YEARS AGO

NOVEMBER 1898. "Mr. Axel Danielson, a correspondent of Stockholm, Sweden, is keeping us informed as to the status of the Nobel bequest. He says that the case has been decided, or rather a compromise has been effected between the contesting parties. The relatives of the deceased will waive 3.800.000 Swedish crowns, a little more than $1,000,000, so that there still remains for the prizes the sum of 25,000.000 crowns, equivalent to $6,950,000. The income, computed at the rate of three per cent, will make the five prizes worth 150.000 crowns or $41,600 each. It will be remembered that these prizes are to be awarded annually to persons making the most important discoveries in physics, chemistry, physiology or medicine. There is also to be a prize for the best literary contributions upon the subject of physiology or medicine, and also one for any person who has achieved the most or done the best things working toward the cause of the promotion of peace throughout the world."

"Mr. Nikola Tesla, of New York, has invented what is known in naval science as a dirigible torpedo which, instead of being self-driven and self-steering, like the Whitehead and Howell torpedoes, now in use by our Navy, is driven and steered by an operator on shore, who controls the torpedo through electrical connections. The most characteristic feature in Mr. Tesla's torpedo as distinguished from others of the dirigible class is that, whereas they use a connecting cable for transmitting the controlling power to the torpedo, he makes use of the Hertzian waves, dispensing with the cable. This method of transmission is more popularly known under the name of 'wireless telegraphy,' and as such attracted considerable public attention during the recent experiments by the British Post Office and the apparatus designed by the young Italian, Marconi."

"Next to the test of actual war, no stronger endorsement of the excellence of a nation's warships can be desired than the fact that its shipbuilding yards are patronized by foreign governments. The first foreign orders placed in the United States for warships of the modern type were those given by the Japanese government to the Union Iron Works, of San Francisco, and the Cramps' Shipbuilding Company, of Philadelphia, for two high-speed cruisers. Following closely upon the successful trial of these ships has come an order to the Cramps' yard for the construction of two first-class ships—a battleship and a cruiser—for the Russian government."

"One of the most astonishing features in the development of modern journalism is the magnitude and audacity of the Sunday issues of the great daily papers, and among these there are none that are quite so successful as those issues which are marked by the distinctive characteristics of yellow journalism. Now the yellow journal, in its quest for startling novelties to whet the palate of its readers, invades every possible sphere of human life and interest and every branch of human knowledge. Science, which, one would have thought, would be severely let alone, is a favorite hunting ground of the reporter, and whole pages of the yellow-journal seventh-day editions are loaded down with pseudo-scientific pabulum. The reporters for these journals are apparently sent out into the domains of science charged with a commission to magnify mole hills into mountains."

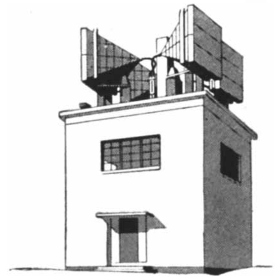
NOVEMBER 1848. "Up to the hour of our going to press election returns from over twenty different States had been received in this city by the Electric Telegraph. General Taylor has received overwhelming majorities in almost every State as yet heard from, and his election is unquestionable. The readers of the SCIENTIFIC AMERICAN may consider it settled that 'Old Zack' is now the President elect. He will be inaugurated on the 4th of March 1849, his term of office expiring in 1853. May he not prove unworthy of the confidence reposed in him!"

"Some have endeavoured to detract from the merit of Prof. Morse as the inventor of the Electro Magnet Telegraph, and make him indebted to Dr. Jackson of Boston for all his information, he being a passenger on the ship Sully with Prof. Morse in 1832, and used to converse with him on the subject. It would have looked more candid if Prof. Morse had mentioned the name of the *passenger* with whom he used to converse on the subject while on his voyage from France in 1832. Yet what of all this, we have no evidence that Dr. Jackson ever constructed an electric telegraph, and although Prof. Henry gives tardy praise to Mr. Morse, the names of great scientific men should not be allowed to weigh as a feather in the balance against a successful inventor but a less distinguished man of science. For more than 30 years Sir Humphrey Davy had the world wide honor of being the first inventor of the Safety Lamp, and it was not till the summer of 1848, that the inventor, Geo. Stevenson the mechanic, was acknowledged before a high Scientific Association."

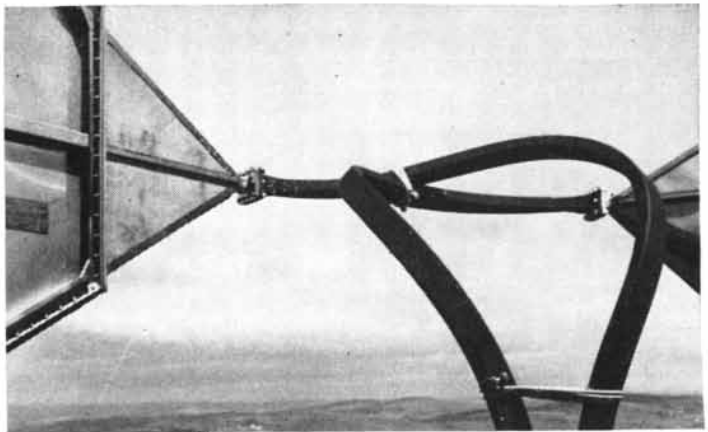
"Two years ago it was announced to the unlettered world that Le Verrier, a French astronomer, had by the dint of sagacity and calculation alone, discovered a new Planet which was named Neptune. A new planet was discovered, but American astronomers declared that it was not that pointed out by Le Verrier. There has been a controversy on this subject among the astronomers of the two worlds, and various reports have gone abroad which have shorn the French astronomer of no small amount of his sudden and high honors. But we perceive by a discussion that took place at the Paris Academy of Science on the 14th of Sept., that Le Verrier ably confounded Mr. Babinet, another astronomer, who held views opposite to the discoverer of Neptune."

"Twenty-three years ago the utility and usefulness of the locomotive were doubted by the most practical and scientific men of the age. In 1814 the speed of George Stephenson's Kilinsworth Engine was 4 miles per hour. In 1825, only twenty-three years ago, Mr. Wood in his treatise on the railway system takes the standard speed at six miles per hour, drawing on a level a load of 40 tons. In 1829 the highest speed attained was 29 miles per hour—working speed 10. In 1848 the highest speed attained is 75 miles—working speed 55. How striking the contrast. In 1829 the maximum load of the Locomotive Engine was nine tons—in 1848, less than 20 years, it is 1200; the highest speed then 15 miles, now 75, and in one instance 84 miles per hour."

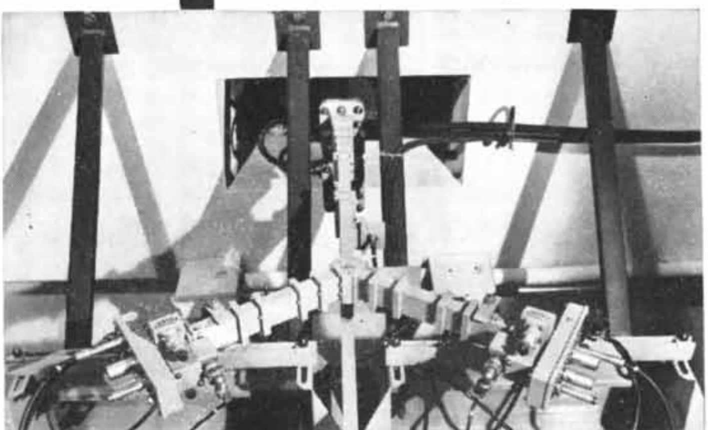
"Sir John W. Lubbock, according to the hypothesis, adopted by him in his Treatise on Heat of Vapors, shows the density and temperature for a given height above the earth's surface. According to the hypothesis, at a height of fifteen miles the temperature is 240° Far. below zero; the density is .03573; and the atmosphere ceases altogether at a height of 22.35 miles. M. Biot has verified a calculation of Lambert, who found, from the phenomena of twilight, the altitude of the atmosphere to be about eighteen miles."



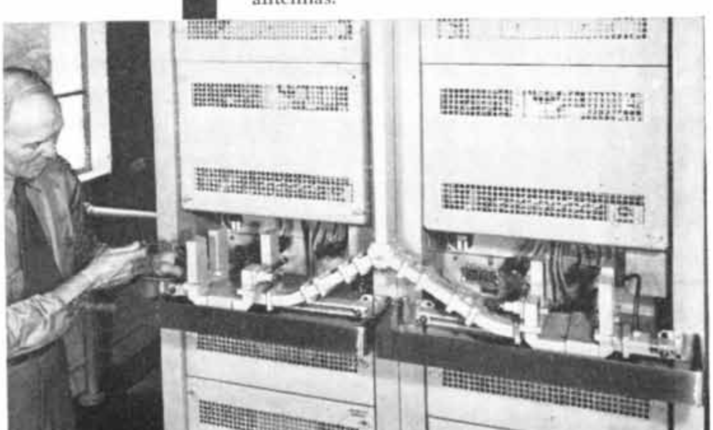
Pipe Circuits



3 The waveguide connects with horn antennas which are pointed toward similar antennas at the next stations miles away.



2 Looking upward, the waveguide continues through the roof of the station toward the antennas.



1 Base of a waveguide circuit in a repeater station of the New York-Boston radio relay system.

UNLIKE radio broadcast waves, microwaves are too short to be handled effectively in wire circuits. So, for carrying microwaves to and from antennas, Bell Laboratories scientists have developed circuits in "pipes," or waveguides.

Although the waves travel in the space within the waveguide, still they are influenced by characteristics found also in wire circuits, such as capacitance and inductance. The screw or stud projecting inside the guide wall acts like a capacitor; a rod across the inside, like an inductance coil. Thus transformers, wave filters, resonant circuits – all have their counterpart in waveguide fittings. Such fittings, together with the connection sections of waveguide, constitute a waveguide circuit.

From Bell Laboratories research came the waveguide circuits which carry radio waves between apparatus and antennas of the New York-Boston radio relay system. The aim is to transmit wide frequency bands with high efficiency – band widths which some day can be expanded to carry thousands of telephone conversations and many television pictures.

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THE COVER

The painting on this month's cover, made by the astronomical artist Chesley Bonestell, shows the sun *(see page 26)* as it might appear from a point above the baked surface of the planet Mercury. Because Mercury has no atmosphere, the features of the sun would shine with a harsh brilliance never observed on the earth. Planets and other stars would also sparkle in the jet-black sky of Mercury's day. At the lower right is the small constellation of the Pleiades, surrounded by its faint nebulosity. At the upper left is the red planet Mars. Visible on the disk of the sun is a large group of sunspots. From the edge of the disk flare great yellow prominences. About the disk is the gray mantle of the corona, clearly seen on earth only during a total eclipse of the sun. Within the corona are the faint lines of force of the sun's magnetic field. Above and below the corona is the ellipse of the zodiacal light, presumably made up of a vast swarm of tiny meteors rotating about the sun at high speed.

THE ILLUSTRATIONS

Cover by Chesley Bonestell

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SCIENTIFIC AMERICAN

Established 1845

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ARTICLES

●

DEPARTMENTS

Best way to put *out* a fire

PUT IT WAY OUT—out of the attic and into the alley, before it ever gets started. Keep closets, attics and cellars clear of rubbish and oily rags. Check home electrical wiring frequently. Handle matches carefully and keep them out of children's reach. This is how you can help prevent the thousand home fires a day that kill 5600 persons annually in the United States.

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SCIENTIFIC AMERICAN

NOVEMBER 1948 VOL. 179, NO. 5

LABRADOR IRON

The red rock of the bleak northern province may be a part of the solution to the coming shortage of ore for the U. S. steel industry

by Herbert Yahraes

IN the rolling hills of northeastern Minnesota yawns a man-made excavation that for scenic splendor has been compared with the Grand Canyon. Great streaks and patches of color—purples, yellows, browns—blend into one another down its tiered sides. The vast excavation, three miles long and in some places a mile wide, is gouged 400 feet deep into the rocks. And it constantly grows as big steel shovels crawl along its cliffs taking many-tonned bites at what is left of some of the world's richest earth.

This is the Hull-Rust-Mahoning, the largest open-pit iron mine in the world, the biggest producer of the fabulous Mesabi Range. From this one pit alone during the war were taken 25 million tons of high-grade ore a year—more than a fourth of the total U.S. production.

For half a century the Mesabi—which is Ojibway for giant—and the lesser ranges of the Lake Superior district have been supplying 85 per cent of the iron ore used in the U.S. Twice they have enormously expanded their output to see the nation through great wars. But the spurt in World War II was exhausting; many mineralogists now consider the Mesabi a dying giant. The production of the Hull-Rust-Mahoning fell to 16 million tons in 1946, and even less in 1947. The rich, easily accessible ore is giving out; from now on the big shovels will have only the bones to pick at. Estimates of the Lake Superior reserves run to something more than a billion tons. A noted economic geologist, W. O. Hotchkiss, gives the ranges 21 more years at the outside; the

BASE CAMP for the geological exploration of Labrador iron is at Burnt Creek, near the boundary between Labrador and Quebec. The land has been burned over by fires and much of the soil scraped away by glaciation.

ORE FOR STEEL INDUSTRY is presently carried by boats from Duluth (*upper left*) to Erie and other lake ports north of Pittsburgh. If the railroad from the Labrador deposits is put through, ore can also be shipped

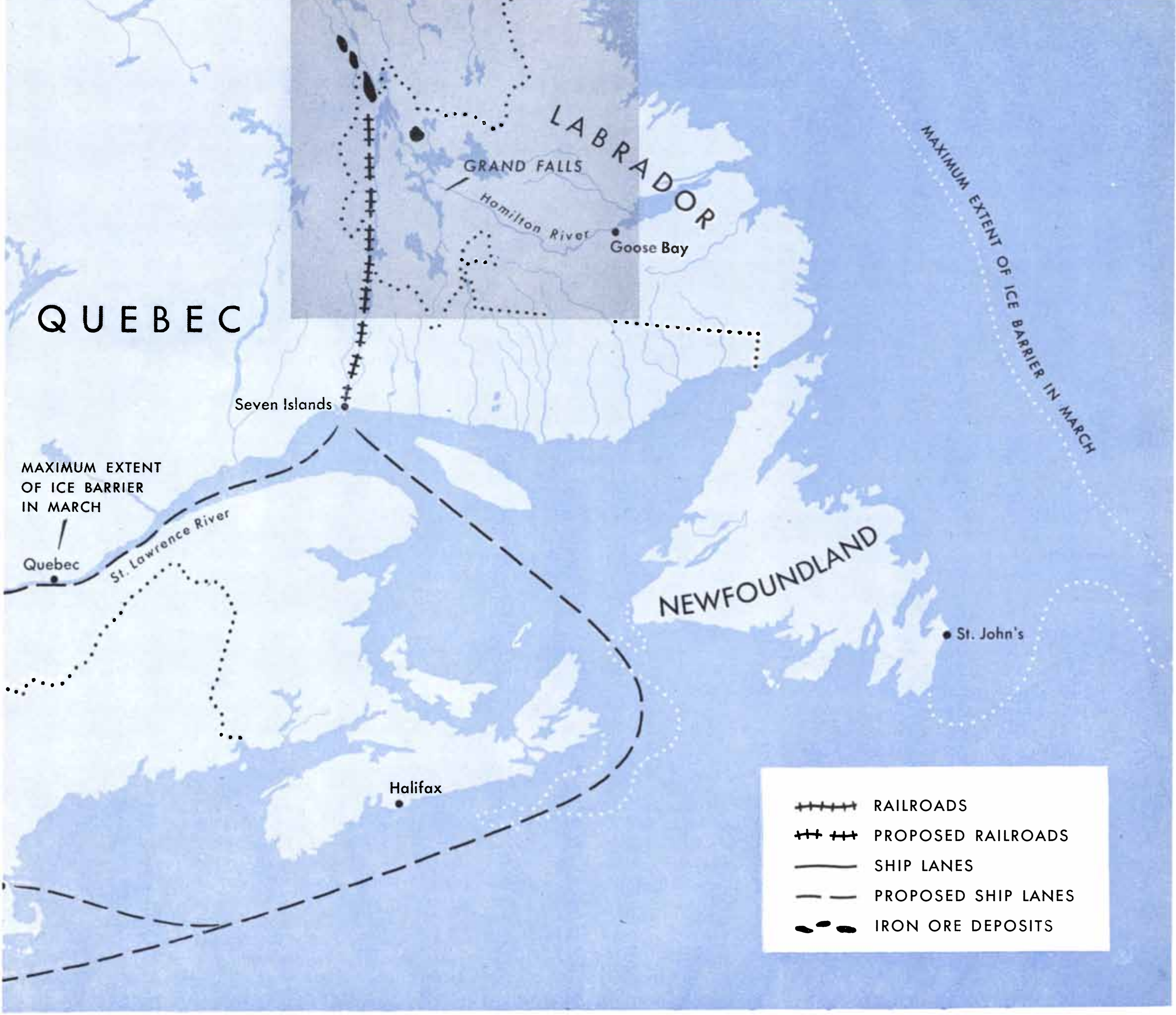
open-pit mines, the heaviest producers, will be exhausted within a decade.

All this has caused the multi-billion-dollar steel industry—and the U.S.—considerable concern. C. M. White, president of Republic Steel, observes: "The industry as a whole faces dire shortages in a period too short to be comfortable." The steel industry, which from furnaces to fabricating plants has been built almost entirely around the Mesabi Range and its neighbors, has been compelled to consider some revolutionary alternatives.

One possibility is to find some practical way of utilizing the Mesabi's vast but hitherto useless deposits of the iron-containing rock called taconite. Taconite can be converted into usable ore by a process known as beneficiation. But this alternative would be extremely costly. Open-pit ore, on which the steel industry has been built, is mined in one step and fed to the iron furnaces without further treatment. The conversion of taconite into usable ore takes 12 steps, and a ton of taconite makes only a third of a ton of furnace feed. In the present stage of technological development, a plant capable of producing from taconite one million tons of ore a year—one per cent of our needs during World War II—might cost up to $10 million, and the production of usable ore would take several times as many miners and technicians and immensely more power than is now required.

Another alternative is to uproot the whole steel industry from the Great Lakes region, where nature has fortuitously provided handy coal supplies and waterways for cheap transportation of the Mesabi ore, and to transplant it along the Atlantic or the Gulf Coast. Then the industry could afford to use imported ore, mostly from Latin America. This idea may seem fantastic, but it would be unreasonable to suppose that an industry that could build a Pittsburgh could not lift it up and set it down by the Atlantic. Whether it would be advisable to concentrate any more vital industries along the eastern seaboard, however, is another question.

Steel men as a group have been casting about to find a solution in some combination of these possibilities. Bethlehem Steel, for instance, already has a huge plant at Sparrows Point, Md., using ore from Chile and Brazil. Two companies are already producing ore from taconite, and others are getting ready to do so. In addi-



from the St. Lawrence port of Seven Islands. Until the St. Lawrence Deep Waterway is built, however, Labrador ore must be carried to the lake ports in small ships. Large ships will be able to carry it only to Atlantic ports.

tion. several large steel companies are exploiting the almost-forgotten but sizable deposits in the Adirondacks of New York State.

NONE of these possibilities is greatly encouraging. But there is now under investigation another alternative which seems breathtaking in its potentialities. It arises from the discovery of immensely rich deposits of iron in Labrador. Labrador iron is an old story; the existence of an ore formation on the peninsula has been known for more than half a century. But only recently have its possibilities been seriously explored. As the result of intensive studies during the past two years, geologists now believe that the Labrador range may contain as much high-grade, open-pit iron ore as one, two or perhaps as many as five virgin Mesabis.

This development must naturally be considered with caution. It is one thing to discover iron and another to get it out conveniently. Whether the iron ore of distant, frigid Labrador constitutes a practical answer to the steel industry's needs is already a matter of considerable controversy among steel men. Nonetheless, the effort to solve the practical problems involved is proceeding with vigor and determination.

The Labrador formation was first noted in 1892—the year the Mesabi was opened—by a Canadian Government geological survey. There was no actual exploration of the deposits. however, until 1929. The area was so remote from good supplies of coal and the climate so rigorous. the thermometer sometimes dropping to 40 degrees below zero. that surveys seemed a waste of time. "Everywhere in Labrador the physically weakest still go to the wall." wrote Sir Wilfred Grenfell in *The Romance of Labrador* in 1934. "No white man is yet able to make a home in the interior, where the only law is still the immemorial code of the hunting ground. The high interior, scrubbed bare of soil by the ice ages and burned over by the great fires, can only become a white man's country when the wealth of its minerals justifies the expense of supplying his needs from the outside."

In 1942 the owners of Canada's largest gold mine began assaying that wealth. Hollinger Consolidated Gold Mines, Ltd., buying control of the earlier-organized Labrador Mining and Exploration Co., acquired sole rights to prospect and develop a large area in the central part of the peninsula. The Hollinger firm was joined in this enterprise by one of the largest independent ore producers in the U.S., M. A. Hanna Co. of Cleveland.

The work went slowly. Geologists and engineers and their food and equipment had to be flown in, for the nearest road ended 400 miles away. Operations were limited to the summer. Discovering that the iron deposits extended into Quebec, the Hollinger interests set up another subsidiary, the North Shore Exploration Co., to follow the ore across the border.

Few hints of this work on the continent's newest frontier have trickled through to the public. Most steel men have viewed it as a distinctly long-range project at best, and even Hollinger-Hanna officials emphasized that before spending the scores of millions of dollars needed to develop Labrador iron, they would require proof of reserves running to at least 300 million tons—equivalent to at least a three-year supply for American furnaces from all sources.

How far the prospectors have progressed toward that goal is not known; precise figures on the amount of ore proved this year are not available. But the explorations are known to be well ahead of schedule, and it is possible that the 300 million tons may be proved this year.

The Hollinger concessions cover 22,000 square miles straddling the Labrador-Quebec boundary. The area takes in part of an iron-bearing formation which is at least 300 miles in length. according to the Bureau of Mines of the Canadian Government. One estimate reckons the total length of the iron-bearing formation as 500 or 600 miles; the Mesabi formation, by contrast, is only 112 miles long. Moreover, in Labrador the formations are repeated in folds across a width of 30 miles, so that instead of a single strip of iron ore, as in the Mesabi. there is a series of parallel strips.

Geologically. the Labrador-Quebec ore is the same age as the Mesabi's. dating back to the pre-Cambrian period. and its deposits were formed by much the same geological processes. Presumably the Labrador site. like the present mining sites of the Lake Superior region, was once covered by a great sea. in which iron—one of the most widely distributed of the elements—and other materials were deposited by tributary streams. Pressure and heat transformed this iron-bearing sediment into rock. and massive earth disturbances raised it to the surface.

Much of this original sedimentary rock, at least in the Lake Superior region, remains as taconite, the iron content of which is relatively low—from 20 to 35 per cent. The higher-grade ore was created by the action of underground water, which over the ages leached out much of the silica in the rock and in some places enriched it by precipitating iron oxide. Some of the Labrador ore, like the Mesabi's, is high-grade hematite. or ferric oxide. But most of it is a blue-brown mixture of hematite, limonite and goethite.

High-grade ore is defined as ore with an iron content of more than 50 per cent and not too high a silica content. In recent years the iron content of Mesabi ore has averaged about 59 per cent. The Labrador peninsula iron seems to be at least as rich. Samples from 11 ore bodies in Labrador, the Hollinger interests reported two years ago, averaged 62.1 per cent of iron in dry ore, and from 11 deposits in Quebec, 61.2 per cent. Both included some manganese. A more recent report on 10 deposits shows Bessemer ores averaging better than 62 per cent and non-Bessemer ores about 58 per cent. In addition, deposits of manganiferous ores have been found with an iron content better than 50 per cent and a manganese content running up to 8 per cent. Manganiferous ores are highly prized by the steel industry.

Like the Mesabi ore, Labrador iron lies close to the surface and can be mined by open-pit operations. Indeed, the Labrador ore may be even easier to dig, for in this region the glaciers scraped the iron-bearing strata bare, while in Minnesota they covered the Mesabi with sand and rock to an average depth of 70 feet, necessitating costly stripping operations.

Almost all of the ore found so far in Labrador has been in surface outcrops. The thickness of the deposits is unknown, but it is believed to range from 300 to 1.000 feet; tunnels 200 feet long and 100 feet deep have been driven through two of the ore bodies. The prospecting so far has been done in only a tiny portion of the vast Labrador and Quebec concessions, and development work has been restricted to those deposits which not even an amateur geologist could miss.

FROM the geological standpoint. then, the Labrador-Quebec discovery seems an ideal answer to the steel men's problem. The big drawback lies in the region's relative inaccessibility. The Government of Quebec hopes eventually to see furnaces built close to the ore bodies, using hydroelectric power instead of coal for fuel.

Coke for reducing the ores. however, will still be lacking. In any case. if the new field is to assume even part of the burden the Mesabi must surrender, the ore will have to be carried to furnaces in the U.S.

A major problem, therefore, is building the necessary transportation facilities. The first step will be the construction of a 360-mile railroad from the Labrador wilderness to the Gulf of St. Lawrence; this distance is three and a half times that from the Mesabi to Lake Superior. With modern earth-moving machinery such as was used to build the Alaska highway. engineers expect no unusual trouble in pushing the rail line through, but the cost of construction. of rolling stock and of the necessary port facilities will approach $100 million.

The Hollinger-Hanna group already has a railroad charter from the Dominion Government and within the past two years has surveyed the entire proposed route. It has also studied port sites. By the spring of 1949 detailed construction plans are expected to be largely completed. The present plan is to locate the rail line along the Moisie and Wacouna rivers, running almost due south from the heart of the deposits to the Gulf of St. Lawrence. There port and ore-loading facilities are expected to be placed at or near Seven Islands. According to the Canadian Government, ore boats could use the St. Lawrence during most of the winter—which would mean a longer season than on the Great Lakes—and there is some hope that an icebreaker might keep the St. Lawrence port open the year round.

To construct and operate the rail line. the development group set up the Quebec North Shore and Labrador Railway Co. in 1947, and to develop and distribute hydroelectric power—for mining operations and possibly for electrifying the railroad—they formed the Ungava Power Co. An excellent power site is available on the Kaniaspiskau River only 30 miles west of the northwestern edge of the ore deposits.

The headquarters of the project is now at Burnt Creek in Labrador, close to the Quebec line. An airstrip, 100 miles of roads. shops, a laboratory and housing for 150 men have already been built, and plans have been made to build two towns, one in the ore field and the other at dockside at Seven Islands, to house future workers. The supply line to the Burnt Creek camps now runs down the St. Lawrence to Seven Islands and Mont-Joli by boat, and thence northward by plane.

The river valleys in this region are forested, assuring enough local timber for construction and mining purposes, but the uplands have only a sparse cover of scrub and moss. Drifting snow settles deeply in the hollows. In spite of the snow, a Hollinger crew spent last winter at Burnt Creek, getting out timber for a sawmill and making other preparations for the 1948 season. They found it possible to keep the needed roads open. A government engineer says that weather conditions "will certainly not prevent such winter mining operations as may be required when full-scale mining is under way."

Thus the activities in the new field since the spring of 1947 seem to have answered satisfactorily two of the big questions. The ore is there—in quantities and grades that may make the Labrador-Quebec deposits the richest ever found. And it can be got to water. Transportation costs, taking into account the favorable downhill grades to the St. Lawrence which would permit long ore trains, are estimated at $1.75 a ton from mine to port. This would be twice the rail cost of transporting Mesabi ores to the Great Lakes, but Canada's lower taxes and royalties may more than make up the difference.

A large question, however, remains: Where does the ore go once it reaches the St. Lawrence? On that question may hinge both the usefulness of Labrador iron and the future of the steel industry.

Some of the ore will certainly move down the Gulf and into the Atlantic to supply present smelting furnaces along the seaboard. One authority estimates this potential market at one million tons a year—a minuscule amount compared with our total needs. Another suggestion is that the ore could be made reasonably accessible to the Great Lakes by water. How by water? The vessels that can now use the St. Lawrence and Welland canals and thus enter the Great Lakes from the east are limited in capacity to 3,000 tons; the great ore carriers that move down from Minnesota hold five times as much.

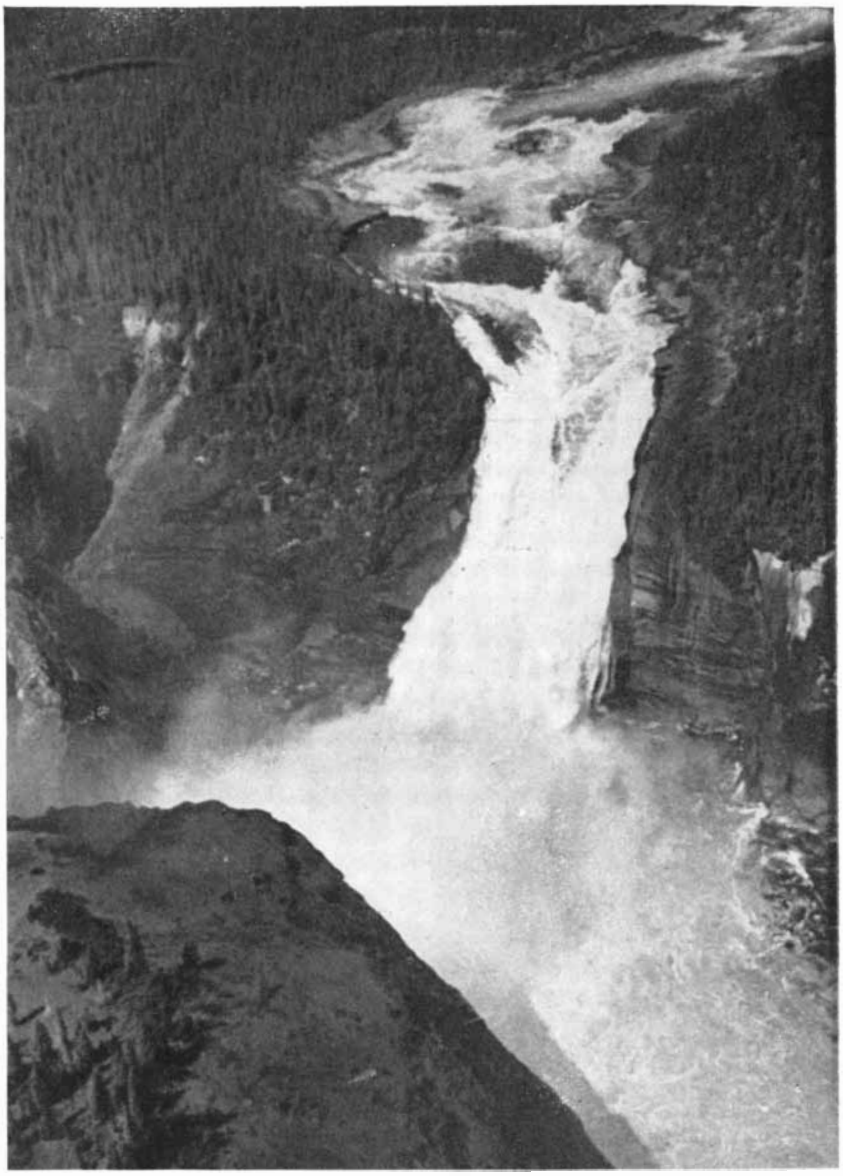
The answer, of course, lies in the proposed St. Lawrence Deep Waterway, which would make the cost of delivering the new iron to buyers in Pennsylvania and Ohio not greatly different from that of delivering the output of the Mesabi and its neighbors. While the distance to Cleveland from Duluth, for instance, is about 200 miles less than from Seven Islands, Canadians are counting on a higher-grade ore to compensate amply for the longer water haul.

The Deep Waterway, however, is still only a blueprinted dream. It is fiercely opposed by eastern seaports and other interests, and only a few months ago Congress shelved it once again. The steel industry is divided on the question. M. A. Hanna, long an opponent of the Waterway, now considers it necessary for the maintenance and expansion of the steel industry. Other steel makers hold that the $500 million which the Waterway would cost the U.S. should be spent in subsidizing beneficiation plants in the Lake Superior region.

The Waterway was projected decades ago to bring the wealth of the continent's interior to the seaboard. The time may come when, ironically, the Waterway will have to be completed for exactly the opposite reason: to bring the wealth of seaboard mines to the continent's interior.

In five years, possibly less if an emergency arises and construction work is rushed, iron ore is expected to begin to come from Labrador in commercial quantities; in a few years shipments very likely could reach the first objective of 15 million tons a year. In the long run we shall probably have to duplicate quickly, cheaply, and on a grand scale the process by which nature converted taconite into high-grade ore. Meanwhile Labrador-Quebec iron offers, at the very least, a breathing space.

Herbert Yahraes is a science journalist.



GREAT WATERFALL on the Hamilton River, almost twice as high as Niagara, is one of many possible hydroelectric sites in Labrador. Quebec Government has suggested using electric power to smelt iron at source of ore.

TERMINUS OF RAILWAY to carry ore south from the Labrador fields would be at Seven Islands. From here the ore could be shipped west up the St. Lawrence to Lake Erie ports or southeast to the ports of Atlantic Coast.

CYBERNETICS

The word describes a new field of study shared by many sciences. Among other things, it looks into the processes common to nervous systems and mathematical machines

by Norbert Wiener

CYBERNETICS is a word invented to define a new field in science. It combines under one heading the study of what in a human context is sometimes loosely described as thinking and in engineering is known as control and communication. In other words, cybernetics attempts to find the common elements in the functioning of automatic machines and of the human nervous system, and to develop a theory which will cover the entire field of control and communication in machines and in living organisms.

It is well known that between the most complex activities of the human brain and the operations of a simple adding machine there is a wide area where brain and machine overlap. In their more elaborate forms, modern computing machines are capable of memory, association, choice and many other brain functions. Indeed, the experts have gone so far in the elaboration of such machines that we can say the human brain behaves very much like the machines. The construction of more and more complex mechanisms actually is bringing us closer to an understanding of how the brain itself operates.

The word cybernetics is taken from the Greek *kybernetes*, meaning steersman. From the same Greek word, through the Latin corruption *gubernator*, came the term governor, which has been used for a long time to designate a certain type of control mechanism, and was the title of a brilliant study written by the Scottish physicist James Clerk Maxwell 80 years ago. The basic concept which both Maxwell and the investigators of cybernetics mean to describe by the choice of this term is that of a feedback mechanism, which is especially well represented by the steering engine of a ship. Its meaning is made clear by the following example.

Suppose that I pick up a pencil. To do this I have to move certain muscles. Only an expert anatomist knows what all these muscles are, and even an anatomist could hardly perform the act by a conscious exertion of the will to contract each muscle concerned in succession. Actually what we will is not to move individual muscles but to pick up the pencil. Once we have determined on this, the motion of the arm and hand proceeds in such a way that we may say that the amount by which the pencil is not yet picked up is decreased at each stage. This part of the action is not in full consciousness.

To perform an action in such a manner, there must be a report to the nervous system, conscious or unconscious, of the amount by which we have failed to pick up the pencil at each instant. The report may be visual, at least in part, but it is more generally kinesthetic, or to use a term now in vogue, proprioceptive. If the proprioceptive sensations are wanting, and we do not replace them by a visual or other substitute, we are unable to perform the act of picking up the pencil, and find ourselves in a state known as ataxia. On the other hand, an excessive feedback is likely to be just as serious a handicap. In the latter case the muscles overshoot the mark and go into an uncontrollable oscillation. This condition, often associated with injury to the cerebellum, is known as purpose tremor.

Here, then, is a significant parallel between the workings of the nervous system and of certain machines. The feedback principle introduces an important new idea in nerve physiology. The central nervous system no longer appears to be a self-contained organ receiving signals from the senses and discharging into the muscles. On the contrary, some of its most characteristic activities are explainable only as circular processes, traveling from the nervous system into the muscles and re-entering the nervous system through the sense organs. This finding seems to mark a step forward in the study of the nervous system as an integrated whole.

EDITOR'S NOTE

The word cybernetics is also the title of a book by Dr. Wiener, just published by John Wiley & Sons, New York. In this article, which is adapted from the book, Dr. Wiener briefly defines cybernetics and discusses some of its possible applications in the pathology of the mind. Dr. Wiener's book may well be the focus of much controversy, both scientific and nonscientific. SCIENTIFIC AMERICAN presents Dr. Wiener's article as an introduction to this discussion.

The new approach represented by cybernetics—an integration of studies which is not strictly biological or strictly physical, but a combination of the two—has already given evidence that it may help to solve many problems in engineering, in physiology and very likely in psychiatry.

This work represents the outcome of a program undertaken jointly several years ago by the writer and Arturo Rosenblueth, then of the Harvard Medical School and now of the National Institute of Cardiology of Mexico. Dr. Rosenblueth is a physiologist; I am a mathematician. For many years Dr. Rosenblueth and I had shared the conviction that the most fruitful areas for the growth of the sciences were those which had been neglected as no-man's lands between the various established fields. Dr. Rosenblueth always insisted that a proper exploration of these blank spaces on the map of science could be made only by a team of scientists, each a specialist but each possessing a thoroughly sound acquaintance with the fields of his fellows.

OUR collaboration began as the result of a wartime project. I had been assigned, with a partner, Julian H. Bigelow, to the problem of working out a fire-control apparatus for anti-aircraft artillery which would be capable of tracking the curving course of a plane and predicting its future position. We soon came to the conclusion that any solution of the problem must depend heavily on the feedback principle, as it operated not only in the apparatus but in the human operators of the gun and of the plane. We approached Dr. Rosenblueth with a specific question concerning oscillations in the nervous system, and his reply, which cited the phenomenon of purpose tremor, confirmed our hypothesis about the importance of feedback in voluntary activity.

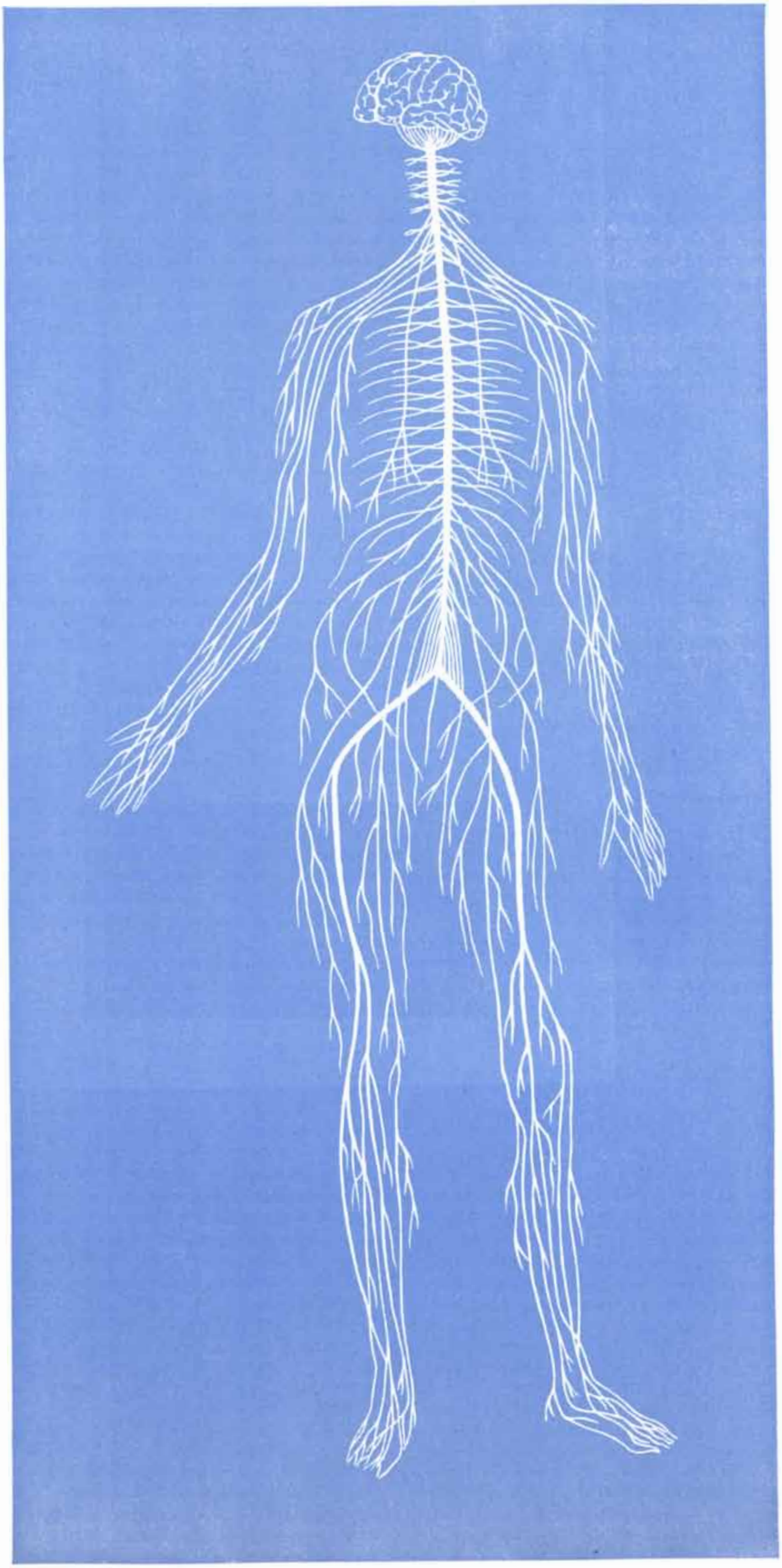
The ideas suggested by this discussion led to several joint experiments, one of which was a study of feedback in the muscles of cats. The scope of our investigations steadily widened, and as it did so scientists from widely diverse fields joined our group. Among them were the mathematicians John Von Neumann of the Institute for Advanced Study and Walter Pitts of Massachusetts Institute of Technology; the physiologists Warren McCulloch of the University of Pennsylvania and Lorente de No of the Rockefeller Institute: the late Kurt Lewin, psychologist, of M. I. T.; the anthropologists Gregory Bateson and Margaret Mead; the economist Oskar Morgenstern of the Institute for Advanced Study; and others in psychology, sociology, engineering, anatomy, neurophysiology, physics, and so on.

The study of cybernetics is likely to have fruitful applications in many fields. from the design of control mechanisms for artificial limbs to the almost complete mechanization of industry. But in our view it encompasses much wider horizons. If the 17th and early 18th centuries were the age of clocks, and the latter 18th and 19th centuries the age of steam engines, the present time is the age of communication and control. There is in electrical engineering a division which is known as the split between the technique of strong currents and the technique of weak currents: it is this split which separates the age just passed from that in which we are living. What distinguishes communication engineering from power engineering is that the main interest of the former is not the economy of energy but the accurate reproduction of a signal.

At every stage of technique since Daedalus, the ability of the artificer to produce a working simulacrum of a living organism has always intrigued people. In the days of magic, there was the bizarre and sinister concept of the Golem, that figure of clay into which the rabbi of Prague breathed life. In Isaac Newton's time the automaton became the clockwork music box. In the 19th century, the automaton was a glorified heat engine, burning a combustible fuel instead of the glycogen of human muscles. The automaton of our day opens doors by means of photocells. or points guns to the place at which a radar beam picks up a hostile airplane, or computes the solution of a differential equation.

Under the influence of the prevailing view in the science of the 19th century, the engineering of the body was naturally considered to be a branch of power engineering. Even today this is the predominant point of view among classically minded, conservative physiologists. But we are now coming to realize that the body is very far from a conservative system, and that the power available to it is much less limited than was formerly believed. We are beginning to see that such important elements as the neurones—the units of the nervous complex of our bodies —do their work under much the same conditions as vacuum tubes, their relatively small power being supplied from outside by the body's circulation, and that the bookkeeping which is most essential to describe their function is not one of energy.

In short, the newer study of automata, whether in the metal or in the flesh, is a branch of communications engineering,

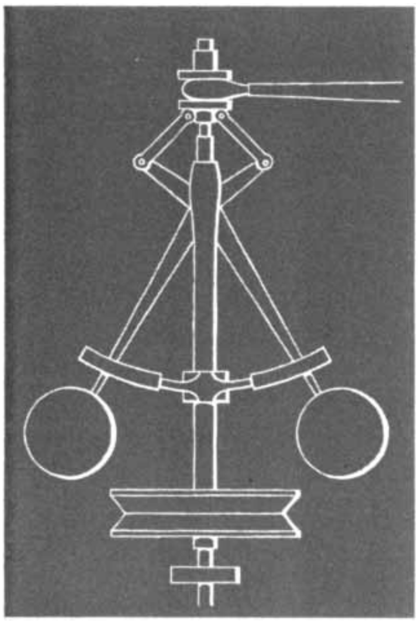


THE NERVOUS SYSTEM, in the cybernetic view, is more than an apparatus for receiving and transmitting signals. It is a circuit in which certain impulses enter muscles and re-enter the nervous system through the senses.

and its cardinal ideas are those of the message, of the amount of disturbance or "noise" (a term taken from the telephone engineer), of the quantity of information to be transmitted, of coding technique, and so on.

This view obviously has implications which affect many branches of science. Let us consider here the application of cybernetics to the problem of mental disorders. The realization that the brain and computing machines have much in common may suggest new and valid approaches to psychopathology, and even to psychiatry.

These begin with perhaps the simplest question of all: how the brain avoids gross blunders or gross miscarriages of activity due to the malfunction of individual parts. Similar questions referring to the computing machine are of great practical importance, for here a chain of operations, each of which covers only a fraction of a millionth of a second, may last a matter of hours or days. It is quite possible for a chain of computational operations to involve a billion separate steps. Under these circumstances, the chance that at least one operation will go amiss is far from negligible, even though the reliability of modern electronic apparatus has exceeded the most sanguine expectations.



GOVERNOR of a steam engine is an example of feedback, one of the most important basic ideas in cybernetics.

In ordinary computational practice by hand or by desk machines, it is the custom to check every step of the computation and, when an error is found, to localize it by a backward process starting from the first point where the error is noted. To do this with a high-speed machine, the check must proceed at the pace of the original machine, or the whole effective order of speed of the machine will conform to that of the slower process of checking.

A much better method of checking, and in fact the one generally used in practice, is to refer every operation simultaneously to two or three separate mechanisms. When two such mechanisms are used, their answers are automatically collated against each other; and if there is a discrepancy, all data are transferred to permanent storage, the machine stops and a signal is sent to the operator that something is wrong. The operator then compares the results, and is guided by them in his search for the malfunctioning part, perhaps a tube which has burned out and needs replacement. If three separate mechanisms are used for each stage, there will practically always be agreement between two of the three mechanisms, and this agreement will give the required result. In this case the collation mechanism accepts the majority report, and the machine need not stop. There is a signal, however, indicating where and how the minority report differs from the majority report. If this occurs at the first moment of discrepancy, the indication of the position of the error may be very precise.

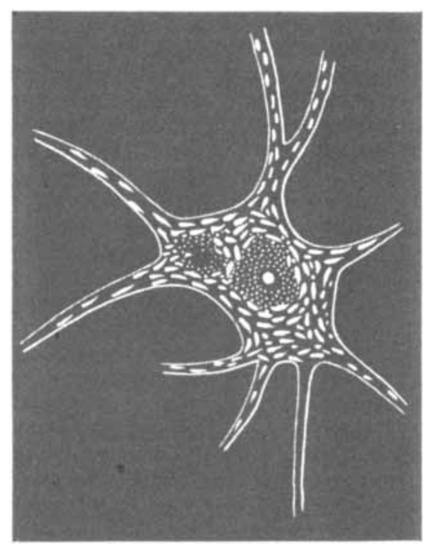
It is conceivable, and not implausible, that at least two of the elements of this process are also represented in the nervous system. It is hardly to be expected that any important message is entrusted for transmission to a single neurone, or that an important operation is entrusted to a single neuronal mechanism. Like the computing machine, the brain probably works on a variant of the famous principle expounded by Lewis Carroll in *The Hunting of the Snark:* "What I tell you three times is true."

It is also improbable that the various channels available for the transfer of information generally go from one end of their course to the other without connecting with one another. It is much more probable that when a message reaches a certain level of the nervous system, it may leave that point and proceed to the next by one or more alternative routes. There may be parts of the nervous system, especially in the cortex, where this interchangeability is much limited or abolished. Still, the principle holds, and it probably holds most clearly for the relatively unspecialized cortical areas which serve the purpose of association and of what we call the higher mental functions.

So far we have been considering errors in performance that are normal, and pathological only in an extended sense. Let us now turn to those that are much more clearly pathological. Psychopathology has been rather a disappointment to the instinctive materialism of the doctors, who have taken the view that every disorder must be accompanied by actual lesions of some specific tissue involved. It is true that specific brain lesions, such as injuries, tumors, clots and the like, may be accompanied by psychic symptoms, and that certain mental diseases, such as paresis, are the sequelae of general bodily disease and show a pathological condition of the brain tissue. But there is no way of identifying the brain of a schizophrenic of one of the strict Kraepelin types, nor of a manic-depressive patient, nor of a paranoiac. These we call functional disorders.

This distinction between functional and organic disorders is illuminated by the consideration of the computing machine. It is not the empty physical structure of the computing machine that corresponds to the brain—to the adult brain, at least—but the combination of this structure with the instructions given it at the beginning of a chain of operations and with all the additional information stored and gained from outside in the course of its operation. This information is stored in some physical form—in the form of memory. But part of it is in the form of circulating memories, with a physical basis that vanishes when the machine is shut down or the brain dies, and part is in the form of long-time memories, which are stored in a way at which we can only guess, but probably also in a form with a physical basis that vanishes at death.

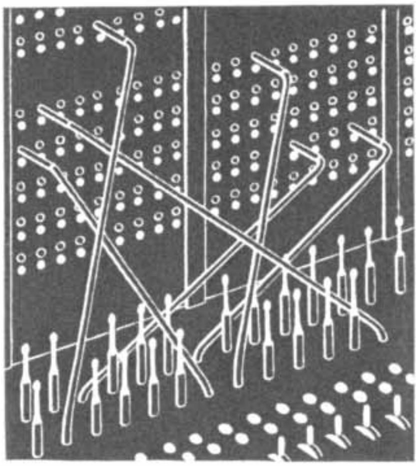
There is therefore nothing surprising in considering the functional mental disorders fundamentally as diseases of memory, of the circulating information kept by the brain in active state and of the long-time permeability of synapses. Even the grosser disorders such as paresis may produce a large part of their effects not so much by the destruction of tissue which they involve and the alteration of synaptic thresholds as by the secondary disturbances of traffic, the overload of what remains of the nervous system and the rerouting of messages which must follow such primary injuries.



NERVE CELL performs functions in much the same situation as a vacuum tube, obtaining power from outside.

In a system containing a large number

of neurones, circular processes can hardly be stable for long periods of time. Either they run their course. dissipate themselves and die out, as in the case of memories belonging to the specious present. or they embrace more and more neurones in their system, until they occupy an inordinate part of the neurone pool. This is what we should expect to be the case in the malignant worry that accompanies anxiety neuroses. In such a case, it is possible that the patient simply does not have the room —*i.e.*, a sufficient number of neurones—



TELEPHONE EXCHANGE, when it is overloaded, has breakdowns rather similar to the kind in human beings.

to carry out his normal processes of thought. Under such conditions, there may be less going on in the brain to occupy the neurones not yet affected, so that they are all the more readily involved in the expanding process. Furthermore, the permanent memory becomes more and more deeply involved, and the pathological process which began at the level of the circulating memories may repeat itself in a more intractable form at the level of the permanent memories. Thus what started as a relatively trivial and accidental disturbance of stability may build itself up into a process totally destructive to the normal mental life.

Pathological processes of a somewhat similar nature are not unknown in the case of mechanical or electrical computing machines. A tooth of a wheel may slip under such conditions that no tooth with which it engages can pull it back into its normal relations, or a high-speed electrical computing machine may go into a circular process that seems impossible to stop.

HOW do we deal with these accidents in the case of the machine? We first try to clear the machine of all information, in the hope that when it starts again with different data the difficulty will not recur. If this fails and the difficulty is inaccessible to the clearing mechanism, we shake the machine or, if it is electrical, subject it to an abnormally large electrical impulse in the hope that we may jolt the inaccessible part into a position where the false cycle of its activities will be interrupted. If even this fails, we may disconnect an erring part of the apparatus, for it is possible that what remains may be adequate for our purpose.

In the case of the brain, there is no normal process, except death, that can clear it of all past impressions. Of the normal non-fatal processes. sleep comes closest to clearing the brain. How often we find that the best way to handle a complicated worry or an intellectual muddle is to sleep on it! Sleep, however, does not clear away the deeper memories, nor indeed is a malignant state of worry compatible with adequate sleep.

Thus we are often forced to resort to more violent types of intervention in the memory cycle. The most violent of these involve surgery on the brain, leaving behind permanent damage, mutilation and the abridgement of the powers of the victim, for the mammalian central nervous system seems to possess no power of regeneration. The principal type of surgical intervention that has been practiced is known as prefrontal lobotomy, or leucotomy. It consists in the removal or isolation of a portion of the prefrontal lobe of the cortex. It is currently having a certain vogue, probably not unconnected with the fact that it makes the custodial care of many patients easier. (Let me remark in passing that killing them makes their custodial care still easier.) Prefrontal lobotomy does seem to have a genuine effect on malignant worry, not by bringing the patient nearer to a solution of his problem, but by damaging or destroying the capacity for maintained worry, known in the terminology of another profession as the conscience. It appears to impair the circulating memory. *i.e.*, the ability to keep in mind a situation not actually presented.

The various forms of shock treatment—electric, insulin, metrazol—are less drastic methods of doing a very similar thing. They do not destroy brain tissue. or at least are not intended to destroy it, but they do have a decidedly damaging effect on the memory. In so far as the shock treatment affects recent disordered memories, which are probably scarcely worth preserving anyhow. it has something to recommend it as against lobotomy. but it is sometimes followed by deleterious effects on the permanent memory and the personality. As it is used at present, it is another violent. imperfectly understood, imperfectly controlled method to interrupt a mental vicious circle.

In long-established cases of mental disorder, the permanent memory is as badly deranged as the circulating memory. We do not seem to possess any purely pharmaceutical or surgical weapon for intervening selectively in the permanent memory. This is where psychoanalysis and the other psychotherapeutic measures come in.

Whether psychoanalysis is taken in the orthodox Freudian sense or in the modified senses of Jung and of Adler, or whether the psychotherapy is not strictly psychoanalytic at all, the treatment is clearly based on the concept that the stored information of the mind lies on many levels of accessibility. The effect and accessibility of this stored information are vitally conditioned by affective experiences that we cannot always uncover by introspection. The technique of the psychoanalyst consists in a series of means to discover and interpret these hidden memories, to make the patient accept them for what they are, and thus to modify, if not their content, at least the affective tone they carry, and make them less harmful.

All this is perfectly consistent with the cybernetic point of view. Our theory perhaps explains, too, why there are circum-

AUTOMATON of the 15th century was one of a long series of attempts to assign human functions to machinery.

stances in which a joint use of shock treatment and psychotherapy is indicated, combining a physical or pharmacological therapy for the malignant reverberations in the nervous system and a psychological therapy for the damaging long-time memories which might re-establish the vicious circle broken up by the shock treatments.

We have already mentioned the traffic problem of the nervous system. It has been noted by many writers that each form of organization has an upper limit of size beyond which it will not function. Thus insect organization is limited by the length of tubing over which the spiracle method of bringing air by diffusion directly to the breathing tissues will function; a land animal cannot be so big that the legs or other portions in contact with the ground will be crushed by its weight (*see page 52*), and so on. The same sort of thing is observed in engineering structures. Skyscrapers are limited in size by the fact that when they exceed a certain height, the elevator space needed for the upper stories consumes an excessive part of the cross section of the lower floors. Beyond a certain span, the best possible suspension bridge will collapse under its own weight. Similarly, the size of a single telephone exchange is limited.

In a telephone system, the important limiting factor is the fraction of the time during which a subscriber will find it impossible to put a call through. A 90 per cent chance of completing calls is probably good enough to permit business to be carried on with reasonable facility. A success of 75 per cent is annoying but will permit business to be carried on after a fashion; if half the calls are not completed, subscribers will begin to ask to have their telephones taken out. Now, these represent all-over figures. If the calls go through a number of distinct stages of switching, and the probability of failure is independent and equal for each stage, in order to get a high probability of final success the probability of success at each stage must be higher than the final one. Thus to obtain a 75 per cent chance for the completion of the call after five stages, we must have about 95 per cent chance of success at each stage. The more stages there are, the more rapidly the service becomes extremely bad when a critical level of failure for the individual call is exceeded, and extremely good when this critical level of failure is not quite reached. Thus a switching service involving many stages and designed for a certain level of failure shows no obvious signs of failure until the traffic comes up to the edge of the critical point, when it goes completely to pieces and we have a catastrophic traffic jam.

So man, with the best developed nervous system of all the animals, probably involving the longest chains of effectively operated neurones, is likely to perform a complicated type of behavior efficiently very close to the edge of an overload, when he will give way in a serious and catastrophic manner. This overload may take place in several ways: by an excess in the amount of traffic to be carried; by a physical removal of channels for the carrying of traffic; or by the excessive occupation of such channels by undesirable systems of traffic, such as circulating memories that have accumulated to the extent of becoming pathological worries. In all these cases, a point is reached—quite suddenly—when the normal traffic does not have space enough allotted to it, and we have a form of mental breakdown, very possibly amounting to insanity.

This will first affect the faculties or operations involving the longest chains of neurones. There is appreciable evidence, of various kinds, that these are precisely the processes recognized as the highest in our ordinary scale of valuation.

If we compare the human brain with that of a lower mammal, we find that it is much more convoluted. The relative thickness of the gray matter is much the same, but it is spread over a far more involved system of grooves and ridges. The effect of this is to increase the amount of gray matter at the expense of the amount of white matter. Within a ridge, this decrease of the white matter is largely a decrease in length rather than in number of fibers, as the opposing folds are nearer together than the same areas would be on a smooth-surfaced brain of the same size. On the other hand, when it comes to the connectors between different ridges, the distance they have to run is increased by the convolution of the brain.

Thus the human brain would seem to be fairly efficient in the matter of the short-distance connectors, but defective in the matter of long-distance trunk lines. This means that in the case of a traffic jam, the processes involving parts of the brain quite remote from one another should suffer first. That is, processes involving several centers, a number of different motor processes and a considerable number of association areas should be among the least stable in cases of insanity. These are precisely the processes which we should normally class as higher, thereby confirming our theory, as experience does also, that the higher processes deteriorate first in insanity.

THE phenomena of handedness and of hemispheric dominance suggest other interesting speculations. Right-handedness, as is well known, is generally associated with left-brainedness, and left-handedness with right-brainedness. The dominant hemisphere has the lion's share of the higher cerebral functions. In the adult, the effect of an extensive injury in the secondary hemisphere is far less serious than the effect of a similar injury in the dominant hemisphere. At a relatively early stage in his career, Louis Pasteur suffered a cerebral hemorrhage on the right side which left him with a moderate degree of one-sided paralysis. When he died, his brain was examined and the damage to its right side was found to be so extensive that it has been said that after his injury "he had only half a brain." Nevertheless, after this injury he did some of his best work. A similar injury to the left side of the brain in a right-handed adult would almost certainly have been fatal; at the least it would have reduced the patient to an animal condition.

In the first six months of life, an extensive injury to the dominant hemisphere may compel the normally secondary hemisphere to take its place, so that the patient appears far more nearly normal than he would have been had the injury occurred at a later stage. This is quite in accordance with the great flexibility shown by the nervous system in the early weeks of life. It is possible that, short of very serious injuries, handedness is reasonably flexible in the very young child. Long before the child is of school age, however, the natural handedness and cerebral dominance are established for life. Many people have changed the handedness of their children by education, though of course they could not change its physiological basis in hemispheric dominance. These hemispheric changelings often become stutterers and develop other defects of speech, reading and writing.

We now see at least one possible explanation for this phenomenon. With the education of the secondary hand, there has been a partial education of that part of the secondary hemisphere which deals with skilled motions such as writing. Since these motions are carried out in the closest possible association with reading, and with speech and other activities which are inseparably connected with the dominant hemisphere, the neurone chains involved in these processes must cross over from hemisphere to hemisphere, and in any complex activity they must do this again and again. But the direct connectors between the hemispheres in a brain as large as that of man are so few in number that they are of very little help. Consequently the interhemispheric traffic must go by roundabout routes through the brain stem. We know little about these routes, but they are certainly long, scanty and subject to interruption. As a consequence, the processes associated with speech and writing are very likely to be involved in a traffic jam, and stuttering is the most natural thing in the world.

The human brain is probably too large already to use in an efficient manner all the facilities which seem to be present. In a cat, the destruction of the dominant hemisphere seems to produce relatively less damage than in man, while the destruction of the secondary hemisphere probably produces more damage. At any rate, the apportionment of function in the two hemispheres is more nearly equal. In man, the gain achieved by the increase in the size and complexity of the brain is partly nullified by the fact that less of the organ can be used effectively at one time.

It is interesting to reflect that we may be facing one of those limitations of nature in which highly specialized organs reach a level of declining efficiency and ultimately lead to the extinction of the species. The human brain may be as far along on its road to destructive specialization as the great nose horns of the last of the titanotheres.

Norbert Wiener is professor of mathematics at Massachusetts Institute of Technology.

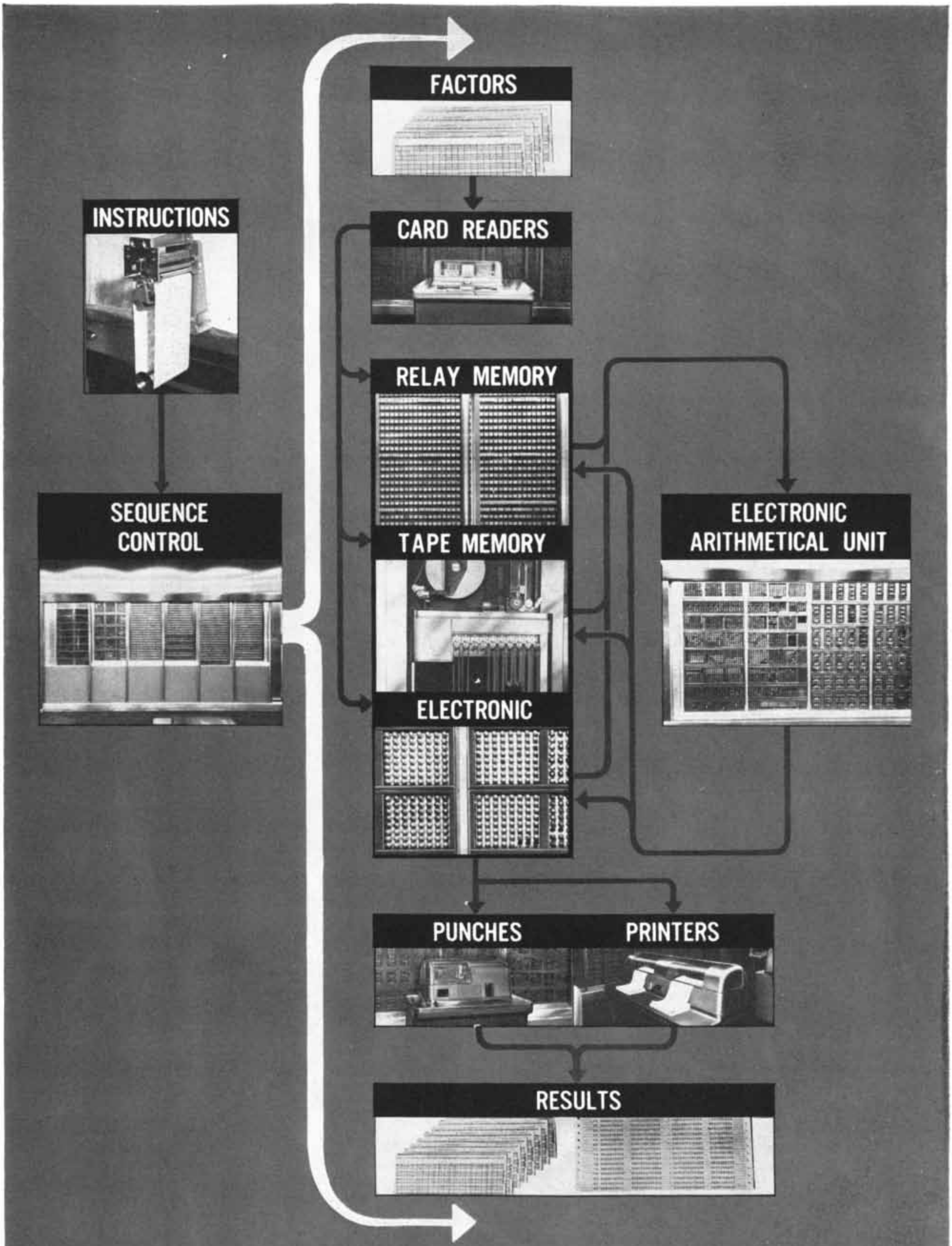


DIAGRAM OF CALCULATOR, in this case the Selective Sequence Electronic Calculator built by the International Business Machines Corporation, provides another cybernetic comparison. Physical structure of the machine is not analogous to the brain. The structure plus instructions and stored memories is analogous. The machine has electronic and relay circuits for temporary memory, punched cards for permanent memory.

SPRUCE, BALSAM AND BIRCH

Three trees that live together in the woods of the North are examples of both beauty and utility. One in a series of articles about trees

by Donald Culross Peattie

THE most beautiful approach to the North American Continent from Europe is up the St. Lawrence to Quebec. The grandeur of this estuary, the greatest, save the Amazon's, in all the world, the storm of gannets from the bird rocks, the white cliffs of the Gaspé Peninsula, would be enough to make it incomparable. But most impressive of all is the vast coniferous forest, so dark a green that it looks almost black, stretching from the north shore away and away to the horizon and beyond, for hundreds of impenetrable miles, to the Arctic limit of trees. In this forest are set the little villages of French Canada, the inevitable white steeple and gold cross gleaming against the evergreens and the raw, elemental blue of the sky. Each of these villages seems, from the deck of the ship, a collection of toy houses and churches pressed closely by Christmas trees. And of all the conifers there, the fairest is the White Spruce, the handsomest of its family.

It was in the basin of the St. Lawrence, indeed, that the White Spruce was first seen by Jacques Cartier when in the autumn of 1535 he sailed up the Saguenay River. "From the day of the 18th to the 28th of this month we have sailed up this river without losing an hour nor a day, during which time we have seen and found as beautiful a country and lands and views as one could wish for, level as aforementioned, and the finest trees in the world, to wit oaks, elms, walnuts, cedars, spruces, ash trees, willows and wild vines."

In youth the White Spruce forms a fine spirelike top, with a central stem straight as a mast, ending at the acute, symmetrical tip; the lowest arms sweep benignly down almost to earth, then turn up at the twig, like fingers lifted in a gesture of easy grace. The foliage tends to curl, no matter from what side of the branch it may spring, toward the top of the twig, and so appears combed up and out. When crushed, it gives out a pungent, almost skunky odor.

Banks of streams and lakes, and borders of swamps, are the habitat of this fine tree; it seeks out ocean cliffs along the coast of Maine, where the salt spray of the Atlantic burns the needles on the windward side, and the sea winds sculpture it into fantastic forms. On the eastern slopes of the Canadian Rockies it attains its greatest height—sometimes 150 feet, with a trunk 3 or 4 feet thick. It reaches almost to the Arctic Ocean in scattered groves, and every one of the rivers of the Mackenzie and Yukon provinces is choked with the naturally fallen logs of White Spruce, while its driftwood is piled, whitening, on their banks and shoals.

In Canada, especially the western provinces, White Spruce is often a fine lumber tree, used for interior finish. Its greatest use, though, is in the making of paper pulp; the least noted of all lumber industries, pulping is, since the disappearance of the great stands of virgin White and Red Pine, the most important forest industry of eastern Canada. Pulp manufacture requires an abundant tree with very soft fibers. White Spruce answers exactly to this description, and so tremendous has become the drain on our pulpwoods that many great newspapers in the U. S. own their own Spruce forests in Canada, and by operating on successive tracts over a sufficiently great area they hope that this fast-growing Spruce will furnish them a self-renewing crop in perpetuity. In vain have American lumbermen sought to raise a tariff wall against Canadian Spruce; for once the lumbermen's powerful lobbies have met their equals in the press, and Canadian pulp still comes in as a precious raw material, just like rubber, silk and coffee.

In the making of pulp, the fiber is torn apart by great grindstones kept cool by water, until the log is reduced to a dirty slush; or else the pure cellulose is freed by dissolving out the gummy lignins with sulfite or soda. To this sludge are added all the fillers, such as rosin, alum, and gelatin for sizing, clays to give body and polish to coated papers, and dyes for colored papers. Then the pulp is drained and mechanically dried, in principle as one dries clothes with wringer or mangle, but by a series of machines that are a marvel of inventive skill. There emerges at last in the great mills a continuous flowing sheet of paper which never stops, year in, year out, unless the paper breaks. To produce a ton of newsprint requires one cord of wood, 2,800 tons of water, nearly 2,000 kilowatt hours of electrical energy or 100 horsepower for 24 hours, and a capital up to $50,000 per ton of daily output.

CANOE BIRCH often dwells with conifers. It grows readily on cutover land, replacing Pines and the Spruces.

THE BALSAM, frequent associate of the Spruce, is fortunately of little practical use to the lumberman. But except with the old-time logger, who had no use for Balsam save to make himself a natural sweet-smelling mattress laid on a springy frame of Spruce boughs, this is the most popular of all the trees in the great North Woods. To anyone whose childhood summers were spent there, the fragrance of Balsam needles is the finest in nature. Merely to remember it is to recall lake waters, or the high swell of the northern Appalachians, or the grandeur of the St. Lawrence Gulf. It brings back the smell of wild raspberries in the sunlit clearing, the white-throated sparrow's song, the flight of the canoe from the paddle stroke. For Balsam loves the rocky

WHITE SPRUCE is a tree of great commercial value because it is used to make paper pulp. In the foreground is a young Spruce; to the rear are mature specimens.

BALSAM is best known as a Christmas tree and for its fine scent. Its resin yields Canada balsam, used to seal microscope slides and in the manufacture of varnish.

soil close to water, where its familiar is often the Canoe Birch. At the edge of any sparkling lake, in the great glaciated province of eastern Canada and the northern U. S., these two grow in felicitous contrast, the Balsam with its gleaming but motionless evergreen foliage and its straight stem and precise whorls of branches, and the white-barked, leaning and gracile Birch with its showers of pale green, restless foliage.

For success in the eternal forest battle for survival, Balsam depends upon its adaptability, the speed of its growth, its fertility. The seeds are many and highly viable, but the grouse and the red squirrels and the pine mice eat them, just as moose and deer browse on the foliage. Balsam is also a danger to itself because of the resin blisters under its bark, which, in forest fires, ignite so that the whole tree is soon a blazing torch.

These resin blisters yield what is called Canada balsam, a sort of turpentine employed in the manufacture of varnish. It is familiar to all advanced students in the biological sciences as a transparent fixative for mounting and preserving specimens under the microscope. It not only seals the cover glass to the glass slide, but is a matrix for the specimen to hold and preserve it from drying or decay. Balsam, moreover, has the fortunate property of refracting light exactly as glass does so that the balsam matrix, the cover glass, and the microscope lenses become one optical system with the same refractive index.

One of the odd things about the lovely aroma of Balsam branches is that many people who live with it constantly can no longer smell it. The city visitor has the sharpest pleasure in it. If he collects the needles to make a balsam pillow, he takes the odor home with him, and for a time he can detect it. But presently he may fail to do so, though the smell is there for others, and he may not notice it again until the fresh Christmas tree is brought into his house. Balsams are the ideal Christmas trees—fragrant beyond all others, with long lower branches and thick, spirelike tops. The needles do not drop like those of the Spruce, even after a month without water, nor do they stab the hand when one is decorating the tree, since they are not tipped with prickles.

The Christmas tree industry is now a big, though a seasonal, business. On forest land the proper selection of little trees will merely result in betterment of the stand. On farms and estates the raising of trees, from seedlings supplied free or at cost by state forestry nurseries, offers, on land not otherwise profitable, possibilities that were dramatized by the highly successful Hyde Park plantations of Franklin D. Roosevelt. Yet from time to time some overzealous moralist decides that we are depleting our forests by cutting millions of young Christmas trees every year for a momentary pleasure, thus robbing ourselves of tens of millions of feet of lumber. But out of every ten young trees in the forest, nine are destined to lose out and die. No harm, but only good, can follow from the proper cutting of young Christmas trees. And the destiny of Balsam, most beautiful of them all, would otherwise too often be excelsior, or boards for packing cases, or newsprint.

WHEREVER it grows the Canoe Birch enjoys the company of conifers and the presence of water; it seeks out rushing streams and cold, clear lakes. Sometimes it is found in swamps and boggy meadows and, if it must leave the neighborhood of moisture, it likes deep, rocky woods with cool soil. Fortunately it is light-tolerant in youth, so it comes up readily on cutover land, and has replaced the White Pine and the Spruces over large

WHITE BARK is the distinctive feature of the Canoe Birch. Pulled away from the trunk in thin sheets, it served the Indians as a covering for canoes. Canoe Birch bark peels more readily than the bark of White Birch.

parts of New England, eastern Canada and the northern peninsula of Michigan.

Thus has Canoe Birch gained ground within historic times, and if there are fewer big specimens than there were, time may take care of that. For the Birch, where it is found near habitations, is usually spared for its beauty. As a result it is now one of the best-loved trees of the New England landscape, and when we remember a scene there, we see Birches in it—gleaming white trunks, houses and churches painted a clean white, and pure country snow stretching over valley and hill.

In its great range, the Canoe Birch takes many forms; on the mountains of New England it is sometimes a dwarfed and bushy plant, while in the rich forests it grows 60 feet high; in the virgin woods it probably attained twice that height, if old reports can be trusted. Though a botanist may quibble over differences in a leaf, all the botanical varieties add up to the same thing—a tree of incomparable grace and loveliness, identifiable at a glance by its shining scaly bark. The only possible confusion would be with the much-cultivated European White Birch, which one knows by its more pendulous "weeping" branches and by the bark that is much closer and tighter than the more readily peeling bark of our Canoe Birch.

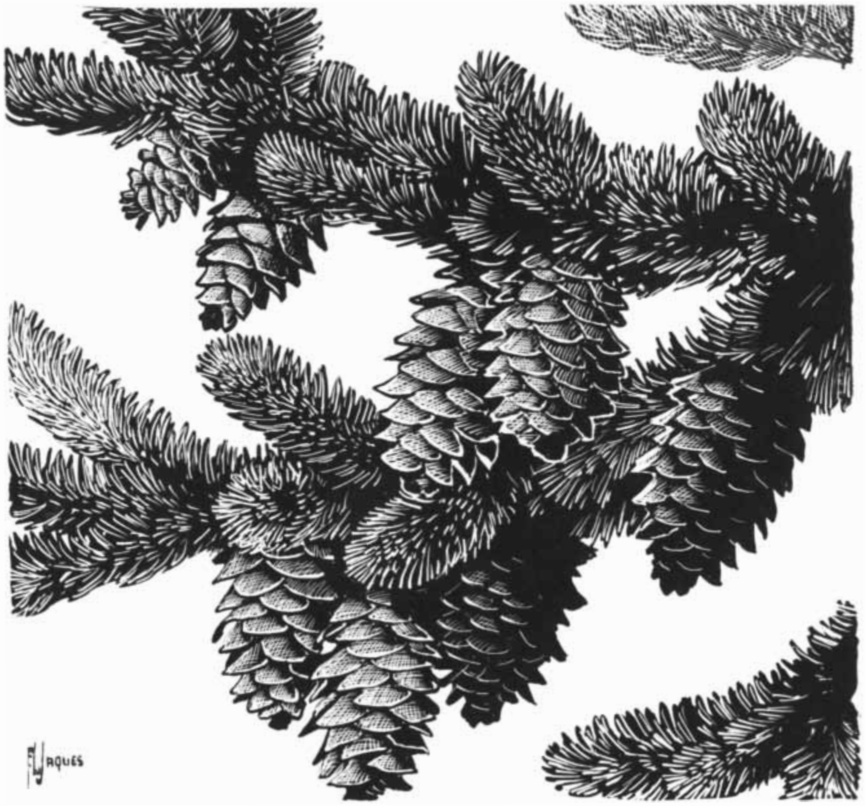
To an American of an older generation, there was no more happy experience than the moment when on his first visit to the North Woods he stepped into a Birch-bark canoe weighing perhaps no more than 50 pounds, but strong enough to carry 20 times as much. At the first stroke of the paddle it shot out over the water like a bird. The Indians taught the early settlers how to strip the bark from the Birch, separate it into thin sheets, and sew them with long, slender roots of Tamarack for thread. The bark was then stretched and tied over the frame—commonly made of northern White Cedar or Arbor Vitae—while the holes in the bark and the partings at the seams were caulked with resin of Pine or Balsam or Balm-of-Gilead. Other barks and skins were often used for canoes, but of them all Birch is the most renowned—the lightest and most beautiful, and yet so strong that the Indian trusted his life to it when he shot the rock-studded rapids.

Birchwood furnished the Indian with snowshoe frames. The bark served him, sometimes, as a covering for the tepee or lodge. Rolled into a spill, it constituted a taper or a punk stick to keep away mosquitoes. It made good paper for kindling a fire started first in punkwood of rotten Yellow Birch. A moose-calling horn of Birch bark was carried by all the Indian hunters in the North Woods—a straight tube about 15 inches long and 3 or 4 wide at the mouth, tied about with strips of more Birch bark.

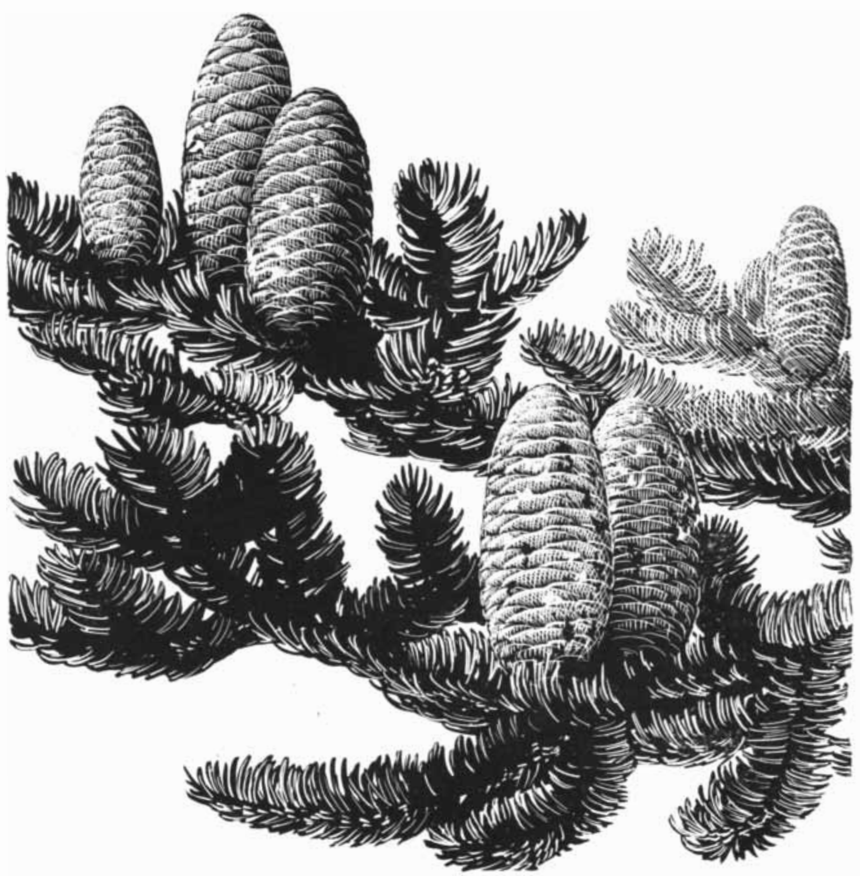
The inner bark of Canoe Birch is a favorite of the beaver, when Aspen is not present. Deer and moose browse the twigs in winter; the buds are eaten by grouse. Sugar can be tapped from this Birch, as from the Maple. Thus to each inhabitant of the North Woods, man or beast, Birch is life-sustaining. Though the lumbermen in the days of the White Pine had little use for the wood itself, they were glad enough to stuff Birch bark, as a waterproof inner lining, under the Cedar shingles of their bunkhouses made of Yellow Birch logs.

And, to the delight of children, the peeling bark has long been a woodland paper. But do not strip it from the living trees, for once the beautiful outer bark is pulled away, it never grows again. Instead, ugly black rings—which you see all too often—take its place. There is always a fallen Birch log from which you can tear sheets. For the Birch is, despite its strength, not a long-lived tree, and once it is dead, decay is swift, and the white trunk soon topples into the old forest loam. Then the mosses gather on its fallen limbs, a green halo that shows how life carries on, though its forms forever change.

Donald Culross Peattie is a botanist and the author of books and articles about botany and other subjects.



SPRUCE CONES hang downward from the branches of the tree that bears them. Their scales are relatively thick and flare outward from the stem.



BALSAM CONES, in contradistinction to Spruce cones, stand upright on the Balsam branch. Their scales are thin and folded close to one another.

SCIENCE AND

First Atomic Power Plant

WITHIN the next few months, the General Electric Company will begin building for the U. S. Atomic Energy Commission the first atomic plant specifically designed for the production of power. The new plant, to be located on a 4,500-acre site nine miles from the famous New York resort of Saratoga Springs, may be completed in three years. Its cost and projected output have not been disclosed.

The G. E. plant is a third step in the AEC power development program. Two other power-generating piles are currently under construction, one at Brookhaven National Laboratory on Long Island and the other at the Argonne National Laboratory in Chicago. The Brookhaven plant will generate only enough power to run part of its auxiliaries. The Argonne pile will be used primarily for testing power plant components. The G. E. installation, combining a high-temperature pile with a steam-turbine generator, is to function as an actual power plant.

Tar Sands

A SUBSTANTIAL part of the world's potential petroleum reserves is locked up in tar sands, an asphaltlike mixture which is widely distributed but from which the oil is not easily extracted. Because much of the world supply of these sands is concentrated in a single gargantuan deposit near the Athabaska River north of Edmonton, Alberta, the Canadian Government and the Research Council of Alberta for several years have sought to develop an economical process for extracting the oil. The Council now reports that progress at last is being made. It has had encouraging results with two processes: 1) distillation; 2) flooding the sand beds with hot water. The hot water method seems somewhat more promising, for it can be utilized on the site and avoids the expense of mining and transporting the sands. There are several problems still to be worked out, however: the sands must be heated to more than 100 degrees Fahrenheit to obtain a worthwhile flow of oil; separation of the oil and water afterward is difficult; the oil has a high sulfur content. These problems will be studied in a pilot plant currently being erected by the Canadian Government at Bitumount on the Athabaska River.

If oil can be extracted economically from the Athabaska sands, Alberta may rival East Texas as a petroleum producer. These sands are believed to contain more than 200 billion barrels of oil—more than the entire remaining reserves in crude oil pools in North and South America. Besides the sands, Alberta has extensive oil resources in pools. Turner Valley in western Alberta, Canada's sole important oil-producing area up to now, has passed its peak, but several new Alberta fields—Leduc, Bantry, Lloydminster-Lone Rock and others—are being opened up. Still others are certain to be found, since evidences of oil are widespread and the province is known to be underlaid with a northern extension of the oil-bearing geological formations of our Great Plains states.

Compton Replaces Bush

AFTER two years of service, Vannevar Bush has retired as chairman of the nation's central military research agency: the Research and Development Board of the Armed Forces. His place is being taken by another outstanding scientist-administrator, President Karl T. Compton of the Massachusetts Institute of Technology.

Bush will return to his post as head of the Carnegie Institution of Washington. He has spent nearly all of the past six years in government service; he directed the Office of Scientific Research and Development throughout the war and was the first chairman of the Research and Development Board. For a few months he will remain on the board as a part-time deputy chairman. Dr. Compton, who also played a leading role in the wartime OSRD, will give his new job full time. His job at M.I.T., which he had held since 1930, will be taken by Dr. James Rhyne Killian, Jr.

Loyalty Problem Committee

A NEW Scientists' Committee on Loyalty Problems has been formed by the Federation of American Scientists under the sponsorship of nearly 50 distinguished figures from the ranks of natural science. The Committee, made up of FAS members at Princeton University and at Brookhaven National Laboratory, will carry on a broad program of activities in defense of scientists' civil liberties, from furnishing advice to scientists with clearance problems to educating the public on the connection between civil rights and scientific progress.

FAS has had an active Committee on Secrecy and Clearance for more than a year. Headed by S. H. Bauer, chairman of the Cornell physics department, and drawn from the FAS membership at Cornell, it has served primarily as an agency for collecting information on clearance procedures and on the difficulties of individual scientists. The new, broader Committee will employ the Cornell group, which will continue a separate existence. for the present at least. as an information-gathering arm.

The new Committee declares that secrecy and loyalty will continue to be problems "until we solve the problem of lasting peace." but "the application of clearance procedures used to date has caused some grave and wholly unnecessary injustices to many scientists."

The Committee. with headquarters in Princeton. is temporarily headed by W. A. Higinbotham of Brookhaven. Its 16 members include Lyman Spitzer, Jr., the Princeton astronomer, and H. D. Smyth, author of the famous *Atomic Energy for Military Purposes.* Among the sponsors are A. J. Carlson of the University of Chicago; E. P. Wigner of Princeton; V. F. Weiskopf of the Massachusetts Institute of Technology; Albert Einstein, and Nobelists James Franck. John H. Northrop and H. C. Urey.

Atomic Debate

LAST spring the United Nations Atomic Energy Commission, over the objections of Russia and the Ukraine, endorsed the U. S. atomic energy control plan and recommended that the UN General Assembly authorize a suspension of negotiations until the U.S.S.R. was ready to accept the U. S. plan. The Commission's report raised a storm in the Assembly, which has been meeting in Paris since September 15. A sizable bloc of smaller powers, led by Australia. New Zealand and Syria, charges that approval of the report will put the atomic control problem in "indefinite cold storage." This the small-power bloc is determined to prevent. At the present writing, it appears that the bloc will succeed.

During the first fortnight of the session, the smaller powers forced withdrawal of a Canadian resolution, which had U. S. and British backing, endorsing the Commission report. Instead, the Assembly created an 11-nation subcommittee to re-explore the possibilities of East-West compromise on the atom. The subcommittee came up with a proposal that the atomic problem be referred to the Big Five plus Canada for study until next year's Assembly meeting. In a single day, seven of the smaller powers delivered strongly worded attacks on the subcommittee proposal. Then the smaller powers put through a directive instructing the Atomic Energy Commission also to resume work on the atomic problem.

Book Exchange

ONE of the most urgent tasks of overseas reconstruction is the restoration of war-ruined libraries. For two years after the end of hostilities, the burden of refilling the shelves of libraries abroad was carried by an emergency organization, the American Book Center for War Devastated Libraries, Inc., which shipped several million pieces of library material overseas. The reconstruction task is now to be continued through an ingenious exchange plan which will be operated by a new non-profit agency, the United States Book Exchange.

The plan will permit foreign libraries to trade books, periodicals and other materials published in their countries for American library duplicates. The program promises American libraries a steady, inexpensive supply of foreign publications. The Book Exchange, in which all leading U. S. library associations are participating, will prepare lists of publications available for exchange here and abroad; the foreign lists will be circulated to American libraries, and the American lists to foreign centers. Libraries will order from these lists.

Until normal conditions are restored, libraries in war-ruined areas will receive two items for each one furnished and will be permitted to overdraw their accounts. Handling charges will be collected only from "hard-currency" countries; the resulting deficits will be made up by private American funds. Eventually, trade will be on a one-for-one basis and the costs of the program will be met wholly out of a small charge for each item a library receives.

The Book Exchange, whose operating executive is Alice D. Ball, will work through both individual foreign libraries and the national book exchanges which are being set up as part of a separate UNESCO program for facilitating the purchase of books in hard-currency countries by libraries in soft-currency areas. The Exchange will also transmit gift book collections.

WHO in China

THE best-known activity of the World Health Organization in the field of tuberculosis is its program, undertaken jointly with the International Children's Emergency Fund, for protecting all uninfected European children by BCG immunization. But WHO is also waging war against the white plague in other areas. In China, for example, WHO is establishing a series of demonstration tuberculosis control centers in cooperation with Chinese health authorities. Five are already in operation, at Canton, Nanking, Peiping, Shanghai and Tientsin.

The Canton center, opened in June, is typical. Its staff, directed by a WHO medical officer, Dr. I. M. Lourie, is largely Chinese. The center, equipped with two X-ray microfilm units furnished by the American Red Cross and UNRRA, examines about 1,000 persons a week. The main treatment is rest—and much is done daily in arranging for it in the chaos of contemporary China. Lung collapse and surgery also are employed. BCG immunization, already in use at the other clinics, will be instituted at Canton early next year. All treatment is free to those who cannot afford to pay. The clinic's activities also include a teaching program for both technicians and doctors. Fourteen additional demonstration tuberculosis clinics are to be set up in other Chinese cities, making 19 demonstration clinics altogether when WHO's Chinese program is completed.

Powdered Milk

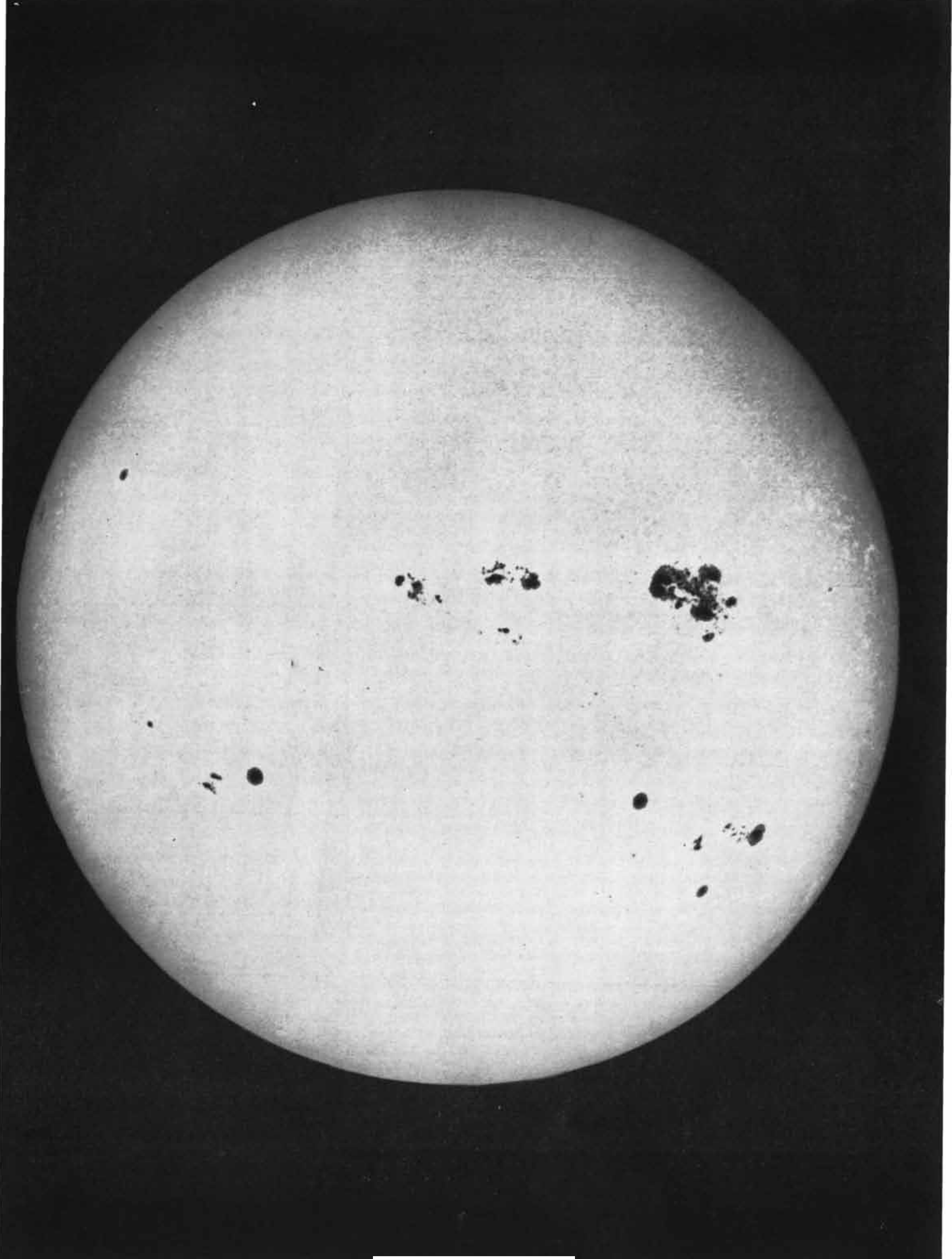
SINCE the end of the war, UNRRA, the International Children's Emergency Fund and other relief agencies have shipped several hundred million pounds of powdered milk to Europe. At first, dried milk met resistance from its intended users. Now it is effecting an important change in European food technology.

In many parts of Europe, pasteurization and refrigeration equipment have always been scarce. Hence milk could not be moved from surplus to deficiency areas, nor held over from surplus to deficiency months; what was not consumed on the spot or converted to cheese was spoiled. Three and a half years of experience, however, have shown that dehydration offers a practical solution. Equipment for drying milk is relatively inexpensive and simple to operate, and powdered milk (whole or skimmed) is as nutritious as the product from which it is made. Consequently, nearly all European countries, either on their own or with help from agencies like the Children's Fund, are making plans to establish local milk-drying industries to provide the first year-round supplies of milk the Continent as a whole has ever had.

Meetings in December

AMERICAN Society of Parasitologists. New Orleans, December 5-8.

Mathematical Association of America. Columbus, Ohio, December 26-31.



THE SUN

Our star is a vast engine for converting matter into radiation. The latter sustains life on earth and also provides some clues for the astronomers

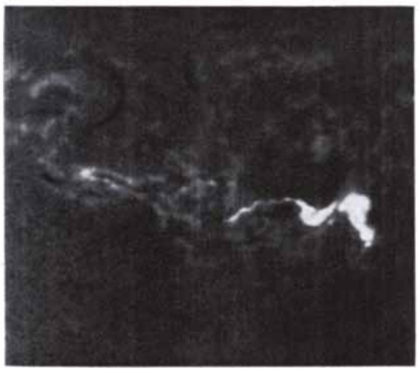
by Armin J. Deutsch

ON July 26, 1946, at 11:15 a.m. E.S.T., astronomers saw a hot, scarlet filament lash out across the face of the sun directly over a large, active sunspot. At the moment of its appearance, short-wave radio transmission blacked out over the whole daylit hemisphere of the earth. On one radio frequency, static from the direction of the sun increased to over 10.000 times its normal volume. In the course of the next 10 or 12 minutes the scarlet filament swelled in intensity; for a few seconds it shone 30 times as intensely in its own red light as the brilliant face of the sun. Then, less rapidly than it had appeared, the flare lengthened, spread out and faded. At 12:30 it had twisted over a distance of 350,000 miles; near one edge of the flare a mass of cooler gas covering an area of a billion square miles was seen falling into the sun at a speed of 45 miles a second.

A few hours after the scarlet flare had first erupted, nothing remained to mark its position over the great group of sunspots. But at 1:45 p.m. the next day, sensitive magnetic instruments in observatories all over the earth simultaneously began a sudden, violent trembling. The magnetic field at the surface of the earth jittered for the next 12 hours, then gradually settled down again to its normal untroubled state. The press wireless circuits between New York and the northern capitals of Europe remained useless during most of July 26 and 27. A brilliant aurora illuminated the skies over the eastern seaboard in the early morning hours of the 27th; in Washington colored streamers flickered past the zenith and down into the southern part of the sky.

This phenomenon was not unique. When the face of the sun is well spotted, as it is now during this period of maximum sunspot activity, solar flares are not especially rare. More than 40 were observed at California's Mount Wilson Observatory in 1946, and it is estimated that on the average they occurred as often as one every 50 hours. Most flares, of course, are less intense than the great one of July 26, and many are accompanied by less violent terrestrial effects. Few, if any, are bright enough to show up in an ordinary telescope. Most of them can be seen or photographed only with an instrument that picks out of the sunlight one of the few narrow bands of the electromagnetic spectrum into which the flares concentrate all their energy. The conventional instrument for this purpose is the spectro-

DISK of the sun darkens at the edge, one indication of the rapid thinning of its atmosphere. On the surface is an unusually large group of sunspots.



FLARE on the sun was photographed by light-selective spectroheliscope. Spectroheliogram is from Michigan's McMath-Hulbert Observatory.

helioscope, which disperses the spectrum of sunlight and passes through a narrow slit just that one particular band of wavelengths which is required to fall on the retina or on the photographic plate. Recently some astronomers have dispensed altogether with the elaborate spectrohelioscope, and have used instead a compact sandwich of thin quartz blocks and slices of Polaroid. which together function as a filter passing a very narrow band of wavelengths.

The Carbon Cycle

The sun, 93 million miles distant from the earth, is some 109 times the diameter of our planet and a third of a million times more massive. Near the center of the sun —at a temperature of 20 million degrees Centigrade, a pressure of a billion tons per square inch and a density seven times that of lead—atomic nuclei collide with such violence that one nuclear species may be transformed into another. The most important of these processes builds helium nuclei out of hydrogen. The transformation takes place through a sequence of six nuclear reactions. The sequence begins with a collision between the nucleus of a common carbon atom and a proton, the nucleus of a hydrogen atom. As the result of the impact, the two nuclei unite to form an isotope of nitrogen. But the mass of this new nucleus is slightly less than the sum of the masses of the two colliding particles. The lost mass appears as a burst of radiant energy, in this case a gamma ray.

The newly formed isotope of nitrogen is unstable; within a few minutes of its birth it ejects a positive electron, or positron, and becomes a heavy isotope of carbon. When this collides with another proton, the two nuclei again unite to form an isotope of nitrogen, and the excess mass is again carried off in a gamma ray. Collision with a third proton transforms the nitrogen into oxygen and produces a third gamma ray. But the oxygen is unstable, and it quickly ejects a positron to transform itself back into nitrogen. Encountering a fourth proton, the new nitrogen nucleus splits in two. One fragment is the nucleus of a helium atom; the other is the nucleus of carbon with which the whole sequence of transformations began. The result of the sequence, therefore, is to join four hydrogen nuclei into one helium nucleus, through the catalytic action of carbon. At the end of the cycle, the carbon atom that set it off reappears, ready to catch another proton and start the cycle over again.

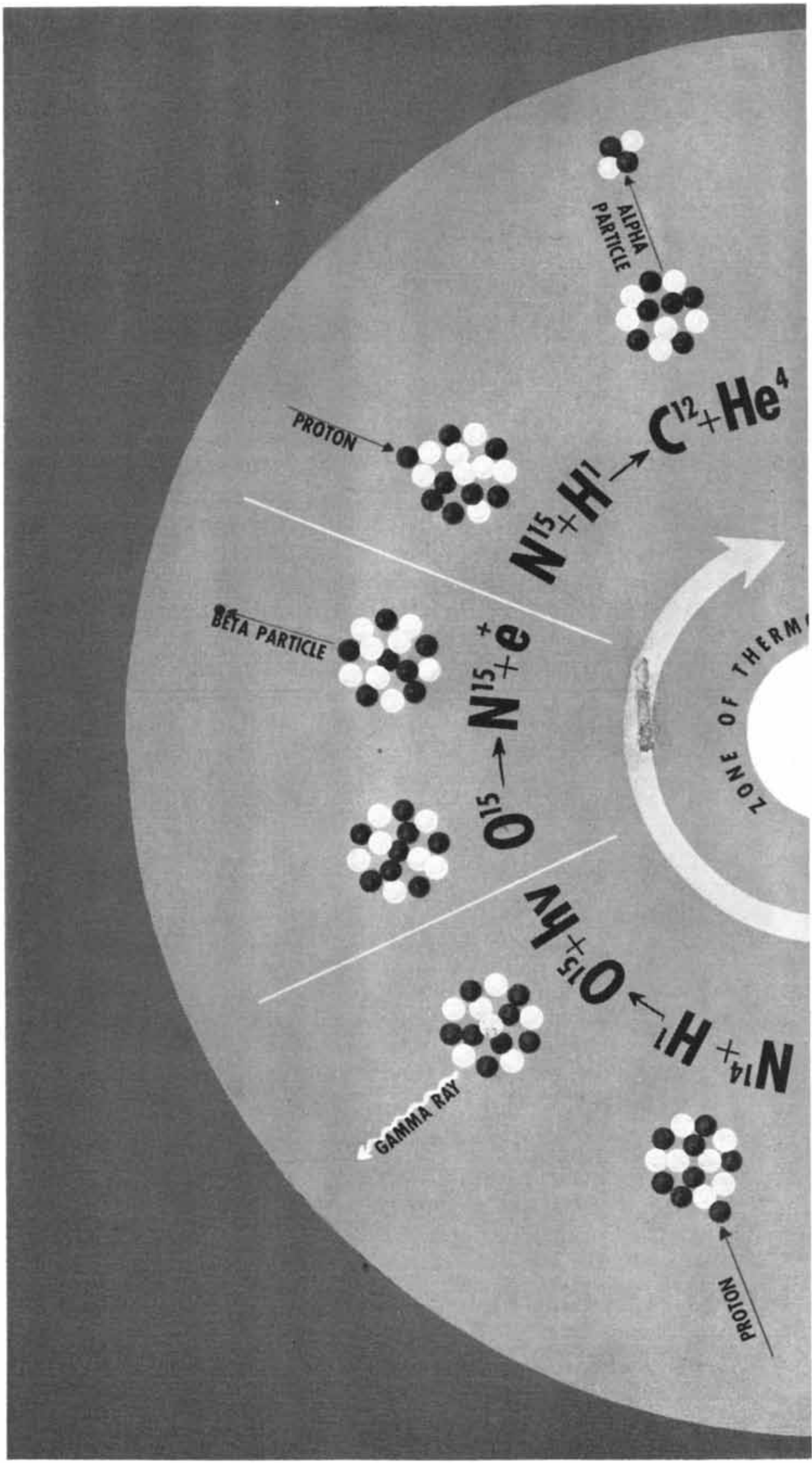
In this way, step by step, 564 million tons of the sun's hydrogen are transmuted every second into 560 million tons of helium. Most of the four million tons of mass that melt away every second are converted into radiant energy, and this flows out from the sun's incandescent surface at the rate of half a million billion billion horsepower. The earth, a small target at its distance from the sun, is struck by less than half a billionth part of the total solar radiation. But that small fraction is enough to hold the temperature of the whole terrestrial surface well above the absolute zero of empty space, to drive the great heat engine that is the atmosphere, to sponsor the complex processes by which plants build living matter from carbon dioxide and water, and, through the plants, to sustain all animal life.

The study of this nearest of all stars has been pursued by astronomers ever since that momentous day in 1610 when Galileo first gazed at its incandescent disk with his new telescope. Galileo actually observed black spots on the sun. At first uncertain whether they were the shadows of bodies lying between the earth and the sun, he soon concluded that they were on the sun itself, and that their motions across the disk from east to west were caused by the rotation of the sun on its axis in a period of nearly a month. Two and a half centuries later, however, Sir John Herschel still could ask, "But what *are* the spots?" The great English astronomer went on to assert that "Many fanciful notions have been broached on this subject, but only one seems to have any degree of physical probability, *viz.*, that they are the dark . . . solid body of the sun itself, laid bare to our view. . . ." Today it is established beyond doubt that the sun has no dark solid body. But astronomers still echo the plaintive query of John Herschel: "What *are* the spots?"

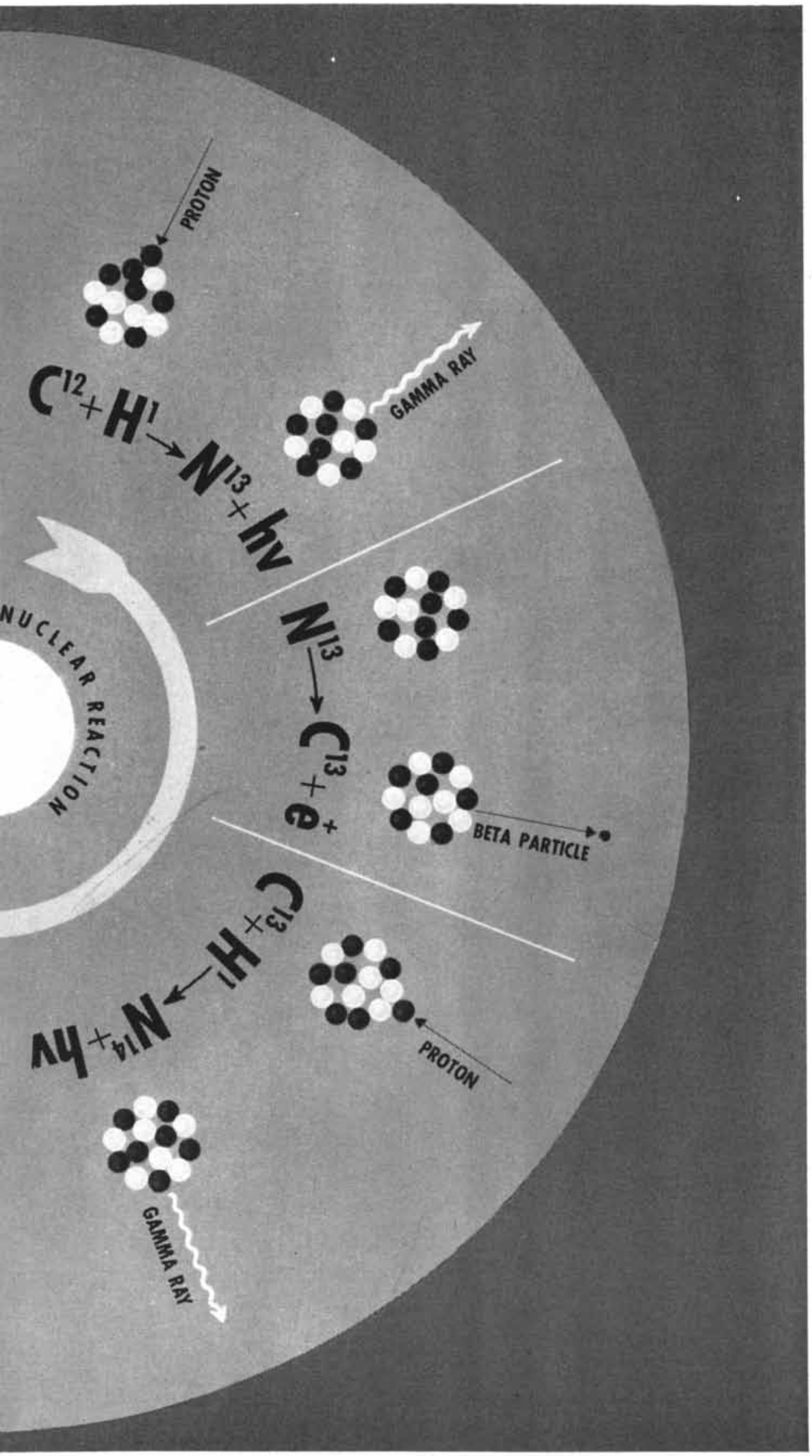
Darkening of the Limb

The spots appear against the background of the bright, white surface of the sun, and this background itself has revealed much to the careful observer. It is not particularly difficult to see, for example, that the disk of the sun is distinctly fainter near the edge than at the center, though the edge itself looks perfectly sharp through the most powerful telescopes. This darkening at the edge, or limb, is even more conspicuous in photographs. It shows up most clearly in blue and violet light, to which the ordinary photographic emulsion is more sensitive than is the eye. Indeed, careful measurements have shown that in the near ultraviolet, the limb of the sun is less than half as bright as the center.

The laws of radiation from hot bodies have enabled us to determine the temperature of the surface of the sun—astronomers call it the photosphere—from its brightness. The temperature is found to be nearly 6,000 degrees above absolute zero (—273 degrees C.). At this temperature all known substances are in a gaseous state. In other words, what seems at first to be the bright, smooth surface of the sun



THE CARBON CYCLE is the chain of nuclear reactions that is the source of the sun's energy. Beginning in the right half of this drawing, the cycle manufactures one helium nucleus, or alpha particle, out of four hydrogen nuclei,



with the release of energy. The large circle outside the cycle represents the sphere of the sun. The small circle in the center indicates the relative size of the small zone in the center of the sun where the carbon cycle takes place.

is instead an incandescent atmosphere some 200 miles thick. In the outer regions of this atmospheric shell the solar gases shine only faintly and are almost perfectly transparent; near the bottom of the shell the gases are intensely bright and nearly opaque. The sun's atmosphere, of course, grows less dense and less hot toward the top. Near the base of the photosphere, the temperature is 6,300 degrees absolute; the pressure is about one-fifth that of the earth's atmosphere at sea level, and the density is less than a millionth the sea-level density of air. Two hundred miles above the base of the photosphere, the temperature has fallen 1,400 degrees, the gas pressure and density have decreased 18 times and 12 times, respectively, and the gas has become more than 60 times as transparent.

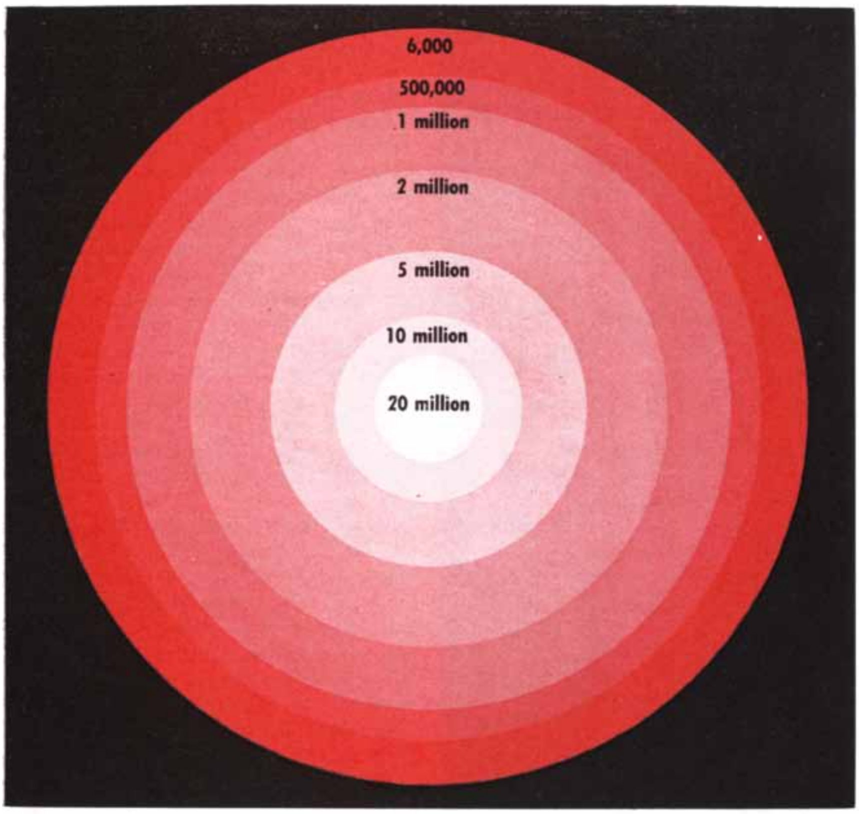
It may seem strange that the bright face of the sun should prove to be nothing more substantial than a mantle of luminous gas which has no sharp boundaries at all. If this picture is the correct one, how are we to account for the razor edge which the disk of the sun shows, even when it is observed through powerful instruments? Why do we not see the atmosphere gradually fade out at the limb of the sun? The reason, of course, is that at a distance of 93 million miles from our telescopes, even an atmosphere over 200 miles thick will look like a sharp edge; at that distance, 200 miles subtends the same angle as a human hair at a distance of 150 feet.

The darkening at the limb of the sun is just a consequence of the fact that we view a semi-transparent atmosphere, not a discrete surface. Near the limb we look obliquely through the sun's atmosphere, and we cannot see as deep into the sun as at the center. The light that reaches us from the center of the disk originates mainly near the bottom of the photosphere; there the temperature is high, and the light we see is correspondingly bright and blue. But the light that comes to us from near the limb starts from near the top of the photosphere; there the temperature is relatively low, and the light is consequently fainter and redder.

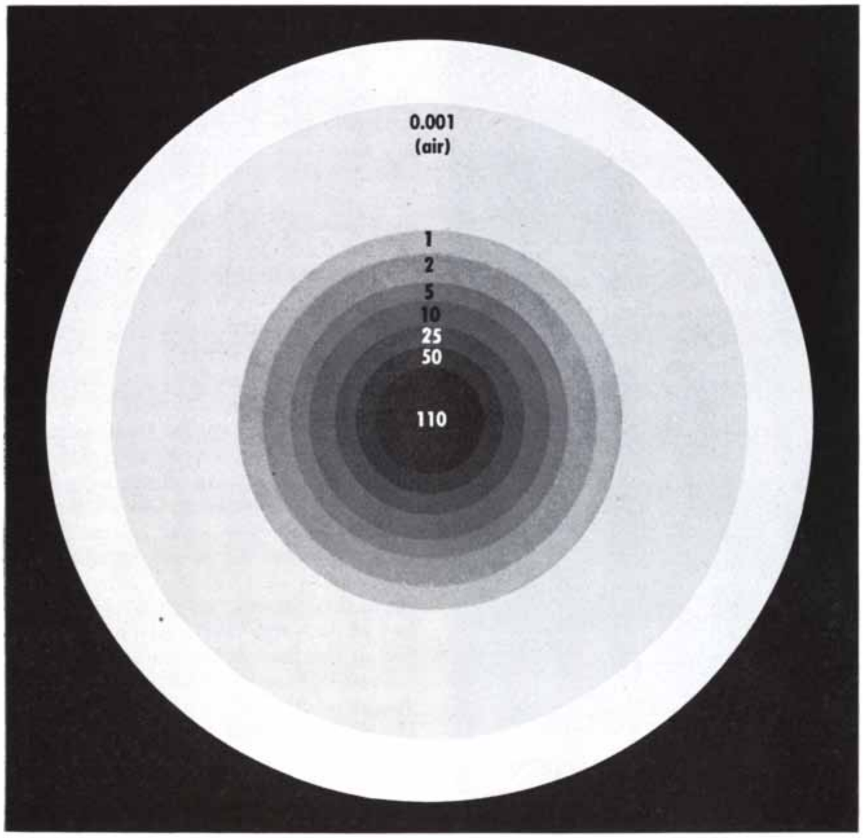
A careful study of the limb-darkening ought, therefore, to convey a great deal of information about the absorbing properties of the photosphere. One of the outstanding puzzles in solar astronomy for many years was the surprising opacity of the tenuous photosphere. There is more gas in the column of air above each square foot of the earth than above each square foot at the base of the photosphere. Yet our atmosphere is almost perfectly transparent, while that of the sun is opaque. The reason for this difference has been ascertained only within the past few years.

The Opaque Photosphere

Consider the behavior of the atoms in the sun's photosphere. Because the temperature is so high, they move about at



TEMPERATURE of the sun is calculated to be 6,000 degrees Centigrade above absolute zero (–273 degrees C.) at the surface and 20 million degrees at the center. Here the sun's intermediate temperatures are also indicated.



DENSITY of matter in the sun's interior is stated in units of the density of water. The density of air is not attained until some distance beneath the photosphere. The density at the center of the sun is 110 times that of water.

great speed. The density is relatively low, so the atoms collide with one another less frequently than do molecules of air on the earth. But when they do meet, the collision is about 20 times as violent, on the average, as that between air molecules. In fact, collisions between atoms in the photosphere, and between light quanta and atoms, often are energetic enough to knock an electron from one of the atoms and to leave the atom as a positive ion. Atoms of the metals are particularly subject to this kind of mutilation, for their electrons are less closely bound than those of most other elements. Consequently, near the base of the photosphere every cubic inch of gas contains in the neighborhood of a million billion unattached electrons that have been knocked out of atoms. The population of these vagrant particles does not increase, because ionized metal atoms snap them up just as fast as others are set free.

Negative Ions

Much more common than the metal atoms, outnumbering them perhaps 8,000 to one, are the atoms of hydrogen. These are the lightest and simplest of all atoms; each is constructed of a massive, positively-charged nucleus and a light, negatively-charged electron. In the hydrogen atom, the electron is very firmly bound to the nucleus, so relatively few hydrogen atoms are ionized. Indeed, a certain small proportion of hydrogen atoms react in a contrary fashion: instead of losing electrons they pick up extra ones from the surrounding crowd. The result is a negative ion of hydrogen—a hydrogen atom with two electrons.

This phenomenon is rare even in the hydrogen-rich photosphere of the sun; it has seldom been detected in terrestrial laboratories, and experiments to determine the properties of negative hydrogen ions have not yet been devised. Nevertheless the modern theory of atomic structure has proved adequate to permit the theoretical description of certain of their properties. The results of these calculations indicate very clearly that such ions are to blame for the opacity of the photosphere.

The reason the negative ions of hydrogen are particularly effective in intercepting the light welling up from the interior of the sun is closely linked to the fact that their extra electrons are easily detached. Ordinary atoms and positively-charged ions usually will let a quantum of infrared or visible light pass. Occasionally they will capture a quantum of ultraviolet light, which is very rich in energy, and the energy will detach an electron from the nucleus. The negative hydrogen ion is less discriminating. Needing only a small amount of energy to free the extra electron, it accomplishes its own demolition by greedily absorbing almost any passing light quantum. It is almost completely indifferent to color: a quantum of weak red light will detach an electron about as well as one of energetic blue light. Thus the negative ions of hydrogen in the photosphere rapidly soak up the light of all colors coming from below. This absorption is what makes the photosphere opaque. Of course, the absorbed light is re-emitted again every time an electron attaches itself to a hydrogen atom to form another negative ion. But the damage is already done; the light from below cannot get through without interference, and so we cannot see through the photosphere.

Although atoms with a normal complement of electrons are less responsive than negative ions of hydrogen to visible light, they are not entirely indifferent to it. Thus a neutral hydrogen atom welcomes the chance to absorb light of a wavelength of 6,563 angstrom units (one angstrom unit = 1/100,000,000 centimeter). A quantum of this particular wavelength contains exactly the amount of energy needed to boost the hydrogen electron from one of its orbits about the nucleus to another. A quantum of slightly redder light will have a longer wavelength and carry only slightly less energy, but the hydrogen atom will invariably let it go by. It is strictly an all-or-nothing proposition: either the hydrogen atom gets just enough energy from the light to push the electron up to another orbit, or else it takes none at all. The hydrogen atom has a neatly systematized collection of orbits for its electron, numbered one, two, three, and so on, and it will not tolerate an electron anywhere else. It works very much like a slot machine which will take a nickel or a dime or a quarter, but not seventeen cents.

The particular set of wavelengths that a hydrogen atom will condescend to absorb has been determined in the laboratory. The essence of this experiment, without going into its complicated details, is that white light, in which all colors are present, is made to pass through a container filled with atoms of hydrogen. The light that is transmitted by the gas is then spread out into a spectrum, and the colors that have been absorbed by the hydrogen reveal themselves by gaps in the spectrum —dark lines which mark the wavelengths absorbed.

Characteristic Absorption

The whole science of spectroscopy is based upon this fundamental selectivity of light absorption by atoms. Experiments have shown that hydrogen atoms always absorb the same wavelengths, and every other atom likewise has its own pattern. Like the fingerprints of men, the absorption spectra of atoms identify them completely. No iron atom has ever absorbed hydrogen's set of lines, or *vice versa.* It is an essential part of the ironness of iron to absorb only iron lines. Depending upon the temperature of the gas, and upon certain other conditions, some iron lines will be relatively stronger at some times than at others. These effects add complication to the job of the spectroscopist, but they also make it possible for him to discover more about the structure of the atom, and for the astrophysicist to discover more about the structure of the sun.

When the light of the sun is dispersed into a long spectrum, it is found to be deficient in the set of wavelengths that the neutral hydrogen atom absorbs. And of course hydrogen is not the only element that steals the sunlight as it seeps up through the solar atmosphere. Of the 92 chemical elements known to reside in the crust of the earth, some 66 have been found in the atmosphere of the sun by their telltale absorption lines in the solar spectrum. Acting together, these 66 kinds of atoms produce some 25,000 absorption lines which have so far been mapped in the solar spectrum. Some of these lines are broad and almost perfectly black (meaning that almost all of the light at these wavelengths has been absorbed); others are narrow and pass most of the light within them. The strength, or total blackness, of any absorption line—a line produced by iron, say—obviously depends on the abundance of that element in the solar atmosphere. Thus a quantitative analysis of the solar atmosphere is possible.

It turns out that the strength of an absorption line depends on many other things besides the abundance of atoms: the temperature of the source, the number of free electrons in the vicinity, the electronic structure of the atoms concerned. All these factors, and several others too, must be taken into account before the chemical composition of the atmosphere is finally obtained. The problem is by no means completely solved today, but the indications are strong that most of the elements occur in the solar atmosphere in very nearly the same relative abundance as in the crust of the earth. The outstanding exceptions are hydrogen and helium, which are enormously more common on the sun than on the earth, presumably because our planet does not have sufficient gravitational attraction to have held these light gases. The fact that there are 26 natural elements whose absorption lines have not yet been found in the solar spectrum is not surprising, for most of them are so rare on the earth that we do not expect to be able to detect them in the sun.

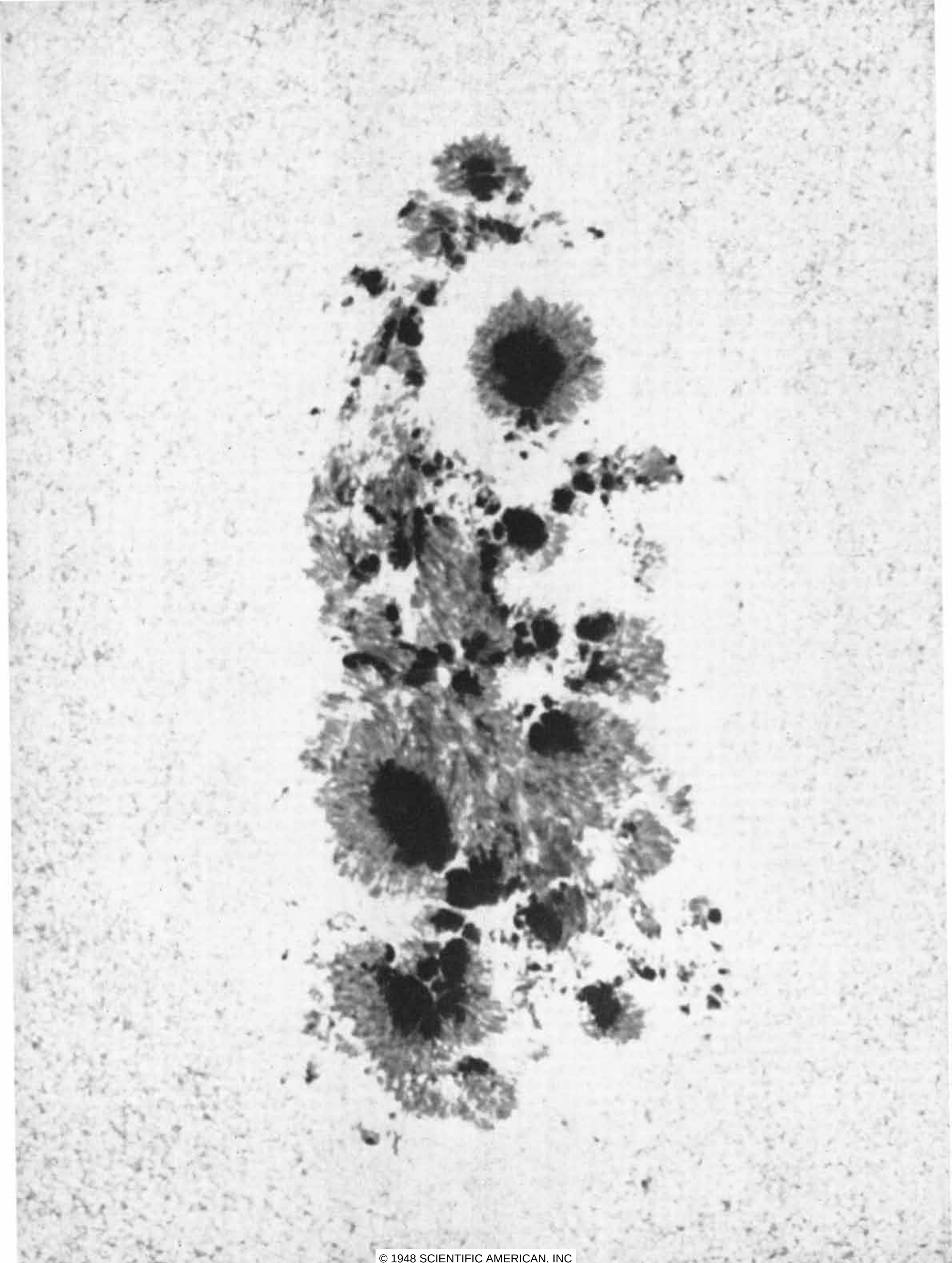
In addition to the absorption lines of most of the chemical elements, the spectrum of the sun exhibits some of the intricate absorption patterns that are characteristic of molecules. A recent count of these so-called absorption bands indicates that at least 18 different two-atom molecules can be identified in the sun. But molecules do not fare well in the rough-and-tumble of the solar atmosphere. Collisions with atoms and with light quanta are too frequent and too violent, with the result that after a chance encounter of two atoms with a chemical affinity, the resulting molecular union is always broken within a split second. There is virtually no chance for a diatomic molecule to survive long enough to meet and pick up a third atom, and even among the simple diatomic molecules, only the hardiest survive long enough to be able to make a showing. The ubiquitous hydrogen atoms manage to work themselves into most of the chemical compounds that are found. Among the commonest are the combinations formed by hydrogen with nitrogen, carbon and silicon. A few oxides, and probably two fluorides, also occur.

All these molecules, and the much more abundant atoms too, are the obstructionists of the solar atmosphere. Even if a quantum of light runs the gamut of negative ions of hydrogen in the 200-mile-thick photosphere, it is unlikely to escape the sun if its wavelength coincides with the wavelength of one of the thousands of absorption lines in the solar spectrum. If its wavelength happens to be one of those that can be absorbed by a hydrogen atom, for example, the quantum has practically no chance of escaping, for it is almost certain to collide with a hydrogen atom in the rarefied layers above the top of the photosphere. These uppermost reaches, though transparent to light of most wavelengths, are still opaque in the wavelengths that hydrogen can absorb. Light of these colors has a fair chance to escape the sun only if it is produced high above the top of the photosphere, where few hydrogen atoms stand in its way.

Monochromatic Photographs

Because of this fact, the isolation of the small amount of light that comes to us from the center of one of the strong, dark absorption lines enables us to take a photograph of the topmost levels of the solar atmosphere. Similarly, isolation of the light slightly off the center of the line, but still within the range of wavelengths absorbed by hydrogen, permits a photograph to be taken of a level intermediate between the photosphere and the top of the extremely diffuse gas above it. The sun has many faces; by a judicious selection of the color of light we admit to our camera, we can photograph them one by one.

Monochromatic photographs of this kind reveal a vast and turbulent atmosphere extending more than 5,000 miles above the top of the photosphere. In the lower levels of this surprising solar envelope, which is known as the chromosphere, the temperature and density of the gas fall off with increasing height at about the same rate as in the lower, opaque levels—a rate which keeps the gas pressure just balanced against the solar gravity. But after the density has fallen several hundredfold, the gas quite abruptly stops thinning out at the expected rate, and the temperature actually seems to start going up again. In this part of the sun, the atoms are so



sparsely strewn that the "temperature" we measure depends on the method we use to measure it. The relative strength of the various lines of hydrogen correspond to a temperature of 10,000 degrees absolute, but the shapes of the lines indicate that the atoms are moving at speeds corresponding to a temperature twice that high, and the very slow thinning out of the hydrogen atoms at great heights seems to indicate a temperature near 30.000 degrees.

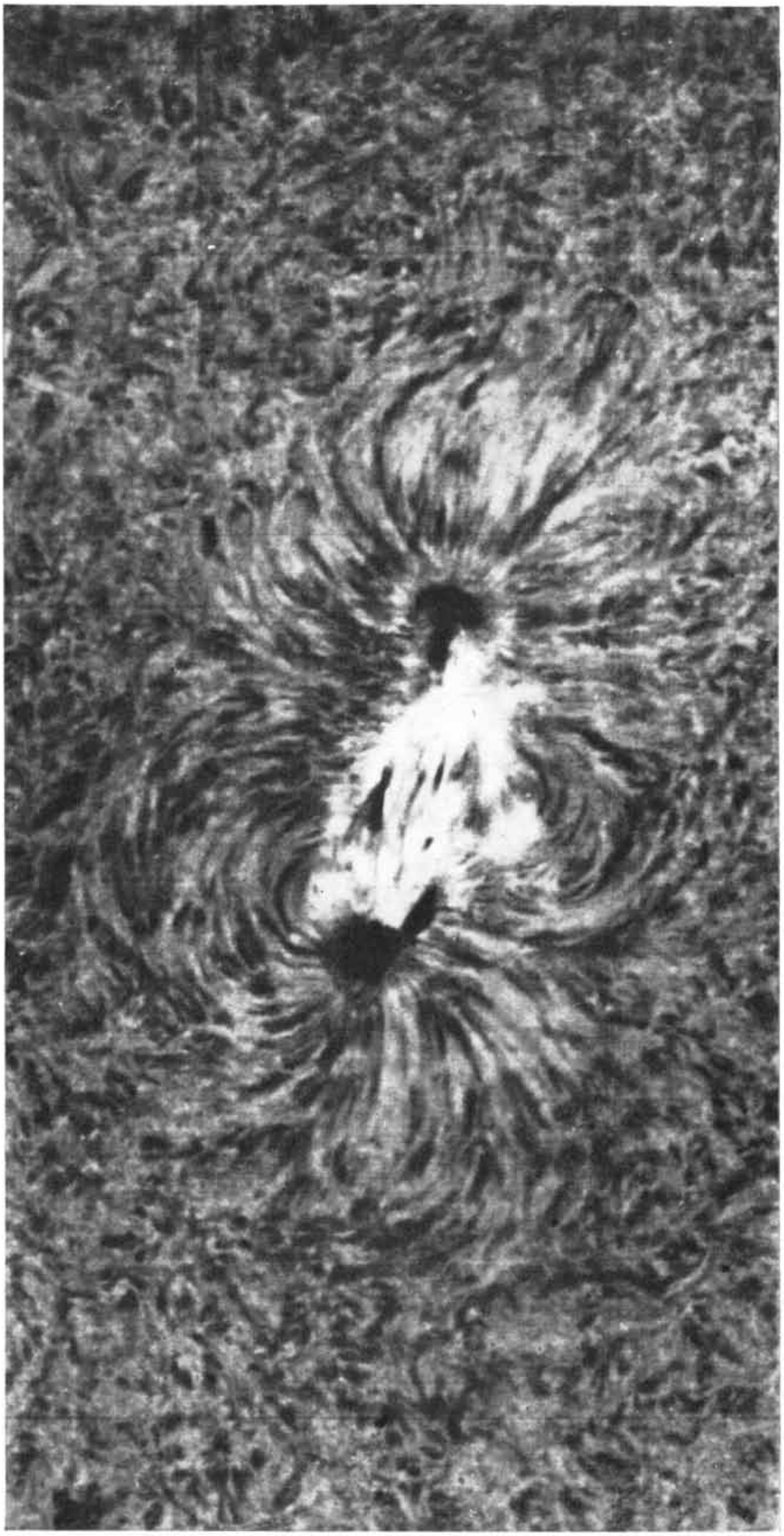
The appearance of the chromosphere at any time depends on the wavelength of the light in which we view it. Photographed in one of the colors strongly absorbed by ionized calcium. the face of the sun looks curiously like the peel of an orange. Against the irregular. mottled background. there frequently appear a few long. thin. dark filaments. These irregular black scars appear also on photographs exposed in the light of one of the hydrogen lines. but the rest of the detail in the hydrogen photographs is more irregular than in calcium light. The true nature of the dark filaments becomes apparent when the rotation of the sun carries one of them to the limb. Projected then against the black sky. instead of against the glowing chromosphere, the filaments are seen to be great flamelike protuberances from the chromosphere. Called prominences. these irregular objects commonly extend 30,000 miles above the chromosphere itself, and many are several times that high.

The Prominences

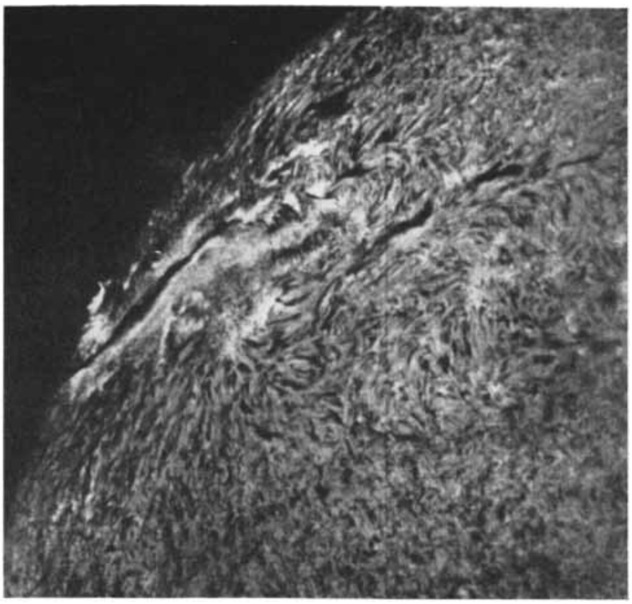
Prominences are apt to appear in any solar latitude. They assume a variety of forms. but usually they are curtain-shaped. their thickness being small compared with their length and height. An average prominence will have a length of 125,000 miles and a thickness of only 6,000 miles.

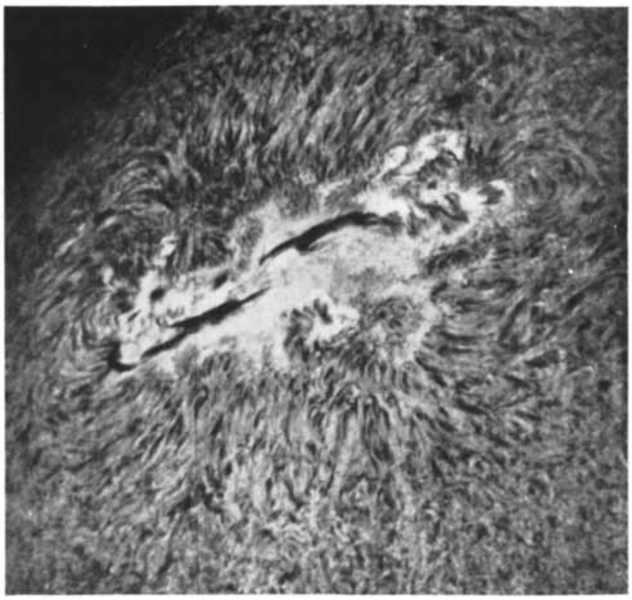
The mass of an average prominence is probably about the same as the mass of the water in Lake Michigan. In some prominences, the gases do not appear to be in rapid motion; for days at a time the great heap of gas may maintain unchanged its general shape and its position on the sun. Other prominences exhibit intricate patterns of motion, best studied by motion pictures. Knots of gas are commonly observed to describe gracefully curved trajectories down towards the chromosphere, and speeds of the order of tens of thousands of miles per hour are the rule. But the motions are by no means always in the same direction. In one and the same prominence, some gas can be seen ascending while other gas is descending, and frequently knots of matter will

SUNSPOT appears as a great vortex in the photosphere. Although the temperature of the spot is some 5,000 degrees, it appears dark because it is cooler than the surrounding area.



SPECTROHELIOGRAM of a sunspot shows whorls of gas resembling the lines of force in iron filings that are sprinkled on paper above the poles of a magnet. This spectroheliogram was made by one wavelength emitted by hydrogen. It shows disturbances in the chromosphere, the layer above the photosphere. In this case the disturbances are huge clouds of hot hydrogen.





CHANGES IN SUNSPOT form are shown by a series of spectroheliograms made as the sun turns. This spectroheliogram, like the one that appears on the previous page, is produced by one spectral line of hydrogen. Pat-

drift along nearly parallel with the top of the chromosphere, meeting and passing other condensations moving in the opposite direction.

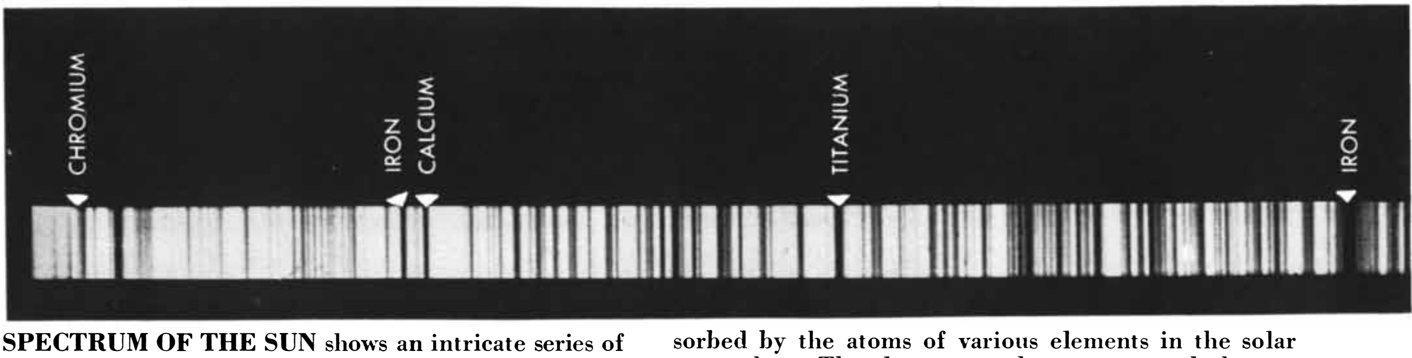
The forces acting on prominence material, like the forces which levitate the whole distended chromosphere, are not yet understood. Whatever the nature of these forces, they sometimes produce the most puzzling and awesome phenomena. Tornadolike prominences occasionally whirl straight up to 100,000 miles above the chromosphere. Narrow tongues of gas shoot out of the region above a sunspot at speeds of 100 miles a second. After reaching out to a height of perhaps 100,000 miles, the gas will as suddenly appear to be retracted, sliding back into the sun without any apparent loss of matter. Occasionally a prominence is literally blown off the sun. A prominence which has quietly arched across 250,000 miles of the chromosphere for days on end will suddenly explode, and the gas will be impelled outwards at speeds of hundreds of miles a second.

Before the invention of the spectrohelioscope, the prominences and the chromosphere could be observed only when the sun was totally eclipsed. With the brilliant photosphere hidden behind the dark disk of the moon, the red ring of the chromosphere and the flamelike protuberances are often visible even to the unaided eye. A still more extensive envelope around the sun also becomes apparent during a total eclipse. Called the corona, this vast pearly halo reaches out into space as much as a million miles in some directions. Although it gives half as much light as the full moon, the corona for many years defied all efforts to see or photograph it outside of total eclipse. Unlike the prominences, the corona does not concentrate most of its light in a few isolated colors; it shines in all colors, and these are mixed in nearly the same proportions as in light from the photosphere. Except during eclipse, minute imperfections in the telescope lens, or even microscopic dust particles in the air itself, scatter enough photospheric light into the million-times fainter coronal image to drown it out completely.

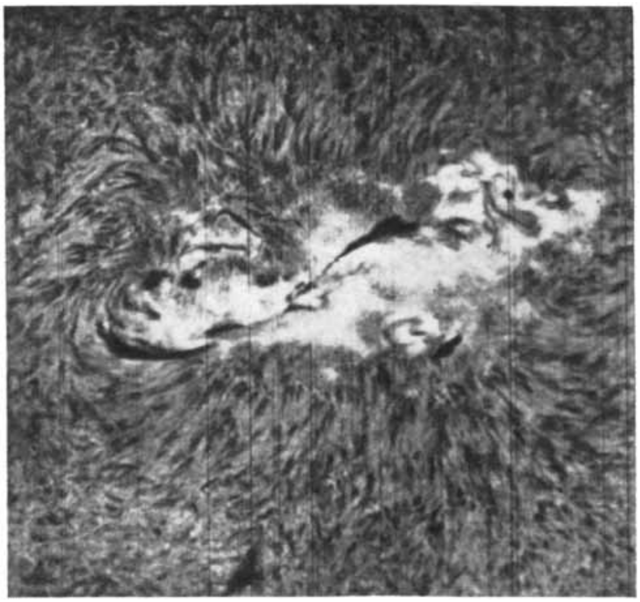
The problem of observing the corona was first solved in 1930 by Bernard Lyot, a young French astronomer. He devised a special kind of telescope using a simple lens of superb optical quality, and fitted it with light traps to deflect out of the image all the photospheric light. He transported the whole instrument to the top of the 9,400-foot Pic du Midi, in the Pyrenees, where the air is unusually pure and serene. On his first attempt, Lyot succeeded where so many before him had failed; he could detect the corona outside of eclipse. Following Lyot, several other coronagraphs have been erected at high elevations in Europe. The only one in the Western Hemisphere, operated jointly by Harvard College Observatory and the University of Colorado, is at a site in the Colorado Rockies 11,500 feet above sea level.

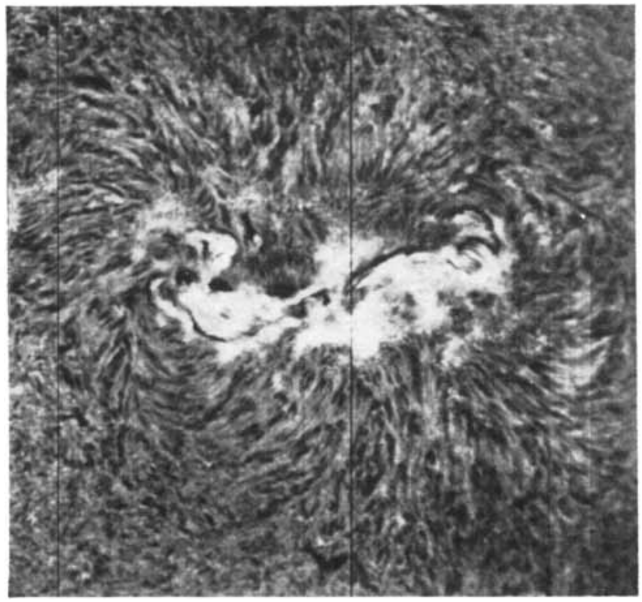
The Corona's Color

The color of the coronal light, and its state of polarization, both suggest that it consists mainly of photospheric light, reflected to the earth by an extremely diffuse cloud of electrons around the sun. But the light that reaches us from within 100,000 miles of the photosphere does not show



SPECTRUM OF THE SUN shows an intricate series of dark lines indicating the characteristic wavelengths absorbed by the atoms of various elements in the solar atmosphere. The elements, and one compound, that ac-





terns in the gas again indicate a magnetic field about the spots. When sunspots are paired, the magnetic field of one usually has a polarity opposite that of the other. These photographs are from Mount Wilson Observatory.

any of the absorption lines that we expect to find in reflected sunlight. Their absence can be accounted for only by supposing that the reflecting electrons are moving in all directions with speeds averaging some 2,000 miles a second! Speeds as great as this imply a temperature of over 500,000 degrees absolute. Can the corona really be as hot as that?

Evidence that it can and must be is provided by the excessive brightness of certain colors in the coronal spectrum. The spectrum shows a line at 5,303 angstroms, for example, which is not a dark absorption line but a bright line representing an excess of light. Elsewhere in the spectrum appear about 25 other so-called emission lines. Unlike the spectral lines that appear in the light from other parts of the sun, these emission lines in the spectrum of the corona have never been duplicated in any terrestrial laboratory. Nor are they likely to be duplicated in the foreseeable future, for they are the so-called forbidden lines—colors which an atom is extremely reluctant to radiate and will not radiate at all unless left undisturbed by collisions for seconds or minutes at a time.

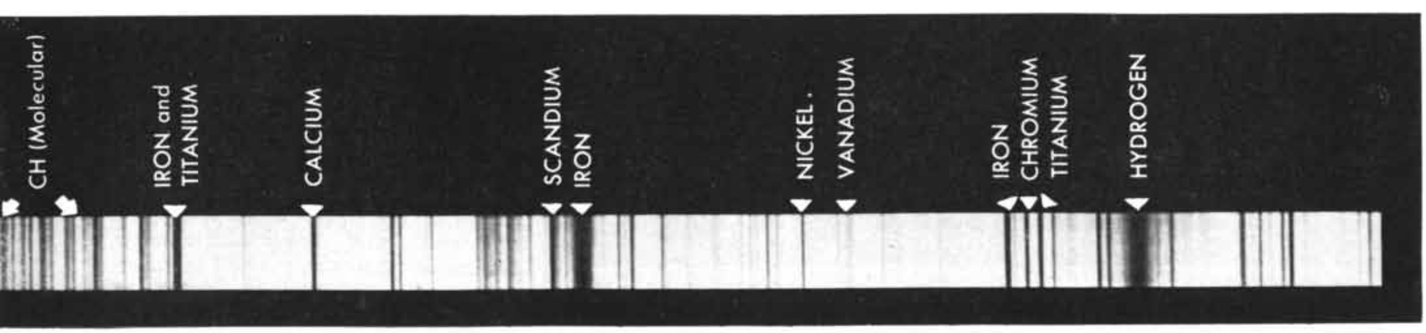
The emission line at 5,303 angstroms, which usually is the brightest one of all, is known to be produced only by iron atoms. But ordinary, electrically neutral iron atoms cannot do the job; it takes an iron atom that has been stripped of 13 of its 26 planetary electrons to radiate light of this wavelength. Other coronal emission lines come from iron atoms which have lost anywhere from 9 to 14 electrons. Atoms of nickel stripped of about half of their normal retinue of 28 planetary electrons also appear in the corona. Still other contributors to the coronal spectrum are highly ionized atoms of calcium and argon.

Now it requires a fairly energetic collision to jolt even one electron off an iron atom, and a much harder collision to remove a second electron once the first is gone. But to remove 13 electrons! This can happen only under conditions of extremely violent impacts, either with other atoms or with very energetic light quanta, and impacts of such violence occur only at temperatures of 500,000 degrees or higher.

The cause of this remarkably high temperature of the corona is unknown. Some have suggested that it may indicate the ejection of relatively small quantities of gas from the extremely hot interior of the sun through unrecognized "cracks" in the photosphere. Or it may mean that powerful ultraviolet light escapes from the sun through small, undiscovered "pores" in the photosphere. Others have considered the possibility that the overheated atoms of the corona are fission fragments, the end products of nuclear reactions similar to those in an atomic bomb.

Sunspots

Under spectroscopic analysis, what seemed to be the "surface" of the sun has been shown to be a relatively thin layer of opaque gas, buried at the base of an ordinarily invisible envelope that extends, with ever greater tenuity, to a height of hundreds of thousands of miles. A sunspot on the photosphere is only one aspect of a disturbance which extends thousands of miles up through the chromosphere, and frequently tens of thousands of miles higher into the corona. And the spots themselves are only one manifestation of a re-



count for some of the lines are indicated above the spectrum. This strip is only a small part of the entire visible spectrum of the sun. On this scale the full length of the solar spectrum would extend more than 35 feet.

current phenomenon which profoundly affects all the parts of the sun accessible to observation.

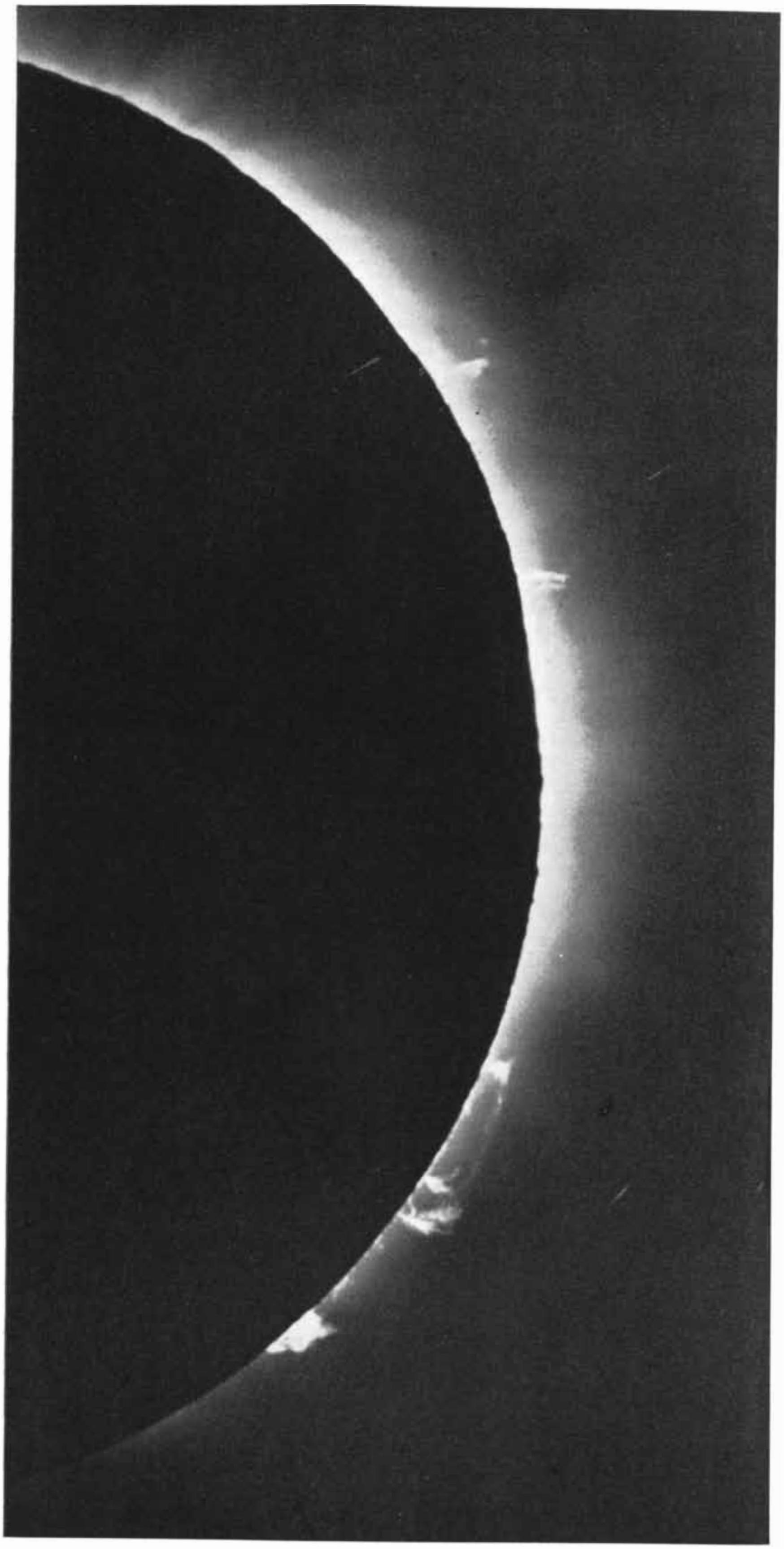
Stated concisely, the facts about the sunspots are these. In size, they range from specks less than 500 miles in diameter, barely resolvable through a telescope, to great, naked-eye objects more than 50,000 miles across. They look dark because they are 1,000 or 1,500 degrees cooler than the surrounding photospheric gases. They have a tendency to form in pairs, one lying nearly due east of the other; occasionally they form a complex group of many spots which blackens an area of several billion square miles. Small spots ordinarily endure for only a few days; large spot groups may persist for two or three months or even longer.

Chromospheric Clouds

The chromosphere above a sunspot usually exhibits clouds of ionized calcium and hydrogen which are hotter than the surrounding gas. These high, hot clouds commonly form before the spot itself can be seen on the photosphere, and they usually last longer than the spot. If exposed to the light of hydrogen a photograph of the chromosphere above a spot often shows a pronounced vortical pattern suggesting a great whirlpool, but the motions of the chromospheric gas are usually not rapid. In hydrogen light the chromospheric pattern around a pair of spots often closely resembles the lines of force around the poles of a horseshoe magnet as delineated by iron filings scattered on a card held above the poles.

Many absorption lines in the spectrum of a sunspot are found to be polarized and split into several components, an effect which is produced whenever absorbing atoms are subject to a strong magnetic field. By measuring the magnitude of the splitting and the direction of the polarization, it has been possible to find the strength and direction of the magnetic fields in the spots. The direction of the magnetic field near the center of the spot is generally straight up or straight down; its strength is sometimes as great as 4,000 gauss, or 8,000 times the maximum strength of the magnetic field at the surface of the earth.

Sunspots never occur within 45 degrees of either pole of the sun. Their numbers fluctuate with a period that averages 11.3 years, but the interval from one date of maximum spottedness to the next may be several years greater or smaller than this. At sunspot minimum, the few spots which appear are small ones far from the solar equator. As the number of spots gradually increases, the spots themselves grow larger and appear in lower solar latitudes. At sunspot maximum, most of the spots appear at latitudes 10 degrees north and south of the solar equator. Then as the spottedness decreases again, the spots approach nearer the equator; at minimum,



PROMINENCES above the photosphere are made visible by a total eclipse of the sun. Also visible is the luminous ring of the chromosphere. Some prominences hurtle through the solar atmosphere at speeds of hundreds of miles a second; others may remain as almost stationary heaps of gas for days.

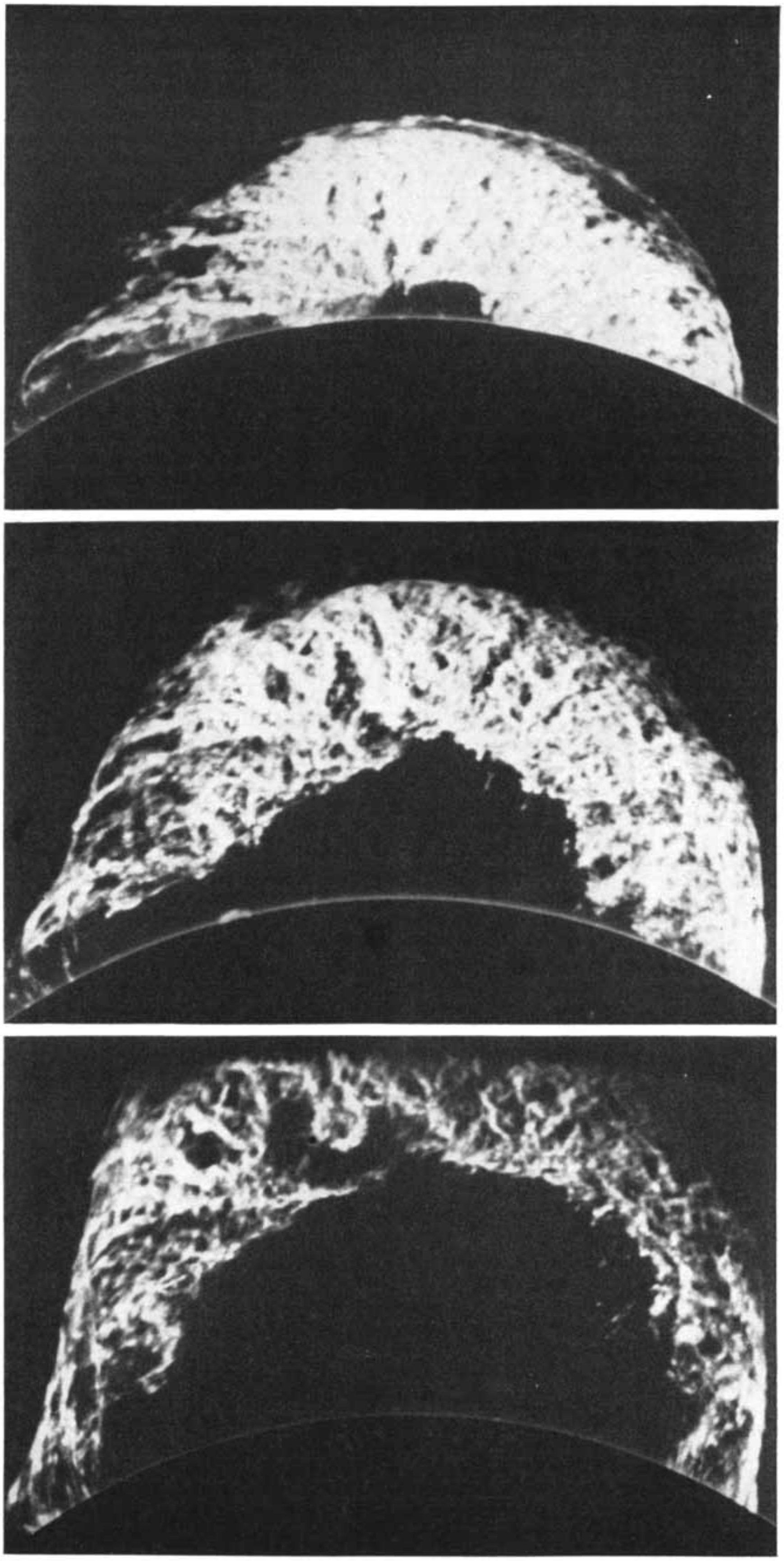
the last small spots of the old cycle lie very near the equator, while the first small spots of the new cycle begin to break out again in high solar latitudes. Throughout any one cycle, almost all pairs of spots in the northern hemisphere have their magnetic polarities paired as to direction; for example, in most northern hemisphere pairs, the easternmost spot will have north magnetic polarity; the westernmost, south. The arrangement of polarities will be just the opposite in southern hemisphere spot pairs. But in pairs of the next following spot cycle, the law of magnetic polarities will be reversed in both hemispheres.

When the solar rotation carries a sunspot to the limb, prominence activity can commonly be seen above the spot. Frequently material seems to "condense" out of the corona, where it is invisible in hydrogen light, and to descend into the spot in the form of brightening streamers.

Above other spots, clouds of rapidly changing form and structure appear. Often the cloud is fed by streamers curving in from the invisible corona and depleted by other curved streamers converging to a center of attraction in or near the spot. On occasion, the mysterious center of attraction appears to become too strong: great pieces of the high cloud may be torn off and drawn downward, and sometimes the whole prominence will suddenly rise several thousand miles upwards, then turn and plunge down into the center of attraction. Above groups of spots, archlike prominences will occasionally connect spots separated by some 25,000 miles, the gas usually ascending along one side of the arch and descending along the other. Solar flares, like the great eruption of July, 1946, generally occur over or near spots, and therefore are much more frequent near spot maximum. They may be related to certain kinds of unusually bright prominences, but they seem to occur at somewhat lower levels than the prominences. The prominences themselves are often not associated with spots or with any other detectable photospheric markings, but their numbers and distribution over the chromosphere change conspicuously with the sunspot cycle. Other characteristics of the chromosphere also vary with the number of spots.

Coronal Changes

Even the vast corona changes its shape and structure with the same rhythm. At sunspot maximum, the outline of the corona is nearly circular. In the inner corona, within 100,000 miles of the photosphere, however, archlike structures appear; the light from these frequently shows unusually bright emission lines. No motion has been detected in such coronal features, but within them there are often prominences and, below them, sunspots. At sunspot minimum, the corona changes its over-all shape, expanding near the solar equator and contracting near the



EXPLOSIVE PROMINENCE of June 4, 1946, was photographed by coronagraph at Climax, Colo. The time elapsed between the photograph at the top and the one at the bottom is 48 minutes. The sun's disk, artificially blacked out by the coronagraph, is arc that appears at the botton of each picture.

poles. A number of short, curved rays appear—reminiscent, again, of magnetic lines of force.

The resemblance is probably more than a coincidence. In 1913 the distinguished American astronomer George Ellery Hale first studied the polarization of the absorption lines in the spectrum of undisturbed regions of the solar disk. He concluded that the sun has a general magnetic field similar to that of the earth, but about a hundred times stronger. Like the much weaker magnetic field of the earth, the field of the sun has an unknown origin. Recently the suggestion has been made that a magnetic field is a fundamental attribute of every large, rotating body, and a simple formula has been discovered which seems to relate the magnetic fields of the earth, the sun and a star to the amount of their respective spins. But the full truth about the magnetic fields of astronomical bodies is not likely to be known in the near future.

Solar Magnetic Effects

There can be no doubt that the magnetic field of the earth is subtly linked to the sun itself. At any point on the earth, small changes in both the strength and the direction of the magnetic force occur almost continuously, but they tend to be much greater at sunspot maximum than at minimum. Isolated magnetic disturbances of moderate intensity show a strong tendency to recur at intervals of 27 days, which is just the apparent rotation period of the spot zones on the sun. Great magnetic storms such as the one of July, 1946, most often occur when a large, active sunspot is near the center of the solar disk. Sunspots covering a total area of more than three and a half billion square miles were photographed near the center of the disk on January 24, 1926; on January 18, 1938; on February 5, 1946; and on July 27, 1946. Within four days of each of these dates, great magnetic storms were observed on the earth.

But the connection between sunspots and magnetic storms is not as simple and direct as these observations might lead one to suppose. As a matter of fact, on three other occasions when sunspots as large as those just mentioned appeared, there were only small magnetic storms, and the biggest sunspot ever recorded—one of over six billion square miles in April, 1947—produced no magnetic storm at all. Moreover, magnetic storms sometimes occur when no spots, or only a few small ones, can be seen on the sun. Further, there seems to be no very close correlation between the times when the seven giant spots that did cause storms were nearest the center of the disk—"pointed" most directly toward the earth—and the times when the storms began. In one case, the magnetic storm began more than four days before the corresponding spot reached the center line of the disk; in another case, the storm was delayed until four days after the spot had crossed the center line.

Perhaps great magnetic storms are produced on the earth only when one or more brilliant flares occur in the chromosphere. Such flares were observed in each of the four largest spots that have caused great magnetic storms, and in none of the four other spots of comparable size that produced only small storms or none at all. Moreover, each of the four flares was followed by a magnetic storm very nearly one day after the flare was observed.

Since magnetism and electricity are closely related, we are naturally led to suspect that electrified particles are somehow ejected from the region of a sunspot during a flare, and that their impact against the earth one day later is responsible for the magnetic storms. To complete the 93 million-mile trip to the earth in one day, these particles must travel with an average speed of about 1,000 miles a second. The bright aurora that so frequently accompanies a magnetic storm is good evidence that the air at heights of 50 to 100 miles is indeed bombarded by energetic particles expelled from the sun.

But the earth need not wait a full day before it feels the effects of one of these furious eruptions on the sun. We have already seen that short-wave radio transmission blacks out at the moment the flare is observed. This implies that something is able to keep pace with the light from the flare as it races across the 93 million miles from sun to earth in just over eight minutes. That "something" can only be some other kind of light, for nothing else can move so fast. A sudden fierce blast of ultraviolet light upon the upper air would, indeed, put a temporary stop to short-wave radio propagation. Radio waves, it is well known, do not travel directly from a transmitter to a distant receiver; they strike the electrified layers of the upper atmosphere (the ionosphere), are reflected back to the earth and in this way are enabled to travel around the earth's curvature. When a shower of powerful ultraviolet radiation strikes the upper air, however, so many molecules are ionized that this region of the atmosphere becomes a great electrical blotter, soaking up and absorbing the radio waves from below instead of reflecting them back to earth.

Absorbed Ultraviolet

So efficiently does the air above us absorb these energetic ultraviolet rays from the sun that virtually none reaches the ground. This shielding action of the atmosphere is probably beneficent to the health of men, but it prevents astronomers from observing directly just those parts of the sunlight that have the greatest effect upon the atmosphere. Judging from the electrical condition of the upper air, and from the spectrum of the sky at twilight, there is good reason to believe that the sun usually radiates far more ultraviolet light than can come from the photosphere, with its relatively low temperature of about 6,000 degrees. These suspicions about the ultraviolet part of the solar spectrum may soon be verified by photographs taken from V-2 rockets at altitudes of 100 miles or so above sea level.

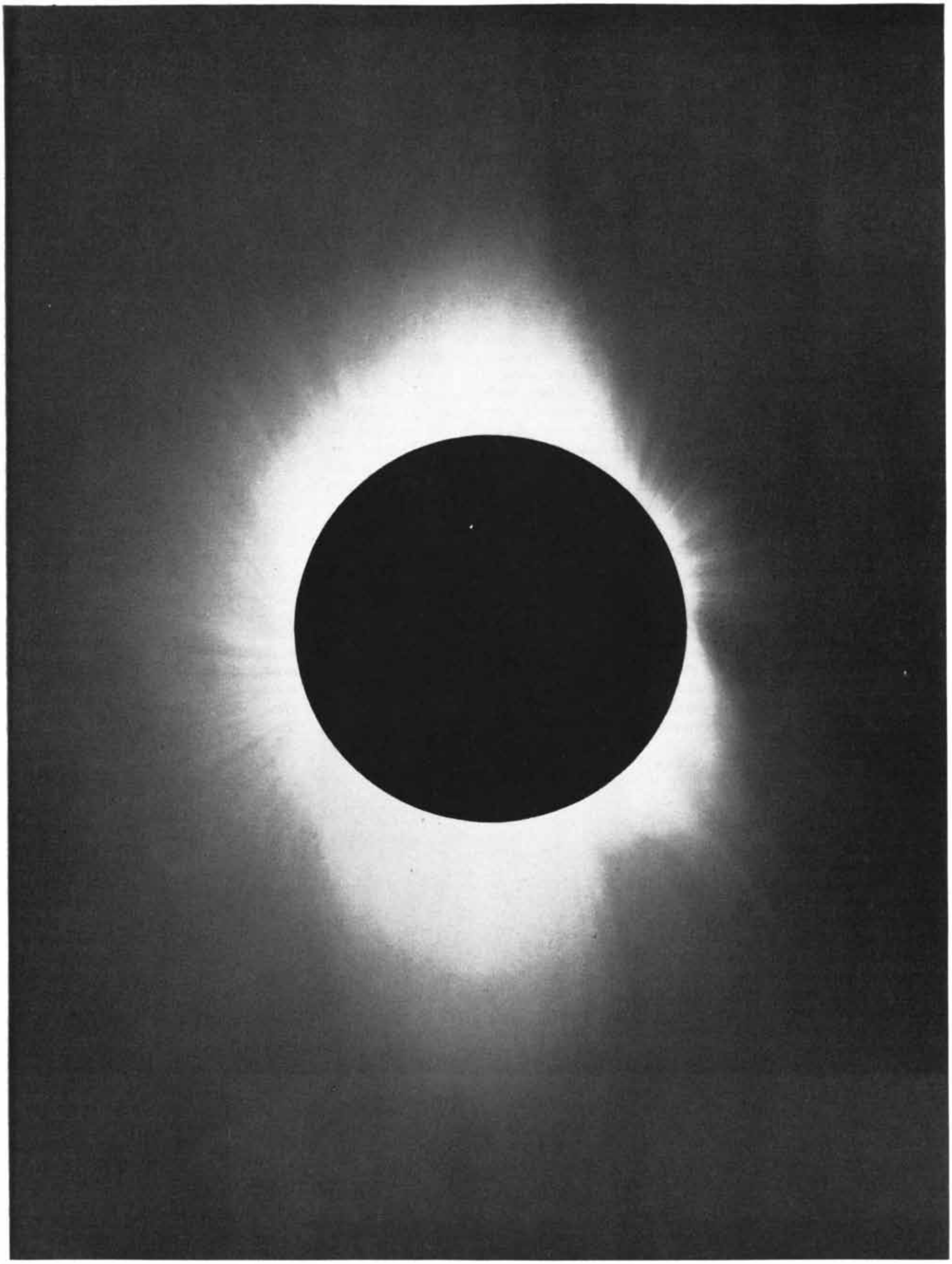
Solar Radio Waves

Not only does the sun govern the propagation of radio waves generated on the earth; it also broadcasts its own radio waves to the earth! This fact becomes a little less startling when we recall that radio and light are both electromagnetic waves. The essential difference between them is just one of wavelength; even a very short radio wave is some 10 million times longer than a wave of visible light. Exploration of the radio spectrum of the sun has begun only within the past few years, but already some surprising results have been achieved. Thus, while the sun seems to radiate on some wavelengths at just the rate to be expected from a photospheric temperature of nearly 6,000 degrees, on other wavelengths it transmits at a power much too high for this temperature. At least some of the excess transmission often comes from the regions around large, active sunspots. In the 5-meter band, for example, radio energy sometimes pours out of a sunspot as though the temperature at the "transmitter" were over a billion degrees!

Perhaps we shall not be able to understand all this tremendous activity throughout the observable parts of the sun until we can give the answer to Herschel's question: "But what *are* the spots?" Today we can give only an incomplete answer. Some astronomers liken the spots to cyclones in the terrestrial atmosphere, and the flares to tornadoes. There is a general tendency to associate the intense magnetic fields of the spots with vortical motion. Since the gas is highly ionized, rotational motion may produce strong electric currents, and these, in turn, may be responsible for the magnetic fields. Recently it has been suggested that flares are comparable to electric discharges: that the changes in the magnetic field of a spot induce currents of electrons in the chromosphere.

There can be little doubt that much of this intense, semi-periodic activity in and above the photosphere is caused by some deep-seated disturbance within the hidden bulk of the sun. For a full understanding of what we see on the sun, we shall probably have to gain a fuller knowledge of what we cannot see—the intensely hot interior, where the atomic fires burn. The task will not be easy. The face of the sun is not without expression, but it tells us precious little of what is in its heart.

Armin J. Deutsch is instructor of astronomy at Harvard University.



SOLAR CORONA, like the prominences on page 36, is made visible when the moon passes in front of the sun. The fine rays in the corona may be effect of the sun's magnetic field. The shape of the corona varies with the 11.3-year cycle of sunspot activity. The principal astrophysical interest of the corona is that it appears to be much hotter than the surface of the sun. This photograph was made by Lick Observatory during an eclipse in 1932.

EROSION BY RAINDROP

The impact of an individual drop on the soil does surprising damage. Multiplied by the billions, it is one of the major problems of soil conservation

by W. D. Ellison

MOST of us have observed the small but violent phenomenon of raindrops splashing on a pavement. On a dark, rainy night, in the beam of a car's headlights the splashes rise like miniature sparkling fountains. On bare earth we see no splashes, yet obviously raindrops must shatter and rebound there too; the difference is that the small splashes, charged with soil particles, are muddy, and more intensive lighting is needed to make them visible.

The displacement of soil by the splash of raindrops is of course a form of erosion, but there has seemed little reason to take it seriously, and until recently no one did. It is not until one makes experimental tests and finds that the impact of raindrops in a violent storm may blast more than 100 tons of soil per acre into the air, and then examines closely what becomes of the blasted soil, that raindrop erosion begins to look like something more than a trifling affair.

The old saying that what you don't know can't hurt you does not apply to splash erosion. We have not known much about this process, but we are learning that it has been hurting us a great deal. Water erosion has generally been thought of solely as the washing of soil by flowing water. We know now that on some soils and terrain, wash-off losses actually account for less than 10 per cent of the erosional damage from a heavy rain; the other 90-odd per cent of loss is attributable primarily to raindrop splashes.

It was while examining an eroded area in my garden that I first noticed the effect of raindrops. I discovered many tiny columns of soil, each capped by a fragment of rock. Each of the odd-shaped columns or pedestals conformed in cross section to the shape of the stone cap protecting it. It was evident that the cap-rock had protected the soil beneath it from raindrops, while the soil around the rock had been splashed away and transported downhill. This theory was consistent with a previous observation: that erosional damage to a field was usually in direct proportion to the intensity of the noise made by raindrops striking on the roof.

The first step in testing the splash theory was to determine whether raindrop splashes could carry significant amounts of soil. I held a small card about an inch from the ground while rain was falling. This soon became spattered with mud. Then I exposed pans of soil with metal disks on top. More than one inch of soil was splashed out during 75 minutes of heavy rainfall, and a soil pedestal was formed under each disk. The next step was to make these splashes visible so they could be photographed. This was accomplished with mirrors which directed light beams across the soil's surface. With a camera time-setting of 1/25 second, trajectories of the flying splashes were made to appear as short arcs of light in the printed photograph. The falling raindrops were visible as vertical shafts of light. Each splash was found to be made up of one or more particles of soil encased in a film of water. It was this water film that reflected the light. The splash described a parabolic curve, which indicated that its lateral movement was about four times its height of rise. Only a few stray splashes rise more than two feet; it appears that some 90 per cent of them may be found within one foot of the surface.

DROP STRIKES the wet soil, carrying tiny particles of it into the air.

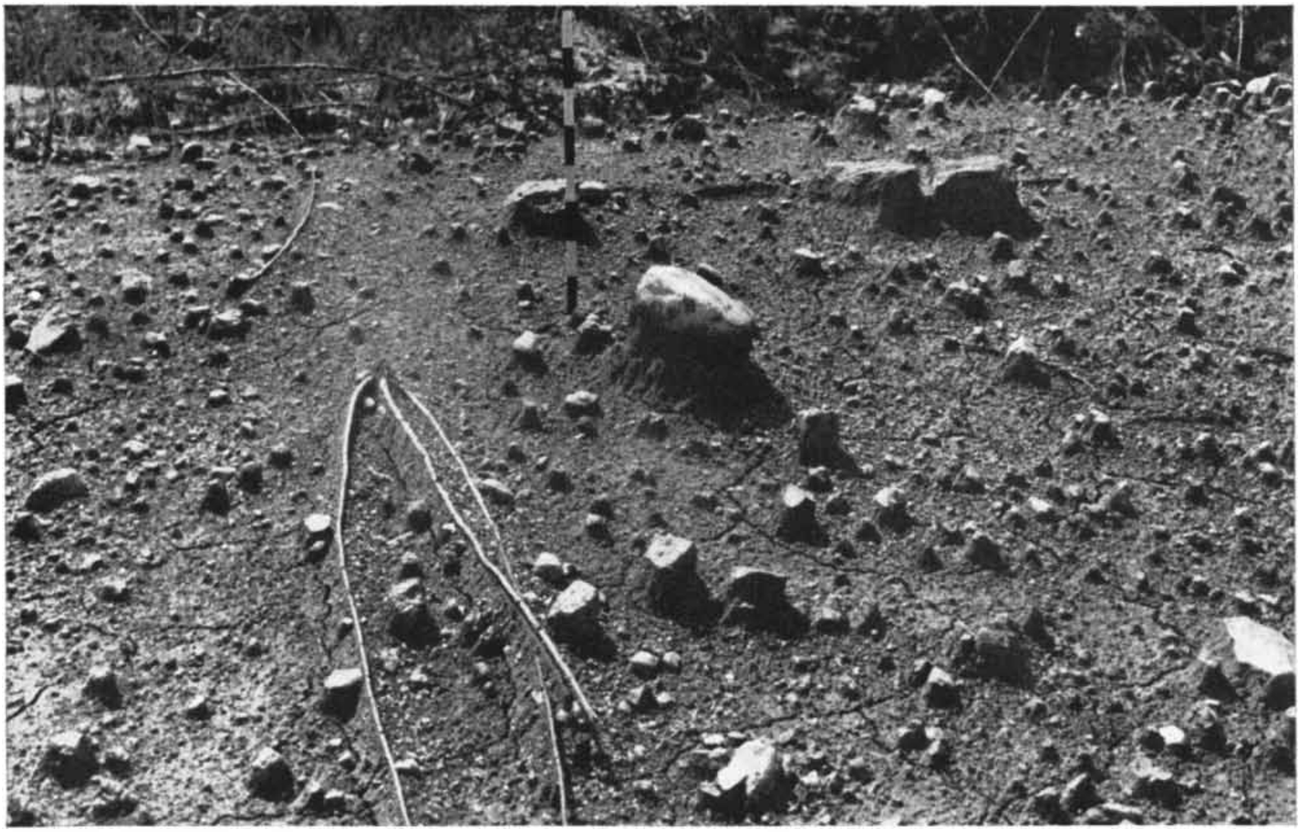
On level land the splashing particles of soil tend to bounce back and forth, so there is no net loss of soil from any point on the field. But on a slope the splashes move the soil downhill. Part of this movement is caused by the drops striking glancing blows which kick most of the particles towards the bottom of the slope. Another part will be caused by the fact that soil splashed in the downgrade direction travels farther in the air than that splashed uphill. Many tests have shown that on a 10 per cent slope the downhill movement is about three times the uphill.

Flowing water on sloping land produces erosion by forming gullies. Regardless of how smooth the surface may be, the washing process, known as scour erosion, always starts by grooving the soil. Scour erosion made the Grand Canyon and carved out our river systems. Gullies make the landscape rugged, so scour process is classed as a land-roughening process.

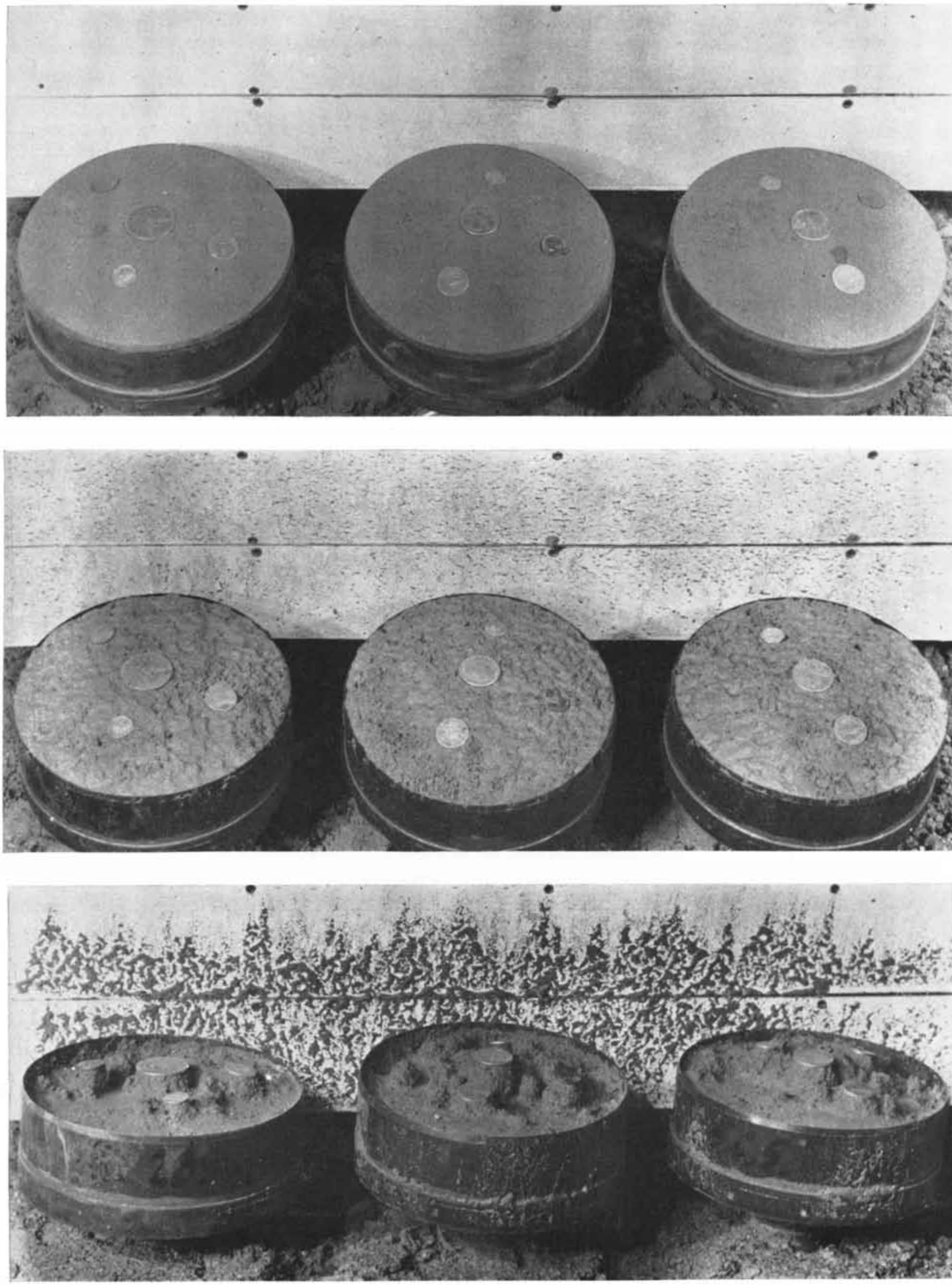
In contrast, splash erosion removes the sloping topsoil in sheets. It acts as a smoothing and leveling agent. These effects are demonstrated in miniature each time that beating raindrops flatten and level a small sand pile in the yard. It works in about the same way on a hill, bringing material down from the crest and depositing it low on the slope. After a great gully is carved by scour erosion, the splash process slopes the vertical side walls and converts the rough gully to a gently sloping valley. After a series of storms, topsoil scalped from the crest of a slope by raindrop splashes can be found piled lower on the hillside.

The splash process produces four different types of erosional damage: 1) piling and burying of topsoil; 2) surface sealing; 3) deterioration of the structure of the soil; and 4) the loss of crop nutrients by the process called elutriation. The piling and burying of topsoil is the result of the land-leveling process. Topsoil that is scalped from the crest of a slope slows in movement as it approaches the gentler slope near the bottom of the hill. This causes "telescoping" of the soil; that is, soil from high on the slope overtakes material in motion low on the hillside. The result is that the topsoil piles up in a bank near the bottom of the hill, and this

MULTIPLIED EFFECT of many raindrops is illustrated by this photograph. Falling from great height, drops strike the soil and shatter into many smaller drops. These describe a parabola as they arch upward.



CHARACTERISTIC RESULT of raindrop erosion is to splash away a whole layer of unprotected soil. Where the soil is shielded by a stone, a little pedestal remains. The rod at the top of this picture is marked in inches.



EXACT MEASUREMENT of the effect of raindrop erosion is made by putting three pans of soil under a laboratory rain-making machine. Coins are placed on the soil to mark its original level. Top picture shows dry soil. Middle picture was made after 45 seconds of rainfall. Bottom picture was made after one hour and 15 minutes.

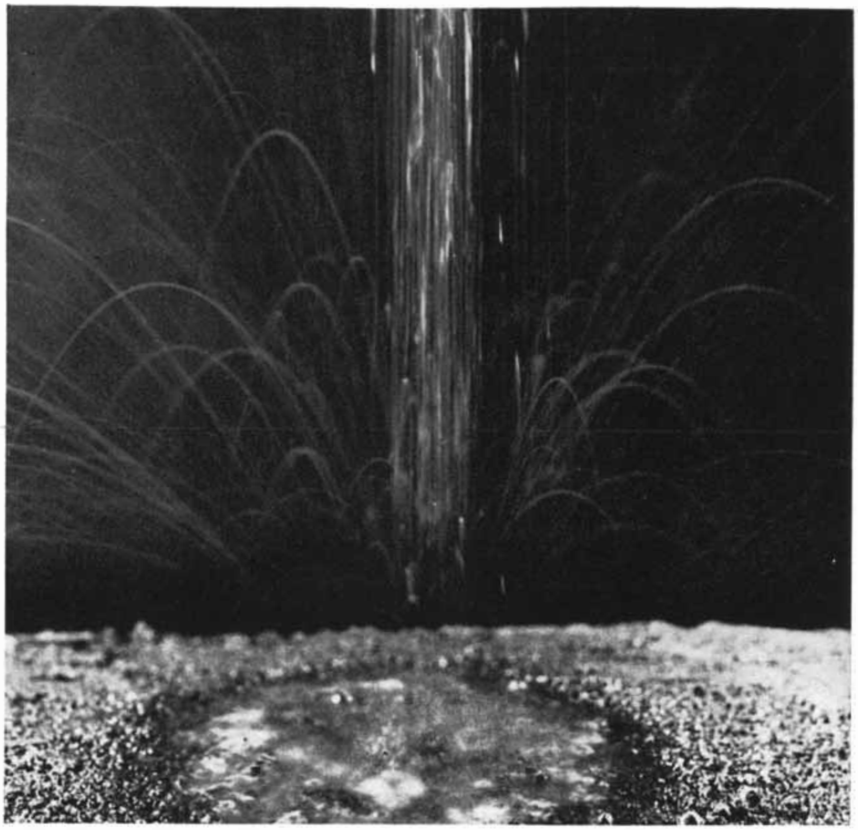
is later covered with subsoil brought down from near the hilltop.

These changes do not come from a single storm. They are long-time developments. The first striking evidence of the splash process is the appearance of "bald" crests high on the slopes. Farmers have been heard to say that during the month of August they can see a rabbit in a neighbor's cornfield a mile away so long as it stays near the crest of the hill. They used to embarrass conservation experts by asking why all the erosional damage seemed to be at the crests of slopes where there was very little surface flow; the answer, although the experts did not know it, is splash erosion.

Damage caused by the piling and burying of topsoil is usually many times more important agriculturally than are the tonnage losses that go down the rivers. Data on the amount of soil carried down the Mississippi can be cited in support of this conclusion. The National Encyclopedia, 1935, states that approximately 400 million tons are carried down the great river annually. Expressed in terms of watershed units—and it must be expressed in those terms to determine its significance—this loss amounts to only about one inch of soil removed from the surface of the entire watershed every 300 to 400 years. That amount is not too important agriculturally. Of course, we do not want to lose this soil if we can prevent it. But its loss does not represent the real erosion problem. A loss of one inch of soil every 300 years probably represents something less than 10 per cent of the important damages to a soil by erosion.

SURFACE sealing, the second soil damage on our list, is caused by raindrop splashes puddling the soil and making it practically impervious to water. This point has been proved by experiments. For example, in a field where the soil splash was one ton per acre, the surface sealing was light; the water intake capacity of the soil was 8.5 inches of depth of water per hour. But in a field of the same soil type which had a splash of 33 tons per acre, there was considerable surface sealing and the infiltration capacity dropped from 8.5 inches to 0.96 inch of water per hour.

We have not been accustomed to thinking of surface sealing as an erosional damage. It does not occur where surface soils are made stable against the action of water. But where it does occur there is a host of ill effects associated with it. For one thing, it makes the soil droughty. Droughtiness and the high temperatures associated with it destroy worm life in the soil and curtail a field's productive capacity. For another thing, surface sealing tends to increase flash runoff, and this increases flood hazards. Surface sealing also interferes with aeration of the soil and with the emergence of seedling plants



VERTICAL IMPACT of raindrops does not shift the position of the soil, although it does cause other kinds of damage described in the text of this article. Soil that is lifted into the air is replaced by the effect of nearby drops.

IMPACT AT AN ANGLE can move large quantities of soil downhill. This scalps topsoil from the crest and concentrates it at the bottom of the slope. Later the good soil may be buried by subsoil splashed down from above.

OVERGRAZING of hilly range land leads to splash erosion. Here sparse grass has offered so little protection against raindrops that organic matter has been splashed downhill, leaving soil too poor to support new growth.

ELUTRIATION is a process that robs soil of clay and organic matter. Here camera is pointed upward from shallow depression. White strips between these rows is not water but sand that has been splashed clean by raindrops.

from the seedbed. Effective control of splash erosion could reduce the surface sealing caused by rainstorms by 70 to 90 per cent.

Over a period of years, after surface sealing has been repeated many times, the structure of the soil declines. This occurs when tiny aggregates of soil on the surface are broken up, and when the pores in the soil of the plow sole (the compacted layer of earth at the bottom of the furrow) are plugged. The plugging can be caused by the intake of water that is charged with colloidal and other fine clay fractions. As this material filters through the soil layers it is deposited in the pores. Deposits near the surface may have only a temporary effect, but those in the plow sole produce more lasting results. By retarding the percolation of water into the deeper layers of soil they increase the runoff during wet seasons.

THE STRUCTURE of a soil changes with each change in the tiny soil aggregates. It seems probable that our failure to understand splash erosion has caused us to develop misconceptions about problems of soil aggregation and structure. Organically bound soil aggregates are developed through natural processes as organic matter is decomposed in mineral soils. They are destroyed in many ways. Principal among these seem to be the depletion of organic matter and the direct breakdown of the aggregates by physical forces. The splash erosion process is one of the chief agents affecting both of these: the raindrop impacts break down many aggregates and this releases organic matter that was bound in the aggregates, permitting the organic material to be floated from the field.

It is through aggregate breakdown that many field soils are made highly transportable. Consider, for example, a single aggregate made up of many thousand clay particles, several hundred silt fractions and half a dozen sand grains. In addition there may be some humus and some fragments of plant residues. So long as these materials remain bound together in a stable aggregate they are not easily washed away. But as soon as the splash process breaks up the aggregate, the clay and the organic matter become highly transportable and may be floated away in continuous suspension. The silt fractions, which are less transportable, may be dragged and rolled along by intermittent stages, with their movements being speeded each time a raindrop agitates the water that is in contact with them. The sand grains are the least transportable, and if the field slopes are gentle there may be no appreciable net loss of sand. Over a period of years everything but the sand will be carried away.

This process, called elutriation, can be very destructive in sandy soils, though it is of less importance on loams and clays. Uncontrolled elutriation on gently sloping, sandy land, besides rendering the soil deficient in crop nutrients, organic matter and clay, also destroys its water-holding capacity. Some agricultural soils in this country which once were fertile have been elutriated to such an extent that they now resemble the sands of a beach.

WHAT can be done about it? There is only one way to control splash erosion, and that is by protecting the soil against the impact of raindrops. As one man remarked after hearing an account of the phenomenon: "Agriculture needs a new umbrella." There is no better way of putting it. The greatest opportunities in soil and water conservation lie in developing the umbrella. It must be a special kind of umbrella which de-energizes the falling raindrops, reducing their impact on the soil. Such an umbrella can be provided by making fuller use of growing crops and better use of crop residues and mulches. Terracing and contouring practices that are effective in reducing scour erosion are at best only palliatives in checking splash erosion. They do not protect the soil against the impact of raindrops. This does not mean that we should do less terracing and contouring. Quite the contrary. we probably should employ these practices more than we do at present. I believe. however, that we have a much greater need for a well-developed cover program that will check the splash of soil. Stubble mulching, the method of tillage which leaves crop residues on top of the soil, is an excellent means of protecting the surface against splashing. The development of faster-growing plants also would provide more effective canopies for our cropped fields.

How much cover does it take to protect the soil against raindrops? The answer depends on the type and condition of soil. Here are the results from a piece of range land. On a section covered with 650 pounds of forage and litter per acre. the soil splash was 28 tons per acre. On the same soil, but with 4.300 pounds of forage and litter per acre. the soil splash was only one ton per acre. The amount of cover needed depends on the extent of each type of damage that may be caused by rain splashes on the particular soil involved.

The differences in erosion caused by splashing raindrops and by flowing surface water have not been well understood. A full knowledge of these differences is fundamental to an understanding of erosion problems. Studies made since the discovery of splash erosion have indicated that soil splash launches a chain of damaging processes. and that these can be prevented only by checking the falling raindrops before they strike the soil.

W. D. Ellison is a soil conservationist with the U.S. Navy and the discoverer of raindrop erosion.

PROTECTION against raindrop erosion is given by leafy plants. These absorb impact of the drops and allow water to trickle down to the soil. Leaving crop residues on the ground also offers protection against effect of drops.

BACTERIA UNDER ATTACK by a swarm of bacterial viruses are shown by the electron microscope. The viruses, which are of the strain T4 described in this article, attach themselves to bacteria and sometimes push inside them. There the viruses reproduce until the bacterium bursts, liberating an entire new generation of viruses.

BACTERIAL VIRUSES AND SEX

Some fascinating experiments have demonstrated that the tiny organisms which prey on bacteria employ a primitive kind of sexual reproduction

by Max and Mary Bruce Delbrück

TWO YEARS AGO, at a summer symposium in Cold Spring Harbor, N. Y., experiments were presented which showed that bacteria, and even some viruses that live on bacteria, apparently have a method of sexual reproduction. This finding was a considerable surprise. Up to that time it had been generally supposed that the simple one-celled bacteria had no sex and that they multiplied simply by splitting in two; the method of reproduction of the still more rudimentary bacterial viruses was entirely unknown. The simplest organisms previously known to have a sexual mode of reproduction were the molds, yeasts and paramecia. Indeed, the recognition of sex even in those organisms was less than 20 years old.

Sex was once thought to be the exclusive possession of life's higher forms. Yet as biologists have looked more carefully down the line, simpler and simpler forms have been found to be possessed of it. Now, among the viruses, we are searching for it at the lowest known level of life.

Since the Cold Spring Harbor symposium, this research has been pushed further, and some rather remarkable facts have been uncovered. This article will discuss a group of the viruses which are parasites of bacteria, and particularly will go into what has been learned recently concerning their reproduction.

Sexual reproduction is the coming together and exchanging of character factors of two parents in the making of a new individual. Aside from its other aspects, sex has a special interest for biologists as a highly useful and indeed almost necessary device for an organism to survive in the competitive evolutionary scheme of life. Plant and animal species, to avoid extinction in the changing environments of geologic time, evolve by utilizing mutations (changes in the basic hereditary material) which enable them better to adapt themselves to their environment. These mutations turn up spontaneously and spread through the population by the convenient means of sexual reproduction.

Mutations are assorted and combined anew in every generation. Thus species that reproduce sexually always have in store a vast array of new types, some of which may be adapted to a changed environment and can become the parents of the next link in the evolutionary chain. This is the evolutionary advantage of sex.

It is logical, therefore, to look for sex in every known form of life. It was with great caution, however, that the discovery of sex in the simplest organisms was reported two years ago. E. L. Tatum and J. Lederberg of Yale University told of experiments in which they had found bacteria which seemed to combine certain traits of two parental strains that had been mixed. Similar findings with respect to the viruses that attack bacteria were reported by A. D. Hershey of Washington University, and by W. T. Bailey, Jr. and M. Delbrück at Vanderbilt University.

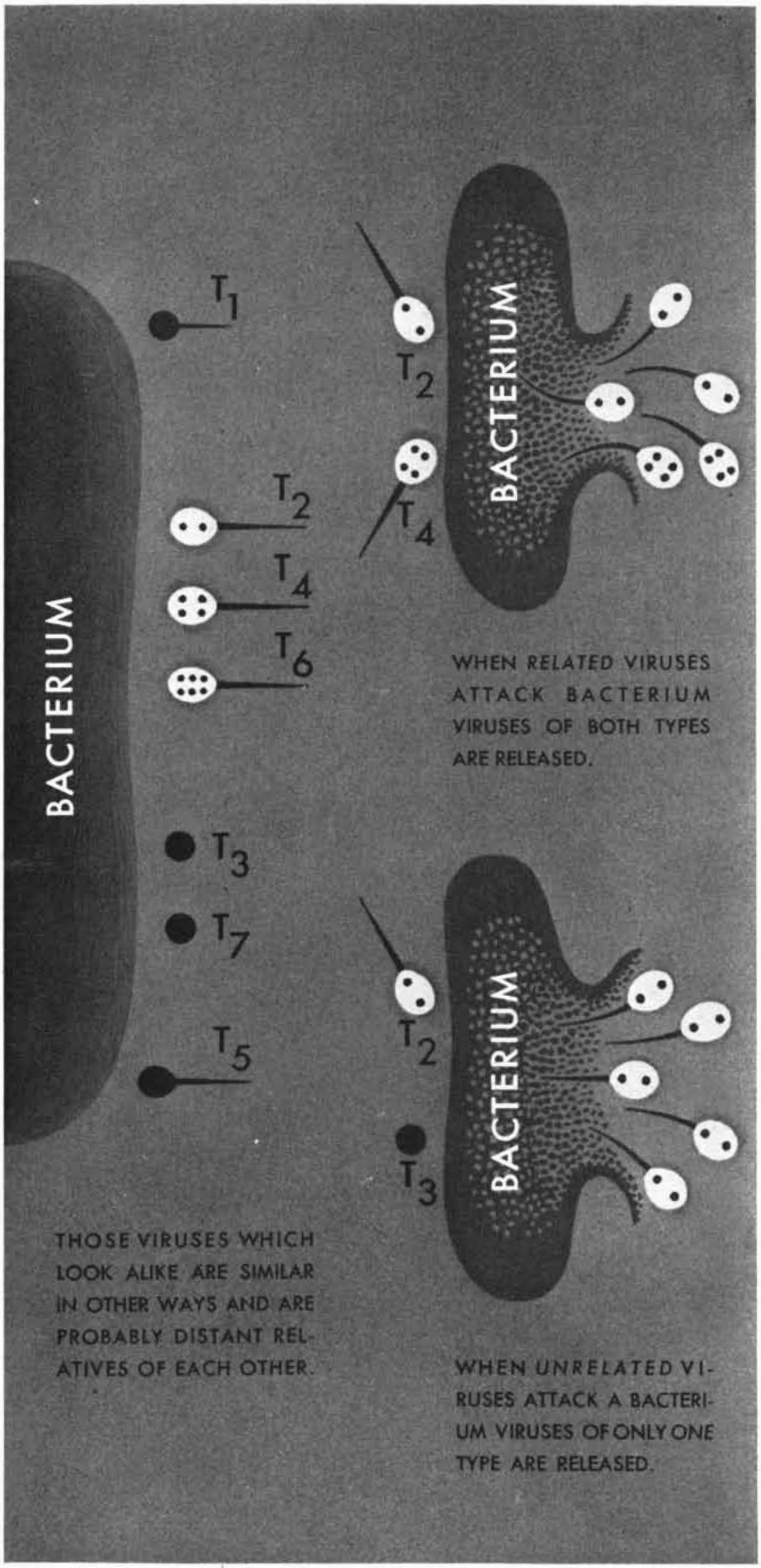
VIRUS T4, shadowed with gold to make a specimen for the electron microscope, has shape of a tadpole.

The bacterial virus is a very small organism which enters a bacterium, reproduces itself and eventually destroys its host. From the latter a generation of new viruses then emerges. The virus thus "infects" a bacterium, even as plant and animal viruses infect plants and animals. Bacterial viruses were first discovered 30 years ago by the French bacteriologist F. D'Herelle, who noticed that the bacteria growing in some of his test tubes mysteriously dissolved. After experimentation D'Herelle concluded that their dissolution was due to some agent much smaller than a bacterium, and that this agent grew at the expense of bacteria. He called the agents that had destroyed the bacteria "bacteriophages" (bacteria-eaters); the same organisms are now often called bacterial viruses.

For many years thereafter bacteriologists and medical men were sure that bacterial viruses existed. The viruses were even measured, isolated and grouped, although they were never actually seen. Bacterial viruses are too small to be seen under the most powerful microscope of the conventional type; they have been made visible only recently by new types of microscopes.

D'Herelle's discovery raised the great expectation that bacterial viruses might be used as "agents of infectious health" to destroy the bacteria that caused human and animal diseases. It was the hope of early research workers that a population infected by a bacterial epidemic could be cured by infecting it with the virus inimical to that bacterium. Their hope has not been realized, but the bacterial viruses remain a subject of keen interest—for good and sufficient reasons.

Viruses seem to lie on that uncertain and perhaps unreal borderline between life and non-life. The uncertainty about this boundary line is both very old and very new. In ancient times all nature was supposed to be animate. Spirits dwelt in stones as well as in animals, and as recently as a few centuries ago the spontaneous generation of complex living organisms from mud was a matter of universal belief. The advance of the scientific method has taught us that there is an enormous difference between the living and



EXPERIMENTAL ORGANISMS of the research discussed in this article are seven bacterial viruses that attack the same species of bacterium.

inorganic worlds. During the development of classical biology in the 19th century. there arose two great generalizations: 1) the theory of evolution. and 2) the cell theory. The theory of evolution proclaims the relatedness of all living things; the cell theory sets forth a universal principle of construction for them. Both of these generalizations unified biology and distinguished it from the study of the inorganic world.

In our generation, however, the pendulum has begun to swing the other way. The great refinement of scientific technique has pushed the limit of observation beyond the point where it had stood for about 100 years. namely, at the resolving power of the light microscope. With this advance has come the recognition of the existence of many things below cellular size which do not fit into the established categories of life or non-life. Of these the viruses have become the most controversial. To learn all we can about them becomes. then. even more intriguing than the original idea that bacterial viruses might be useful in medicine.

Bacteria-eating viruses are common. and where bacteria exist in the natural state, viruses capable of destroying them almost always can be found. Outside of the bacterium, the virus seems dead. But it does not die; it lies quiescent and functionless until a bacterium presents itself. The virus then attaches itself firmly to the bacterium. Many viruses may cling to a single bacterium. but only one needs to enter the cell to begin a cycle of viral reproduction. Once within the host. the virus quickly comes to life and multiplies prodigiously. How it grows from the one or more particles that are known to enter the cell to the several hundred that burst from the suddenly ruptured host is a secret still closely guarded within the walls of the bacterium.

The guinea pigs of bacterial virus genetics have been seven different viruses which all attack the same bacterium. Some of these viruses. which we shall speak of as T1. T2 and so forth. are surprisingly complex in form and behavior.

The viruses that were first made visible by the electron microscope in 1941 were revealed to be spermlike forms. Some were seen lying free. others were clinging to the exterior of a bacterium. Other pictures revealed the bacterium with new viruses streaming from a hole ripped in its cell wall.

The seven viruses do not all look alike. In appearance they fall into four categories. The members of one family, consisting of T2, T4 and T6. look like tadpoles. with dark forms visible within their bodies. T5 has a round, solid body and a tail. T1 is similar to T5, but smaller. T3 and T7 are the smallest, with spherical bodies and no visible tail.

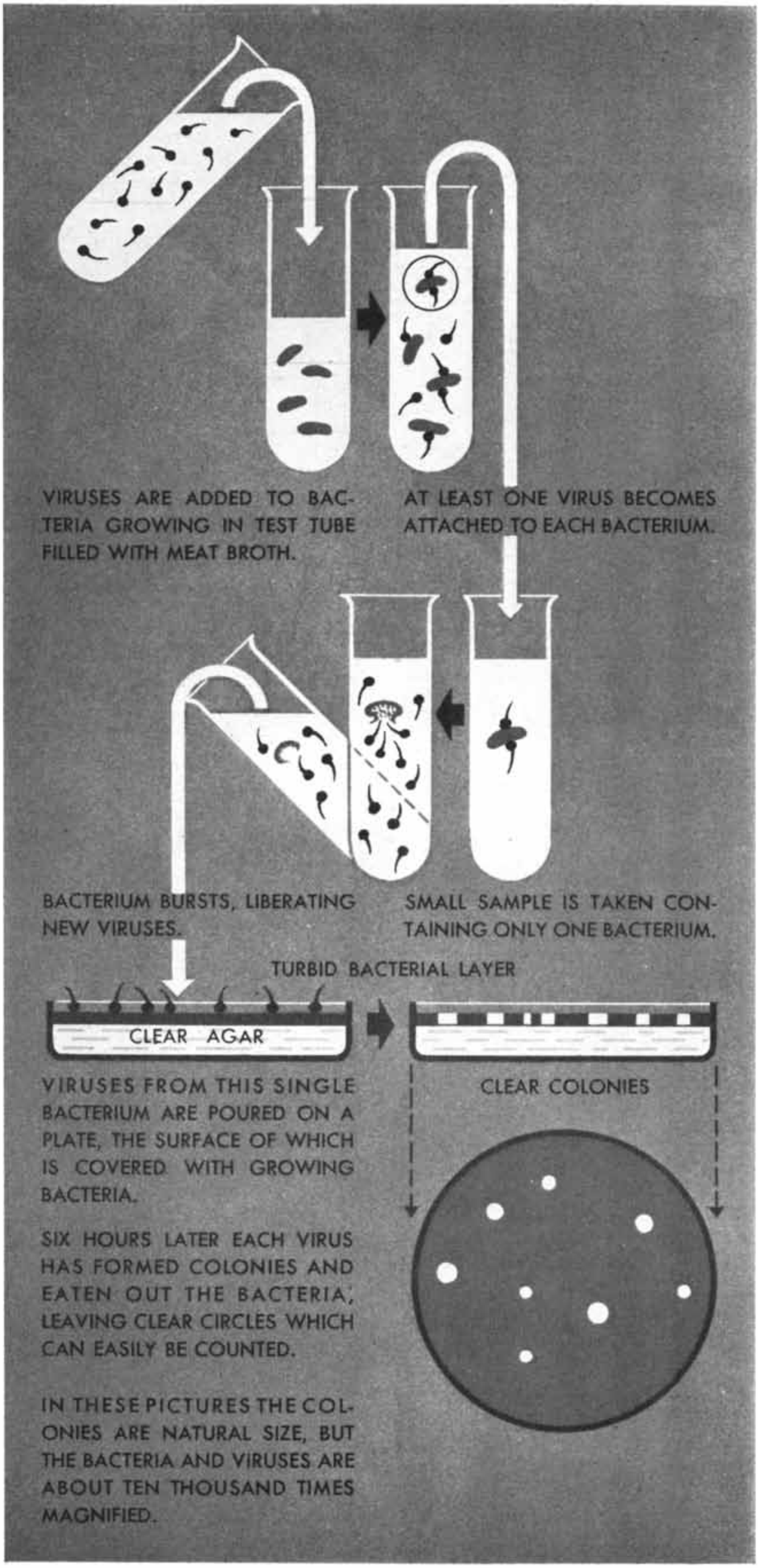
The viruses which look alike are related in several other respects, and the way they behave as a family is illustrated by a very curious phenomenon. When two viruses which are not related happen to attach themselves to the same bacterium, one successfully enters the bacterium and multiplies, but the other perishes without leaving any offspring. If the two viruses seeking the same bacterial home are related, however, both enter and reproduce. This rule has certain exceptions and certain special modifications, depending on the degree of relatedness between the contending viruses; as among human beings, the restriction of real estate among the viruses has subtle points.

One might wonder how the biologist can learn anything about the behavior of organisms so small that he generally cannot see them. The answer is that bacterial viruses make themselves known by the bacteria they destroy, as a small boy announces his presence when a piece of cake disappears. Much of what we know about the viruses is based on the following experiment, which requires only modest equipment and can be completed in less than a day.

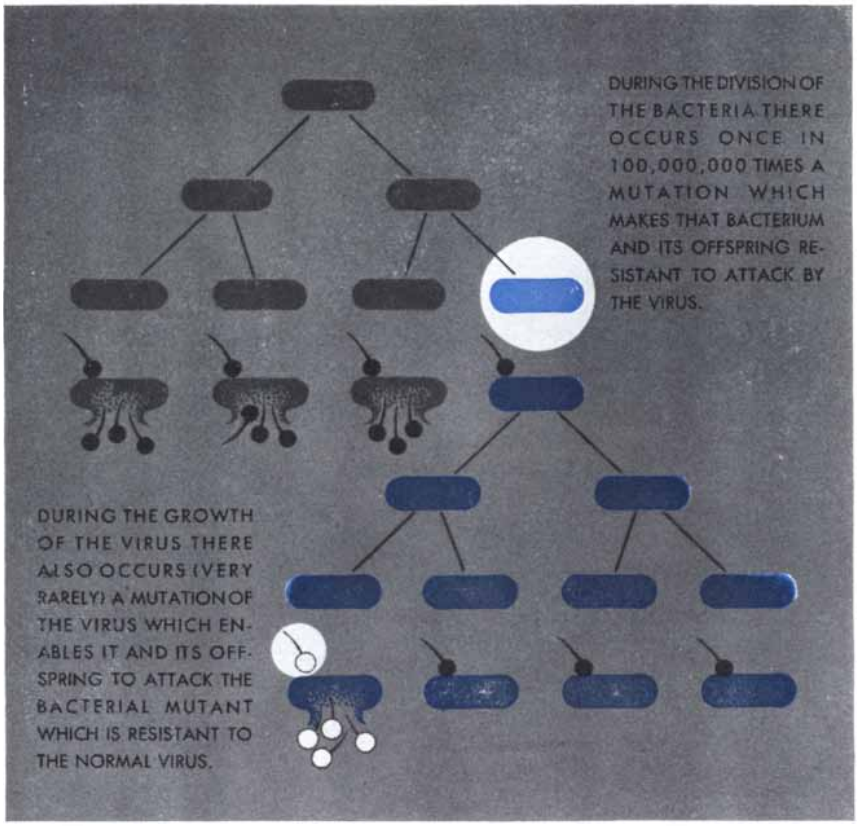
Bacteria first are grown in a test tube of liquid meat broth. Enough viruses of one type are added to the test tube so that at least one virus is attached to each bacterium. After a certain period (between 13 and 40 minutes, depending on the virus, but strictly on the dot for any particular type), the bacterium bursts, liberating large numbers of viruses. At the moment when the bacteria are destroyed, the test tube, which was cloudy while the bacteria were growing, becomes limpid. Observed under the microscope, the bacteria suddenly fade out.

Before the bacteria burst, however, part of the liquid is taken from the test tube and diluted. From this diluted liquid the experimenter takes a small sample expected to contain only a single infected bacterium. When this bacterium has liberated its several hundred viruses into a liquid medium in a test tube, the liquid is poured on a plate covered with a layer of live bacteria. Each virus deposited on the plate will start attacking the bacterium on which it rests. Each of the offspring of the virus, in turn, will attack the nearest bacterium. Successive generations of offspring from the one original virus will spread out in a circle, attacking bacteria until after a few hours a small round clearing becomes visible to the naked eye. The number of such clearings, or "colonies," formed on the plate is a count, therefore, of the number of viruses liberated by the original infected bacterium.

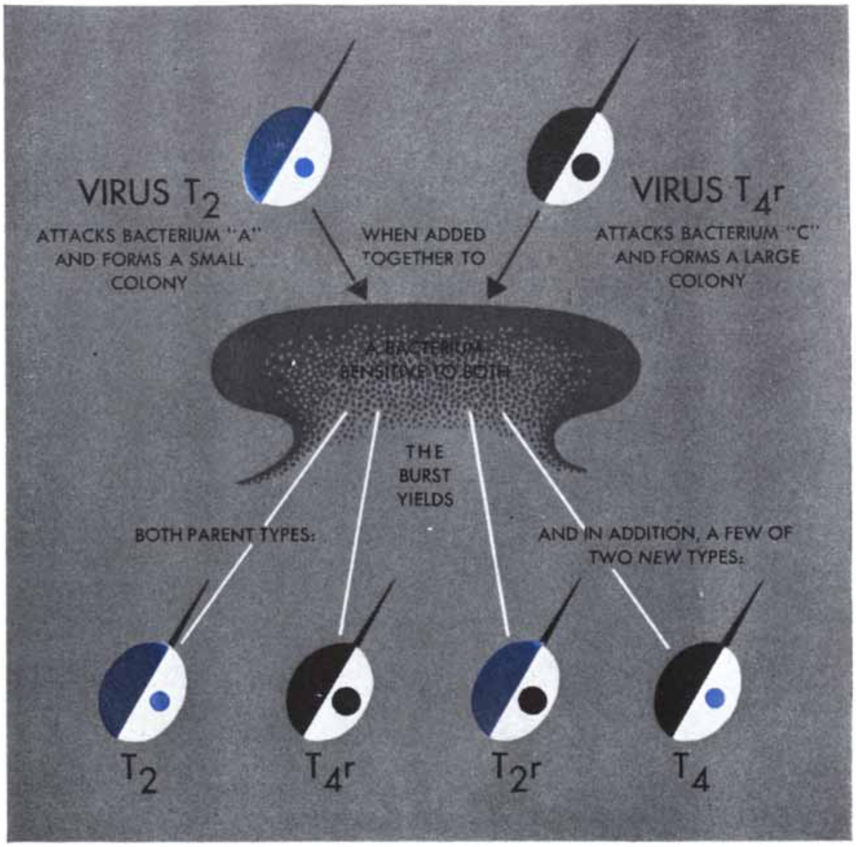
The union of the virus and its bacterium takes place under rather complicated and specific conditions which are not well understood. Of the life of the virus inside the bacterial host, still less can be divined. Does the virus multiply by one individual producing another, by simple splitting, or by some other process? What specific elements of nutrition are necessary for virus



EXPERIMENTAL TECHNIQUE that is used in bacterial virus research is outlined in this drawing. The equipment required is remarkably simple.



MUTATION is the mechanism that enables bacteria and viruses and all other living things to adapt themselves to changing environmental conditions.



EXCHANGE of virus characteristics is form of sexual reproduction. Here characteristics are type of bacterium attacked and the size of the colony.

reproduction? Is it possible to break open the cell before it would normally burst and from the contents at this intermediate stage learn something of the process of multiplication? What causes the violent disruption and dissolution of a bacterium?

Although we cannot fully answer these questions. it has nevertheless been possible to wrest some remarkable secrets from the viruses. We have learned something about the way in which they transmit characteristics and survive from generation to generation. One method of investigation has been to study the fashion in which viruses are able to meet emergencies in their environment. For example, when viruses are mixed with bacteria, most of the bacteria are destroyed. One in perhaps 100 million bacteria, however, will mutate to a form that is resistant to the virus, thus establishing a line of defense for its species. The virus, on the other hand, is capable of launching a new attack by mutating to a form which can destroy the resistant bacteria.

ALL kinds of mutations, many of them easy to recognize. turn up among the viruses. Some produce variant types of colonies on the bacterial plate; they may create fuzzy clearings instead of sharp-edged ones. or large clearings instead of small round ones. This kind of virus mutation was discovered in 1933 by I. N. Asheshov (who now heads a research project on bacterial viruses at the New York Botanical Garden) during his studies of anti-cholera vibris viruses in India. Other breeds of viruses have been found which need some particular substance. such as a vitamin or calcium. to become capable of attaching themselves to the bacterium. T. F. Anderson. of the Johnson Foundation for Medical Research at the University of Pennsylvania, opened up a totally unexpected new angle in viral research when he discovered that viruses T4 and T6 will not attack a bacterium in a medium lacking a simple organic compound called 1-tryptophane.

The discovery that bacterial viruses have a sexual form of reproduction came about in the following way. M. Delbrück and W. J. Bailey, Jr. were working with viruses T2 and T4r (a mutant of T4), which are relatives that can reproduce in the same bacterium of strain B. Each has two distinguishing characteristics: T2 produces a small colony and can destroy a mutant strain of bacteria called A; T4r produces a large colony and can destroy a mutant strain of bacteria called C. When T2 and T4r were added to a bacterium, viruses of both these parent types were released upon burst. as expected. But in addition two new types of virus came out. with their characteristics switched! One of the new types produced a large colony and destroyed bacterium A; the other produced a small colony and destroyed bacterium C. Obviously the parents had got together and exchanged something. The number of individuals of these new forms coming from a single bacterium varied, but the maximum number found was about 30 per cent of the total yield.

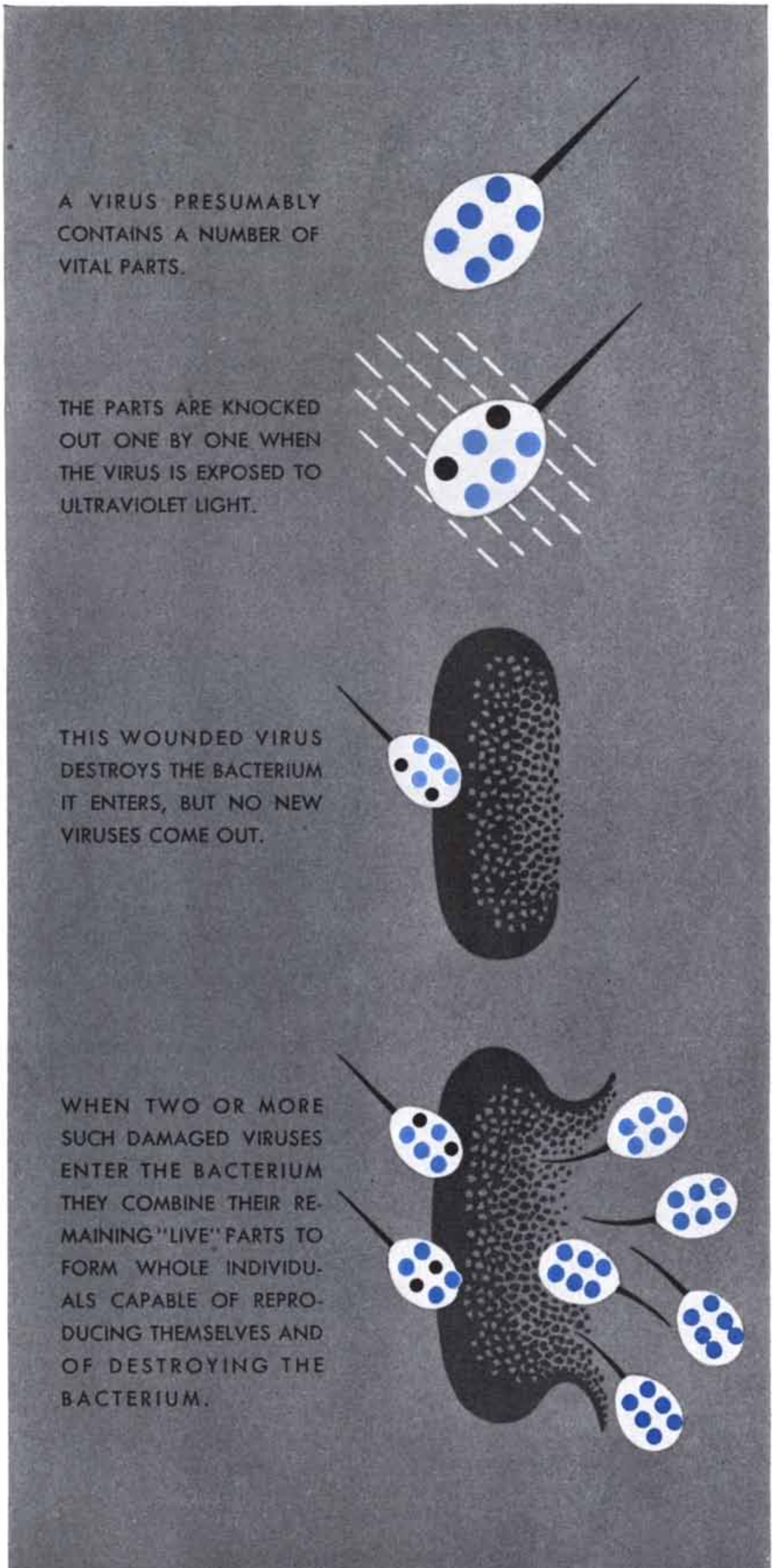
The most surprising discovery of all, however, was made by S. E. Luria of Indiana University. It came about as a sequel to an accidental observation in our laboratory at Vanderbilt University. When a virus that has been "killed" by exposure to ultraviolet light is added to a bacterium, the bacterium is destroyed but no new viruses issue from it. In one such experiment, Bailey irradiated viruses long enough so that most, but not quite all, of them were killed. He then transferred some samples, as usual, to a bacteria-covered plate. He wanted to determine the number of survivors. and expected to find less than 100 virus colonies on the plate. Instead, the next morning he found thousands of colonies! Puzzled, Bailey repeated the experiment, with the same result. The supposedly dead viruses had in some way come to life.

Later, at Indiana. Luria took this problem up seriously. He discovered a curious fact: although a bacterium infected with only one "killed" virus dies and yields nothing, a bacterium infected with two or more "killed" viruses bursts and yields several hundred new viruses. Luria therefore assumed that inside a bacterium two or more "killed" viruses (or perhaps we had now better call them mortally damaged) can pool their undamaged parts to make whole individuals capable of reproducing themselves and of escaping from the bacterium. He estimated that each virus of the T2, T4 or T6 type has about 20 vital units. Assume that each time a virus is shot at, or exposed to ultraviolet light, one vital unit is knocked out. If there are two viruses, each of which has been shot at four times, there is a good chance that the same vital unit has not been hit in both. The remaining units then seem to have a way of combining and forming effective individuals.

This "revival of the dead," as we might call it, which indicates some substitution of vital material, is interrelated with the previously mentioned exchange of character traits in viruses, a phenomenon which has been explored very successfully by A. D. Hershey at Washington University.

Gradually the study of these two phenomena should reveal something more of the way in which one virus produces another and—the most ambitious hope—even something of the simple facts of life. Here, as far as mind and imagination and skill can reach, is a vast region of the very small that is open for exploration.

Max Delbrück is professor of biology at the California Institute of Technology. Mary Bruce Delbrück is his wife.



DAMAGE to viruses by ultraviolet rays (*second drawing from top*) is added proof that they exchange characteristics. Damaged viruses pool resources.

GULLIVER WAS A BAD BIOLOGIST

Jonathan Swift's famous fantasy gives the modern biologist an opportunity to reflect upon the way living things are tailored to their environment

by Florence Moog

WHEN Jonathan Swift's Captain Lemuel Gulliver first published his account of his remarkable adventures in undiscovered Pacific lands, his contemporaries appear to have responded with some skepticism. Their reluctance to believe in six-inch men, floating islands and educated horses is mirrored in Gulliver's overprotesting preface to the second edition of his now-famous *Travels*. Whether his contemporaries were impressed by his insistence that from consorting with the Houyhnhnms he had been able to rid himself of "that infernal habit of lying" common to Yahoos is doubtful. In any case the two centuries that have elapsed since then have seen the growth of a body of knowledge by which the improbability of the creatures of Gulliver-land may be translated into impossibility.

Much of this knowledge has been the direct concern of biologists, those present-day kindred of Gulliver's academicians of Lagado. Indeed, for a student of comparative biology Gulliver's book may serve as an unpremeditated textbook on biological absurdities and, as a corollary, on the nicety with which all living organisms are tailored to the physical conditions of their existence.

The most unlikely of Gulliver's inventions, the 60-foot Brobdingnagians, actually could have been explained away, long before the biologists got around to it, by a principle of physics first developed by Galileo almost 100 years before Gulliver's odyssey appeared. According to the principle of dimensional analysis, the weight of a system increases as the cube of its linear dimensions. The principle seems to have been well known to Gulliver's Lilliputians, for it was the means they used in calculating that Gulliver equaled 1,728 Lilliputians. Since six-foot Gulliver was 12 times as tall as a six-inch Lilliputian, they computed that he weighed as much as one Lilliputian times 12^3 ($12 \times 12 \times 12 = 1{,}728$). The weight of a 60-foot Brobdingnagian may be similarly calculated as 10^3 times that of a six-foot man, let us say 180 pounds times 1,000, which is 180,000 pounds or 90 tons!

No wonder Gulliver neglected to mention the Brobdingnagians' weight! No very acute insight into structural principles is needed to see that such a tremendous bulk could not be borne in a frame of human proportions. The upper limit of weight which a body built on the human pattern will carry is perhaps no more than the 500 pounds reached by an occasional

GIANT Brobdingnagians, here talking with tiny Gulliver, can be shown to be an engineering impossibility.

eight- or nine-foot rarity. A greater bulk would necessitate a truly ponderous skeleton. The long bones of the legs would be shortened relatively to prevent their bending under their great burden; the head would become comparatively small, for reasons we shall look into later, but its larger absolute size would entail shortening and thickening of the neck; much of the increased weight would be taken up in the trunk, for the internal organs would have to undergo relative enlargement to provide adequate power to move the huge machine.

Examination of a few hoofed mammals will neatly illustrate this adaptation of form to mass. A gazelle of 150 pounds, for example, has a rather long neck on which is mounted a head which, though large in relation to the slight body, is small as tall animals' heads go; the heavier head of a 1,200-pound horse, though smaller in proportion to body size, requires a shorter and more powerful neck to support it; while the great head of a five-ton elephant, though not large in relation to the gargantuan body, is too heavy to afford the luxury of any noticeable neck at all. Similarly, the slender legs of the gazelle may constitute two thirds of the height at the shoulder, whereas the sturdy limbs of a plow horse are only about half the height, and the pillarlike props of the elephant not much more than one-third. The mind shrinks from picturing the broad-beamed corpulence of a Brobdingnagian. In fact we need no more than the zoo-keepers' rule that once around the forefoot of an elephant is half the height of the body to make it clear that the delicacy of the feminine ankle must have been a matter of no interest in Brobdingnag.

We need have no fear of ever finding such a neckless, short-legged monster peering into our sixth-story windows, for no 90-ton animal could ever walk on dry land. Certainly such bulk could not walk on the arched structure of the human foot, which is too ready to flatten under a little additional strain in normal-sized people. A flesh-and-bone foot ten times longer than the normal human one and a thousand times heavier would have as much difficulty supporting even itself as would a covered bridge enlarged to span the Mississippi. Mount 90 tons on it and such a foot would require bones of steel bound by ligaments of wire cable.

The limiting strength of living tissues, especially muscle and connective tissues, is probably the reason why nature, in millions of years of experimentation, only once succeeded in designing a land animal even half as ponderous as a Brobdingnagian; this animal was a now long-extinct rhinoceros. The tremendous dinosaurs, in their vain attempt to make muscles outweigh brains, may have approached a Brobdingnagian weight, but they were not strictly land animals; they lived in swamps, sharing their burden with the buoyant water as the whale does today.

IF the Brobdingnagians were too big to exist, the mouse-sized Lilliputians were too small to be human. So long as the laws of physics and chemistry obtain, living cells cannot vary much in size. Hence large animals must be built of more cells than small ones. In many organs cell number is not important, but the brain is in this respect like a telephone system (*see page 14*): a small private telephone system is of limited usefulness compared with one in which a great number of individual units, with their connecting wires and central switchboard equipment, make it possible for any person or institution to get in quick touch with any other. The human cortex, which is the portion of the brain that receives sensory information and deals intelligently with it, has an estimated 14 billion cells. On the inconceivably numerous interconnections which keep this vast assemblage of units in touch with one another depend the adaptability and educability of the human being. Were this tremendous number of cortical cells to be much reduced, the apparently inexhaustible capacity of good human minds for learning, remembering, perceiving and thinking would wither; it would shrink perhaps to the low level of defectives in whom the brain is cramped by a "pinhead" skull or by the abnormal presence of fluid in the cranium.

Now if we allow to a Lilliputian nerve cells as large as those of a mouse (which have about one-fourth the volume of human nerve cells), his tiny cranium could accommodate something like 35 million cortical cells—a large number indeed, but only a small fraction of what even a chimpanzee has at his disposal. On such a small allotment of intellectual equipment the Lilliputians could never have devised their delightful court routine, which yielded nothing in intricacy or absurdity to the best that Augustan England had to offer.

The Lilliputians also would have needed disproportionately large heads to carry useful eyes. Anyone who has ever quizzically scanned an elephant, trying to determine just where the enormous beast has its diminutive eye, must realize that eye size varies far less than body size. A small animal seems to have too much eye in relation to the expanse of its head, and this is because the limits of eye magnitude are dictated by the physical properties of light, which must enter through a pupil not too small, and must impinge on a sufficient number of seeing elements—the rod- and cone-shaped cells of the retina

TINY Lilliputians have various logical drawbacks, among them the difficulty of constructing an eye that would fit their small heads. The drawings on this and the opposite page are from a 1768 edition of the works of Swift.

—of almost invariable size. The eye is thus in a sense a doorway which must admit a certain minimal amount of light, but need not admit much more; just as an architectural doorway, whether of a cottage or a mansion, must be big enough to admit a man, but need not be much bigger.

So if a Lilliputian had had a head large enough to hold an intelligent brain and serviceable eyes, he would have needed a heftier body to hold up the head. The smallest known human race, the African pygmies, stand four and a half feet high. Even the tiniest human dwarfs, who never achieve quite correct physical proportions, are almost always more than two feet tall.

But overlooking for the moment the matter of unaccountable intelligence in unreasonably small heads, let us take note of another Lilliputian character that casts doubt on their creator's veracity. The voices of the miniature people, we read, were shrill—a shrewd guess, but not shrewd enough. Had Gulliver considered the difference in pitch which a small difference in size makes among the members of the viol family, he might have been more cautious about assigning any audibility to the Lilliputian voice. Pitch, measured in cycles per second, varies inversely with the square of the linear dimensions of the vibrating surface. So the vocal cords of a six-inch human being would vibrate 144 times faster than those of a six-footer; allowing our voices to center comfortably at 256 cycles per second (middle C), the small voice would vibrate at about 37,000 cycles per second—more than seven octaves higher! This would not inconvenience a Lilliputian, whose ears would probably have a sensitivity proportioned to his voice, but Gulliver's ears must have been practically deaf to sound of more than 10,000 cycles per second. Even had the captain been a prodigy of aural acuity he could not have heard a Lilliputian voice any more than we can hear the cries that bats seem to utter constantly as they fly; to such sounds only the ears of their small confreres are attuned.

WITH Brobdingnagians the case is no better, for their voices must have been at the lower limit of audibility—averaging perhaps three cycles per second. At such a rate the vibrations, though they might be heard, would not merge into a continuous sound, but would seem like the sad undulations of a phonograph record dragging to a stop. Now and then a Brobdingnagian soprano or piccolo player might have produced some notes that Gulliver could hear normally, but the sensation could hardly have been pleasant, for the lowest (as well as the highest) tones to which our ears are sensitive can be heard only when they are so loud that they can also be felt. Thus Gulliver was doubly wrong in claiming that he improved the giants' music by retreating from its loudness: most of it would not have sounded like music at all, and those few notes that might have had the earmarks of music would have become inaudible as soon as they became painless.

The apparently modest appetite of the Lilliputians is another reason why we may doubt their existence. Small, warm-blooded animals must take in more calories per unit of body weight than large ones, for the rate of living varies with size; small lungs breathe faster, small hearts beat faster, small bodies consume oxygen and turn out waste products faster. So a six-inch man might be expected to have about the same food requirements as a mouse,

PYGMIES of Africa are good evolutionary approximation of the smallest practical size for human being.

that is, approximately eight times as many calories per ounce of body weight as a full-scale man needs—or 24 meals a day instead of three. Gulliver missed on two counts here; he failed to realize that the creatures of his invention would have spent the larger part of their time stuffing themselves with food, and by the same token he did not see that by allowing him 1,728 times their dietary they were giving him as much food in a day as he could conveniently eat in a week.

Indeed, had Gulliver known anything of differential metabolism, his concept of a Lilliputian humanity would have been altered in every respect. For it is not difficult to see that an animal that has to provide itself with the equivalent of 24 of our meals a day would not have time enough left over for developing the nicer aspects of civilization. Worse than that, the very duration of life is related to size; an elephant may see a century pass, but fast-burning, voracious little mammals run through their lives in a space of time too brief to allow for the sort of education on which civilized society depends.

It must be concluded that the author of the Houyhnhnm hoax could have had no adequate appreciation of the physical characteristics from which human life has sprung. From the evolutionary point of view man is in essence a tall anthropoid whose big head accommodates a sizable brain and is provided with forward-looking eyes that can be used stereoscopically; he stands easily erect on flat, supple feet and carries at the end of his long, free-swinging arms a pair of instruments so beautifully designed, so perfectly adapted to uses without number, that even the products of his clever brain have never equaled them.

Our remotest apelike ancestors may not have been much more attractive than the Yahoos of Houyhnhnmland, but they were able to take the road to civilization because they were physically equipped for the journey. Their equipment did not include manual dexterity or conceptual thought, for these were goals farther along the road. Primitive man, their descendant, could enlarge the use of his brain partly because his hands, shaped by the tree-living habit of his forebears and freed by the erect posture derived from the same habit, could pick up and handle what his excellent eyes—another product of arboreal life—wished to examine; to this day the tendency to touch what we see is almost instinctive in most of us. Eyes and hands thus produced material on which the brain could work. The ideas that began to come in their turn provided work for the hands and eyes: the rock that was used as a weapon would be shaped into a blade and then mounted on a shaft; the thick-growing boughs that provided shelter would be used to construct a hut; the skins that served for clothing would be fashioned with bone needles and gut threads. Through innumerable such cycles of action and thought and action, civilization rolled slowly on toward atom bombs and prefabricated houses and the garment workers' union.

IF the indispensability of our apelike (or Yahoo-like) appointments in the development of civilization is not at once apparent, a suitable appreciation of them can be readily derived from a critical examination of Gulliver's educated horses. Even if we overlook the horse's low-browed construction, with a head so weighted down with jaws that it can hardly indulge in the luxury of a big intellectual brain, and even if we credit horse-lovers' accounts of the remarkable intelligence of the much-admired animal, we must still draw the line at Gulliver's stories of horses cooking oats, grinding flints and building houses.

An unlettered stableboy would snort at the notion of a horse threading a needle

—even if the limbs could do the trick, both eyes would be looking the wrong way! For the horse, having neither offensive weapons nor the hands to make them with, must tend first of all to his own safety; his eyes are placed to sweep a wide area for signs of danger; his limbs are designed to carry him swiftly away should danger materialize. To this end the limbs are so fixed that they swing freely in only one direction, and the body is so mounted on them that the horse, unlike certain small-clawed quadrupeds, cannot disengage his forefeet from their normal task even by sitting down. Nor is this any real disadvantage now, for the five fingers that might have led to the ability to grasp and manipulate objects were long since paid by the ancestors of the horse as the price of the stout single digit that makes such a superb running instrument. This exchange is typical of the law of compensation that nature rigidly enforces; only by refraining from specialization that might enable it to do anything perfectly has the flexible five-fingered human hand on its loose-jointed arm retained the ability to do everything after a fashion. A similar rule holds for the mind.

This brief catalogue by no means exhausts Gulliver's crimes against nature. The alterations which an increase or diminution of body size would enforce on the heart, lungs, liver and intestines could be made the subject of a large treatise. As for larks so small that they were provided with invisible feathers, eagles so big that they could not possibly pack enough power to get themselves into the air, insects far beyond the size limits imposed by the simple respiratory mechanisms of their kind—the very blades of grass in Gulliver's fantastic kingdoms cry out their impossibility. No biological principle is clearer than that every living thing—from man with his rapaciously expanding control over the environment, to the patient, insensible slime mold—lives in harmonious adjustment to the conditions of its life.

But, after all, we must not be too hard on Gulliver for failing to understand the biological conditions that made him a man—and an implausible liar. His talents, like those of his friend and teacher, the unhappy Dean Swift of Saint Patrick's, were in the psychological realm. The etymology of the name Houyhnhnm, his master horse tells us, is "the perfection of nature." Gulliver may not have understood biology, but he did understand biologists, who after his time were to endow their own species with the somewhat wishful name, *Homo sapiens.*

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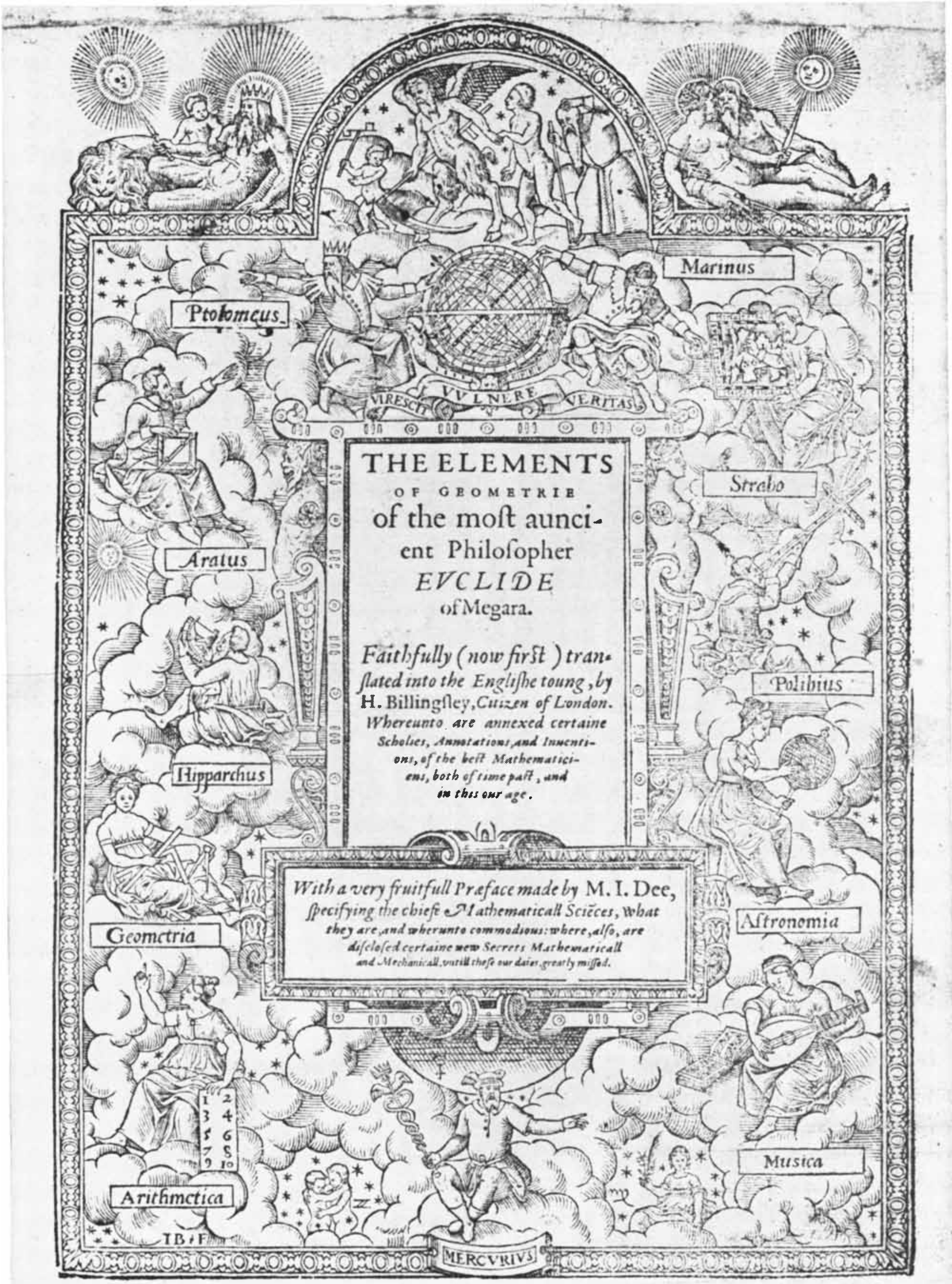
WATUSI of Uganda, in East Africa, are among the world's tallest people. Many of them exceed a height of seven feet. Although there have been other kinds of big human beings, probably few were much taller than the Watusi.



EUCLID'S GEOMETRY was first translated into English in 1578. Here shown is the frontispiece of that work which, besides presenting the propositions of the Greek philosopher, promised "new Secrets Mathematicall."

BOOKS

On the nature of mathematics and of mathematicians: two new semi-popularizations of the subject for intelligent laymen

by James R. Newman

WHAT is mathematics? What use is it? What are mathematicians like? How is mathematics related to our society and culture? Here before me are two new books on mathematics which furnish at least a partial answer to such questions. They are "Makers of Mathematics," by Alfred Hooper (Random House, New York) and "Mathematics, Our Great Heritage," edited by William Schaaf (Harper & Brothers, New York). Both volumes have something useful and interesting for the adult who is not given to boasting of the fact that while he may once have been taught the method of manipulating fractions he has long since forgotten it—and good riddance.

The questions are not easy, and like all profound or philosophical questions they have produced a large literature of unsatisfying answers, ranging from the baffling to the merely silly. "The Mathematics," said Francis Bacon, makes a man "subtle." But in this the Lord Chancellor was no more accurate than usual. For one thing I doubt that mathematics makes a man anything, in the sense that glass-blowing swells the cheeks or ballet dancing strengthens the calves. It may be that subtle men become mathematicians, but this, on my experience, seems unlikely. Mathematics has its subtleties, to be sure, but they are peculiar to its domain and are not the subtleties of painting, jurisprudence, theology or finance.

A psychologist might of course describe the strong points and quirks of the mathematician, but I have yet to see it done convincingly. Mathematicians are often credited with such attributes as "spatial intuition," "analytical powers," "number-sense," "logical mind." Yet what do these loose phrases tell us? Does not everyone possess such virtues to a degree? And are we any wiser for being told that the mathematician possesses them to a higher degree than others do—as if to say that Isaac Newton was like everyone else except that he concentrated more effectively?

Another way of analyzing mathematicians would be to define what they feed on. To the first known mathematical treatise, the Rhind Papyrus of ancient Egypt, Ahmes the Slave gave the title *Directions for Knowing All Dark Things*—which is still appropriate after 4,000 years. But we can hardly rest there. Plato felt that men were unfit to be leaders unless they knew geometry. If the test were applied to the members of Congress, we would no doubt lose the services of a number of statesmen, but is there reason to believe that the replacements would be better? Mathematics has been defined as the "science of quantity or magnitude," which has the one dubious merit of being obviously wrong. The Harvard mathematician Benjamin Peirce said that "mathematics is the science which draws necessary conclusions"—as one might do if a fish were found in the milk pail. Some eminent men have suggested that mathematics is no more than a branch of logic; their opponents, evidently utilizing Oscar Wilde's famous formula for manufacturing epigrams, have replied that logic is no more than a branch of mathematics. In our times we have enjoyed a number of brilliant (and occasionally impish) definitions by Bertrand Russell. On the other hand, with the German mathematician David Hilbert's flat dictum that "mathematics is a meaningless game" we have come a good distance from the somber reflections of Ahmes the Slave. It is evident that this is not the path to our goal, since the guides so strongly disagree.

The two books which are the subject of this review have at least the virtue that they are more concerned with explanation than with epigrams. Alfred Hooper's "Makers of Mathematics" is a pleasant, lucid and unpretentious survey, embracing a number of elementary branches of mathematics extending through the calculus. It combines exposition with historical material, mostly in the form of anecdotes about the great mathematicians, which have been skillfully selected so as to lubricate the more didactic portions of the text. Hooper's book does not compete with other accounts such as Alfred North Whitehead's *Introduction to Mathematics*, Lancelot Hogben's *Mathematics for the Million*, Tobias Dantzig's *Number: The Language of Science* or Eric Temple Bell's *Men of Mathematics*. Each of these is a more original contribution to the literature of mathematical popularization. and each possesses special attributes not to be found in Hooper. Hooper does not claim to be either a historian or a philosopher, and he lacks Whitehead's rare gift for striking to the heart of a difficult concept with a few simple phrases. But he does well enough. He has his own fresh way of explaining the elements of mathematics, and I am inclined to think that his thoroughness, concern for detail, effective repetition and knack for apt examples will illuminate a number of mathematical ideas which for many readers would otherwise remain veiled in obscurity.

HOOPER'S sidelights on mathematical history and the etymology of terms and symbols are particularly satisfying. Take the origins of the words "root" and "surd." The Greeks did not use the word "root," but in keeping with their geometrical thinking spoke of the "side" of a square number, as 2 is a "side" of 4, and so on. When the Arabs, who got much of their mathematics from the Greeks. began to use numbers instead of geometry as the pivot of their mathematical reasoning, they conceived of a number as "growing like a plant out of a root." So 16, for example, was thought of as growing out of the root 4. In the next stage of the history of mathematics. when European mathematicians took over the Arabic advances, the Arabic word for root was translated into the Latin *radix* (from which also come "radish" and "radical"), the source of the term in current use.

As part of the same process of word transformations. which mirrors in miniature the history of mathematical development, there is the evolution of nomenclature for the irrational numbers. From this evolution came the word "surd," which is a technical name for the square root of 2, 3, 5, etc. How the word came to this duty is part of the story of the Arab legacy of science. To designate any number which can be expressed as the ratio of two integers the Greeks had the word *logos*, which ordinarily meant "word" but in this instance stood for something like "the mind behind a word," that is to say, a number that their minds could grasp. Irrational numbers, on the other hand, were called *a-logos*. Faced with the problem of translating *a-logos*, the Arabs took the word in its primary sense—*i.e.*, "without a word" or "not expressible in a word"—and decided on the Arabic word meaning "deaf." Thus al-Khowarizmi, the famous Arabian algebraist, referred to the square root of 2, as "deaf." Again, during the Renaissance, Latin scribes engaged in the task of recapturing ancient learning through Arabian books simply turned the Arabic word "deaf" into its Latin counterpart *surdus*—whence we derive the absurd term for the irrationals.

I regret not having space to tell of Robert Recorde, who invented the sign =

RHIND PAPYRUS, a section of which is here reproduced, is one of the oldest known mathematical treatises. An Egyptian work of about 1650 B.C., found by archaeologists on the site of Thebes, it shows that ancient Egyptians had a well-developed arithmetic and could even work with fractions.

for equality "bicause noe 2 thynges can be moare equalle"; or of Pascal's toothache and the cycloid; or of "jiva" and trigonometry; or of medieval barbers who called themselves *algebristas* to describe their side line of bonesetting (one of the meanings of *al jabr* is reunion); or of Napier's special piece of artillery which, he guaranteed, would "kill 30.000 Turks without the hazard of one Christian"; or of other diverting matters. Readers will doubtless also be interested in Hooper's quotation of Whitehead's famous lines on Archimedes' murder—lines with a special meaning for our period: "The death of Archimedes at the hands of a Roman soldier is symbolical of a world change of the first magnitude. . . . No Roman lost his life because he was absorbed in the contemplation of a mathematical diagram."

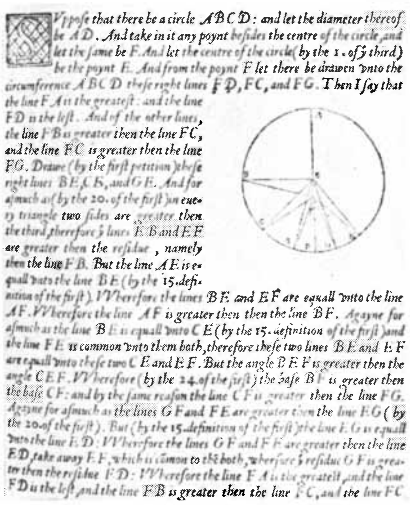
IN "Mathematics, Our Great Heritage," William L. Schaaf of the education department at Brooklyn College has gathered a number of interesting essays on the nature and cultural significance of mathematics. Each essay is written by a mathematician of recognized academic standing and comes under one of several headings such as: The Creative Spirit, Wellsprings, The Handmaiden, Humanistic Bearings.

On seeing the announcement of the book I had hoped that the editor had prepared an anthology of the writings of Henri Poincaré, J. J. Sylvester, Whitehead. Russell and others of like stature. But the book is a miscellany which includes the writings of none of these—only one mathematician of international reputation is represented—and it resuscitates a few essays that might well have been left undisturbed in the academic graveyard. Yet the larger part of the collection is worth having in permanent form, especially because there are, to my knowledge. no other books in English covering the same ground.

For the section on the creative spirit. Schaaf has chosen J. W. N. Sullivan's *Mathematics as an Art*, one of the less impressive pieces by this sensitive and gifted writer. *Mathematics, the Subtle Fine Art*, by James Byrnie Shaw, does not say much but says it at some length in a style marked by exaltation rather than clarity. From the late G. H. Hardy's charming but not unprecious *A Mathematician's Apology* the editor has excerpted a few pages supporting Hardy's thesis that mathematics is a "serious" subject—a thesis which, in all seriousness, I had not thought required proof. Nevertheless Hardy's illustrations of "serious" mathematics are set out with economy and high skill, and there is a certain something about a master craftsman practicing his craft which gives joy to the onlooker.

E. T. Bell, an able mathematician and an intelligent, colorful commentator on the history of the subject, remarks, in a fragment taken from his *The Development of Mathematics*, that the 20th century "led to what appears to be the final abandonment of the theory that mathematics is an image of the Eternal Truth." The same point is made by several other contributors.

John Von Neumann, another contributor, is among those mathematicians who have emphasized another aspect of this idea in insisting that mathematical foundations (which determine the mathematical system that follows) are matters of taste, and their choice is not compelled by some higher law. One may of course seek to develop systems of the greatest practical use, but this is a matter of applied rather than pure mathematics, and there is in any case no intelligence capable of foreseeing how useful the consequences of a given bundle of postulates may turn out


Suppose that there be a circle ABCD: and let the diameter thereof be AD. And take in it any poynt besides the centre of the circle, and let the same be F. And let the centre of the circle (by the 1. of ỷ third) be the poynt E. And from the poynt F let there be drawen vnto the circumference ABCD these right lines FB, FC, and FG. Then I say that the line FA is the greatest: and the line FD is the least. And of the other lines, the line FB is greater then the line FC, and the line FC is greater then the line FG. Drawe (by the first petition) these right lines BE, CE, and GE. And for asmuch as (by the 20. of the first) in euery triangle two sides are greater then the third, therefore ỷ lines EB and EF are greater then the residue, namely then the line FB. But the line AE is equall vnto the line BE (by the 15. definition of the first). Wherefore the lines BE and EF are equall vnto the line AF. Wherefore the line AF is greater then then the line BF. Agayne for asmuch as the line BE is equall vnto CE (by the 15. definition of the first) and the line FE is common vnto them both, therefore these two lines BE and EF are equall vnto these two CE and EF. But the angle BEF is greater then the angle CEF. Wherefore (by the 24. of the first) the base BF is greater then the base CF: and by the same reason the line CF is greater then the line FG. Agayne for asmuch as the lines GF and FE are greater then the line EG (by the 20. of the first). But (by the 15. definition of the first) the line EG is equall vnto the line ED: Wherefore the lines GF and FE are greater then the line ED, take away EF, which is cōmon to thē both, wherfore ỷ residue GF is greater then the residue FD: Wherefore the line FA is the greatest, and the line FD is the least, and the line FB is greater then the line FC, and the line FC

PROPOSITION in Euclid's geometry, as it is set down in first English translation, is good example of the mathematician's "useless" curiosity.

to be. Tobias Dantzig gives an admirable summary of the usefulness of "useless" ideas:

"The conic section, invented in an attempt to solve the problem of doubling the altar of an oracle, ended by becoming the orbits followed by the planets in their courses about the sun. The imaginary magnitudes invented by Cardan and Bombelli describe in some strange way the characteristic features of alternating currents. The absolute differential calculus, which originated as a fantasy of Riemann, became the mathematical vehicle for the theory of relativity. And the matrices which were a complete abstraction in the days of Cayley and Sylvester appear admirably adapted to the exotic situation exhibited by the quantum theory of the atom."

What of the sociology of mathematics? Apart from regarding mathematics as a culture clue, one may ask: How is mathematics motivated? How do its forms, the various lines of its development, the rate and direction of its growth depend upon social and economic circumstance? The inquiry is in its infancy; even Dirk Struik of the Massachusetts Institute of Technology, who for some years has investigated the relation between mathematics and the social order, has only provisional suggestions to offer.

Among the best of Schaaf's entries are the essays by C. V. Newsom and C. G. Hempel which discuss the nature of mathematical thought, its relation to logic and the problem of mathematical truth, touched on earlier by Bell and Dantzig. What is the most that can be claimed for a mathematical system? Only, it appears, that it is consistent; not that it is true. The journeys of mathematicians in search of the slippery essence of truth are like the journeys of the Princes of Serendip who, seeking one thing, often by accident or by sagacity found another. In quest of one overriding truth mathematicians have found many truths but not the one they sought. One might have hoped that the grand attempt within its own confines to prove a mathematical system consistent would have been forever ended by Kurt Godel's prodigious and terrifying demonstration that any program to prove consistency in mathematics "will lead in itself to inconsistency." But the academicians quarrel among themselves and the search for the great truth continues.

THE dissection of mathematical concepts resembles the attempt to smash the atomic nucleus and to uncover the ultimate elements of the physical world. Mathematicians, recognizing that the fundamental postulates from which their systems are drawn are true only by definition, seek to mitigate this blemish by reducing the fundamental or "primitive" concepts to a minimum. Among the vexing questions that arise is not only: What are the fewest and most primitive primitives from which fruitful results may be obtained? There is also the question: How is the choice of primitives forced by our mode of thought? And the answer to the second question must always be suspect as a product of the circular process of passing from thought to thought.

With respect to applied mathematics, Dr. Hempel states the matter very well when he says: "While mathematics in no case contributes anything to our knowledge of empirical matters, it is entirely indispensable as an instrument for the validation and even for the linguistic expression of such knowledge." In this area the criterion of mathematical validity is entirely pragmatic, but we are to remember that "it is not nature that is mathematical; man is merely reflecting the quality of his own thought processes while in the act of trying to comprehend nature." So we might conclude that the experiences we experience, the thoughts we think, the dreams we dream, all thoroughly mixed together, are the stuff of mathematics. Nor are we likely by the successive distillation of abstractions to get much closer to the heart of the problem.

THE AMATEUR

Conducted by Albert G. Ingalls

Most small telescopes are kept pointed at the star that is being observed simply by moving their tubes along by hand as the earth's rotation carries the star across the field of view. The same result can be accomplished a little more nicely with a handscrew on the telescope mounting. If the telescope tube is too long for the observer to reach this handscrew, it may be given an extension—a long swiveled rod with a handle at one end.

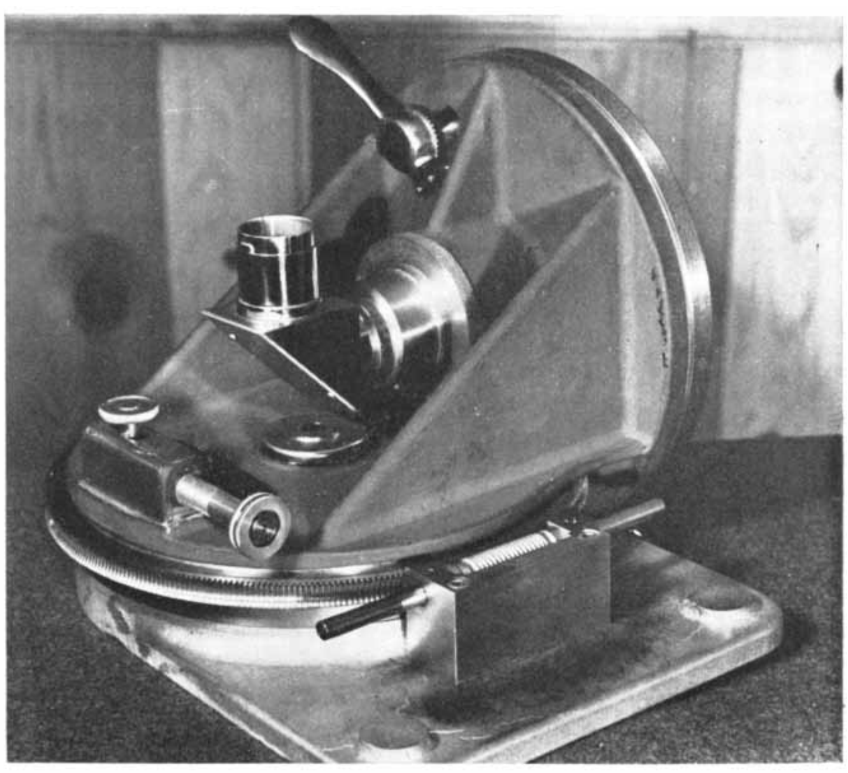
An amateur telescope maker, E. S. Ensign of the Ensign Foundry Co., 2100 Hendon St., Toledo, Ohio, has devised another kind of extension "rod," an electrical one. On the mounting of his telescope—a four-inch refractor made by himself—is a tiny electric motor (145 r.p.m.). In the observer's hand is a spring switch on the end of a flexible cord. Whenever the observer presses the switch the motor sets and keeps the telescope in motion until he releases it.

Actually, there are two switches. These are soldered together as shown in Russell Porter's drawing made from the original. The over-all circuit is shown in the diagram. There are eight cells on either side of a neutral wire. Thus the motor can be reversed.

Better still, the plunger-type radio switches used combine rheostats. This permits micro control of the telescope.

It all looks fine in the illustrations, but it proved to have one "bug." Ensign writes, "I have found that no matter how tightly I set up the tripod screws the telescope shakes when the motor is started and stopped." If a prize were offered for a torsion balance the familiar structure called the tripod might win it. Vertically a tripod is as stiff as a post. Laterally it is stable in any situation short of a hurricane. Due, however, to an inherent diagonal weakness it is rotationally unstable. If a long object, say a telescope, having a large moment of inertia and a slow period of oscillation, is placed on top of it, this instability is accentuated. Add a breeze and your prize is won. Despite this, tripods have good points—at least show us something better. One of these points, however, is not their use as engine beds or motor pillows. Ensign is substituting an iron pedestal for the tripod and retaining the electrical feature.

One experimenter who reads this department recently remarked that the lot of



Porter-revised Springfield mounting cast in aluminum by Ensign

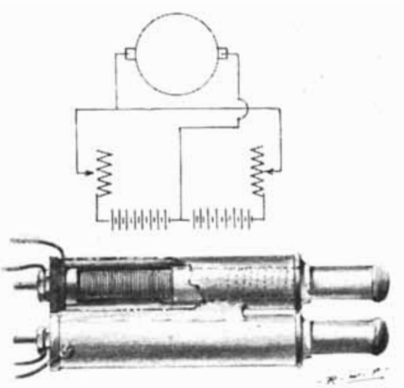
ASTRONOMER

the experimenter would be a happier one if other experimenters would similarly record not alone their successes but their mistakes. This department likes to publish valuable mistakes.

Ensign's refractor mounting was cast in aluminum. The polar axis has at top and bottom, respectively, 1¼-inch and ⅝-inch double-race ball bearings. The declination axis shaft turns in a plain bearing.

SINCE Ensign runs a foundry he was well situated to make a Springfield mounting more closely similar to Porter's revised Springfield described in *Amateur Telescope Making—Advanced* than any this department has seen. Perhaps because the patterns look formidable the revised Porter Springfield has seldom been tackled. After examining the original of the photograph reproduced here, Porter remarked, "A fine-looking job." This more than casual remark—for Porter doesn't effuse—carried more than common weight to one who has heard him loudly say nothing when shown photographs of compromise Springfield jobs.

Ensign writes: "The mounting was made from Porter's design in *ATMA*. The main casting is aluminum with a ground steel insert to take the axis tube. The



Wiring diagram; switches

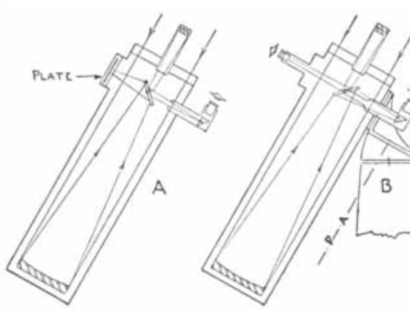
Ensign's telescope control

clutch plate is brass and has a stud staked to it which comes through the slot in the casting near the top. The stud is fitted with a handle and pinion gear running on a segment of curved rack, thereby giving a sort of vernier in declination. This was done to take the place of the more difficult worm-and-gear method, as in the original design. The worm gear for the hour circle was made on a 10-inch Logan lathe. I cut it with a ⅝-inch tap and it came out well except that the teeth don't match very well on the complete revolution. The base casting is also aluminum, but I should have used iron, as aluminum is not heavy enough. The mounting is to be used with an 8-inch mirror with 10-inch tube."

Smelling a possible chance to make this rare Porter Springfield available to amateurs, this department sounded out Ensign about castings for others. Reply: "I have the patterns but we do not pour aluminum. I would have to take it to another foundry. If some now and then would like castings out of iron I could probably accommodate them, but the prices might seem steep." Ensign specializes in a low-carbon iron with nickel and chromium called Tensloy.

In the month after the above reply was received more inquiries about Springfield castings reached this department than during the previous three years. Do you believe in telepathy?

THE FOURTH illustration shows a trick Springfield telescope ("Very ingenious."—Porter) proposed by Daniel Langpoop of Los Angeles. The diagonal

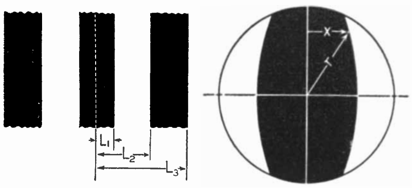


Langpoop's combination Springfield

mirror is on a pivoted support and is aluminized on both faces. In *A* the observer is guiding a photographic plate. In *B* two persons are observing simultaneously. The smaller telescope is also a finder, the best aspect of this rather stunty proposal.

ADVANCED amateur telescope mirror makers examine and study in the minutest detail the shapes and outlines of the Foucault shadows on mirrors and thus come to know their finer subtleties, many of which are not even perceived by the tyro. The same painstaking study has not yet been given the map of the bands in the useful Ronchi test. George P. Arnold of State College, Pa., and Joseph Vrabel of Boalsburg, Pa., argued heftily about the curvature seen on the Ronchi bands in testing a short-focus mirror they were making. Should these bands neck in as much as they did at the top, or should they have the same curvature everywhere along their length?

This started Arnold, a graduate student in physics, on a hunt for a general formula by means of which the exact shape of the bands for a mirror of given specifications may be worked out in advance for



Grating distances. Compass setting

the particular Ronchi grating used. He found one which he says will do the trick with fewer pains than may at first appear. "Of interest," he comments, "is the fact that one formula can give so many shapes." On its use he has prepared what follows:

The correct appearance of the bands for any point inside or outside focus may be plotted. The lines are drawn in for the separations between the light and dark shadows thrown by each wire or edge of the grating, and the areas within these boundaries are blacked in solid. The formula is:

$$x = \frac{LR^2}{N}\left(\frac{1}{s^2 \pm r^2}\right) \quad \text{where}$$

x is the distance of a point on a band from the vertical diameter of the mirror;

L is the distance of an edge of the actual grating wire measured horizontally from the optical axis;

R is the radius of curvature of the mirror;

N is the fractional correction (for a parabola, $N=1$);

r is the distance of a chosen point on a band from the optical axis;

s is the radius of the zone at the focus of which the grating lies. (s is related to the distance of the grating from the center focus by $d=Ns^2/R$.)

The plus sign is used in the denominator if the grating is outside the center focus, and the minus sign if it is inside.

The formula is easy to apply, using cross-section paper and a compass. Take, for example, a six-inch f8 mirror and a grating having 200 lines per inch. Suppose we want the correct appearance of the bands when the grating is 0.15 inch inside center focus. In this case L_1 is 0.00125 inch; L_2 is three times that amount or 0.00375 inch; L_3 is 0.00625 inch; R is 96 inches, N is 1; and, since s^2/R is to be 0.15 inch, s^2 is 14.4.

Confining our attention to one side of the first band we have

$$x = \frac{(0.00125)\ (96)^2}{14.4 - r^2}$$

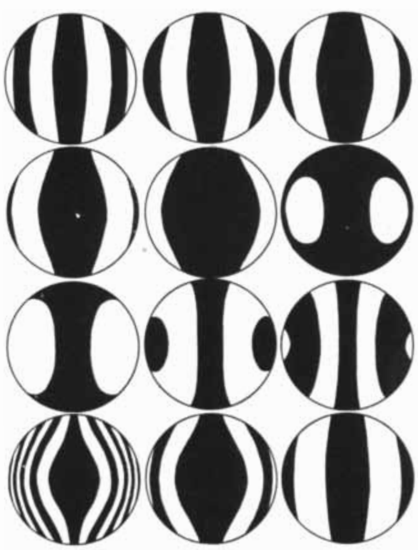
The compass is set at values of r and swung to the corresponding x's calculated from this equation, where points are marked. Enough points are plotted to enable a smooth curve to be drawn joining them. This is done for the L's on both sides of the center until the bands no longer fall within the circle which represents the mirror. Any values of x that turn out larger than the corresponding r are discarded.

One of the illustrations shows the results of applying the formula to four 6-inch mirrors; once I started this I couldn't stop—the drawings looked so pretty. They were done with some care.

Drawings 1 to 9, reading across from left to right, show the appearance of an f8 paraboloid, with a grating having 200 lines per inch, located at various positions ranging from 0.15 inch inside to 0.30 inch outside the center focus, 5 being the appearance at focus.

Ten is an f3, 11 an f5, both having been made with the grating at the focus of the center zone. Compare with 5.

Twelve is the f8 with a grating having 100 lines per inch, adjusted so that the band width is the same as in 2. Note the decreased curvature.



Four worked-out examples

Since the formula gives only the lines separating light and dark areas, the black and white bands may be interchanged and the effect will be that obtained by moving the grating laterally half a line.

Because of diffraction the bands will never appear exactly as shown. If, however, the grating is not too fine and is kept fairly close to focus the figures will agree closely with the actual patterns, the main difference being a slight widening of the bands. Very fine grating wires give bands that may be several times the geometrical band widths.

The formula was developed independently of the method and related formula that are alluded to in *Amateur Telescope Making—Advanced*, page 108. That approach was developed in 1932 by Franklin B. Wright.

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