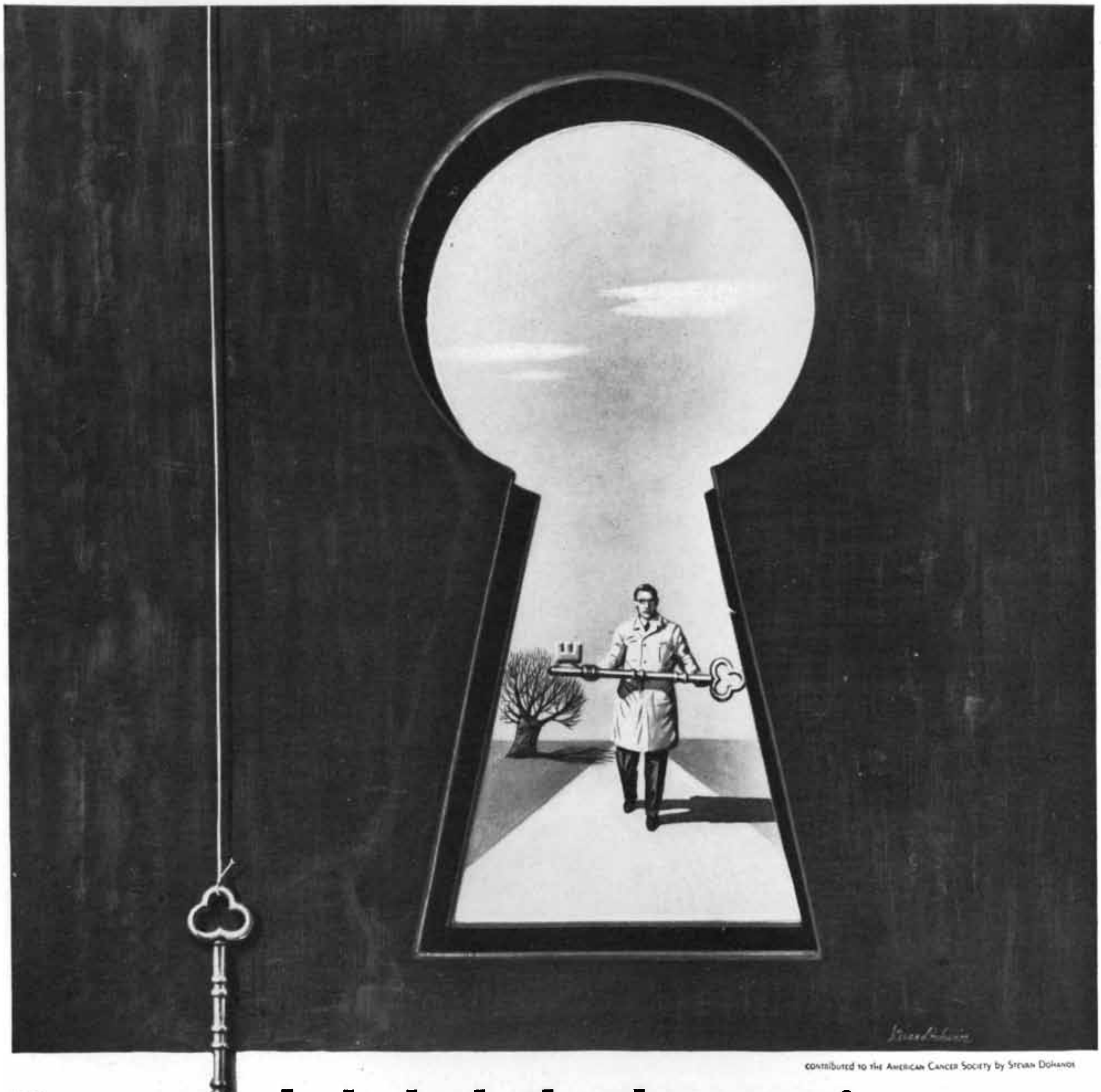
SCIENTIFIC AMERICAN

THE ELECTRON: PARTICLE AND WAVE (PAGE 50)

FIFTY CENTS

May 1948



CONTRIBUTED TO THE AMERICAN CANCER SOCIETY BY STEVAN DOHANOS

You can help lock the door against cancer

This is a story about a door and two keys. The story will have more point if, first, we state three facts:

- *Every 3 minutes an American dies of cancer.*
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LETTERS

Sirs:

Two years ago you described to me your plan for the founding of *The Sciences*, a new magazine which was to cover all of science for the intelligent layman. Now, I understand, you have combined your plan for *The Sciences* with the acquisition of the venerable *Scientific American*. I hope you have not taken the change of title too literally. Science is not American—it transcends nations. But the *Scientific American* is an established name, doubtless chosen for good reasons. What will be between your covers is the important question.

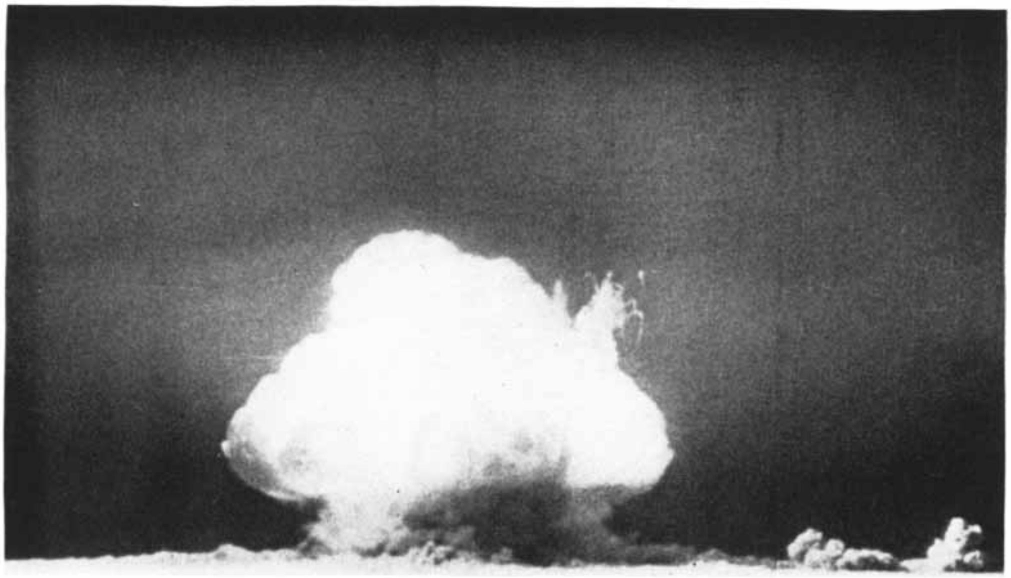
Your original prospectus asserted that the new *Scientific American* would be designed to fill a gap in American journalism. I, for one, have been acutely aware of this gap.

Technical journals for technical readers abound and are, mostly, excellent. Popular articles, even entire magazines, on science and technology for mass readers have also grown in abundance and, more slowly, in excellence. Twenty years ago, those of us in science who were concerned with the problem cried for almost any science coverage that would give the citizen (who pays the bills and should enjoy the party) even the simplest undistorted information. Today, while plenty remains to be done, trained science writers, working with the media for reaching men by the millions, do present the findings of science and some of their underlying significance, and often do it well, sometimes superbly. But even if this job of mass communication were done to perfection, certain inexorable limitations would exist.

Science writing addressed to the citizen must not assume general erudition, a background of understanding, an intelligent interest that he does not possess. College science presented to grade-school pupils will alienate, not educate, them. The bulk of adult Americans, even those of entirely adequate intelligence, is not today beyond a most elementary acquaintance with science. We must hope that better teaching in schools, that adult-education efforts, that the presentation of simple but genuine science in print and by exhibits and over the airways, will slowly raise this level.

What then of the tens or hundreds of thousands prepared and eager to keep abreast of science at, say, a college level? Each scientist is an advanced layman outside his limited area of expertness. So are professional men of all callings. These men need something between the particular technical journals and the generalized mass magazines. I hope the *Scientific American* will meet this need.

I am concerned that the need be met, not so that some magazine or other be a



Men, money, and an idea built the bomb. Countless energies and resources were risked, and a new world opened up in that blinding instant at Alamogordo.

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success, nor that some intellectuals be satisfied, but that civilization be aided. For this group of men, largely if not wholly self-selected by talent and enterprise, dominates the thinking of the larger citizenry. The lawyer, the doctor, the engineer, the business executive, hardly less than the educator, the minister, the publicist, the artist, is a maker of the minds of men; it is vital that he help make them well. No more important ingredient can be included in the mix than that habit of rational analysis and calculated testing and objective evaluation which is epitomized in the scientific method. If I may quote a few words I wrote a year ago:

"If we think of science as an exciting sport, as indeed it is, then the final score of each game is certainly for the public. So also is the inning-by-inning progress, provided it is clearly recognized by all as just a progress report and provided the reporter has some official or semi-official authority for his statements. Still better, if the public is taught some of the rules of the game, it can follow with excitement a play-by-play account. It must never be placed in the role of umpire. Also, it must learn to respect the expertness of the players. A democracy that does not respect expertness in the intellectual area, as it does in the sports arena, is bound for extinction in an age of technology.

"Let me sum up. For a healthy democracy the following circular relations should hold: The public should be kept informed of the authoritative advances of science and, even more, should be instructed in the manner in which science achieves them. The public must be made aware of the dignity of expertness and the compulsion of facts. Only so can the state, and all states, act rationally in this era of great sociological interdependence and tremendous physical power. Only so will science receive the financial support and dignified position it must have for the good of the whole. Only so will science flourish and serve. Those who work with the mass media of communication must insist on ever better standards of reliability and significance in what they communicate—standards which guarantee the discharge of a public duty as well as accumulation of a private gain. Only so will they be allowed long to continue as private enterprises. Only so can the public learn what it must know to function as a democracy."

So if the new *Scientific American* has indeed chosen to convey science in an accurate and lucid manner to the intelligent layman, it has chosen a momentous and difficult task. It is earnestly to be hoped that it will succeed.

R. W. GERARD

Department of Physiology
University of Chicago
Chicago, Illinois

50 AND 100 YEARS AGO

MAY 1898. "It is interesting to recall that just thirty-five years ago—on March 4, 1863—the National Academy of Sciences was created. This year, as in years gone by, the academy met in Washington. A programme of twenty papers was presented at this meeting. Of these, three were by Alexander Agassiz, the director of the Museum of Comparative Zoology, in Cambridge. Dr. Agassiz has spent considerable time during the last year studying the coral reefs of the Pacific."

"The brilliant operations of the American fleet in Manila Bay have served to emphasize several well established principles of naval warfare, the truth of which has been recognized through many centuries of struggle for the mastery of the seas. We believe it was Napoleon who said that Providence was on the side of big battalions. That may be true on land, but the history of sea fights without number has taught us that Providence is on the side of forethought, good judgment, discipline, dash, well-timed audacity and above all straight shooting."

"The 'Windward,' the Arctic exploring ship which was presented to Lieut. R. E. Peary, U.S.N., the Arctic explorer, by Mr. Albert Charles Harmsworth, owner of The London Daily Mail, arrived at New York, May 11, after a rough passage of fifty-two days. The 'Windward' is notable as being the vessel which took Nansen and Johansen from Franz-Josef Land to Norway. Lieut. Peary's plan has also been outlined. He will leave in July for the North, and as the expedition may be gone several years, the 'Windward' will carry stores from New York at intervals of a year or two."

"In the middle of June the great star Arcturus is overhead. Even for those who know and care but little about astronomy it is worth while to look carefully at Arcturus, because Arcturus is the very mightiest sun that the heavens are known to contain. Its distance is about a thousand millions of millions of miles, or more than ten million times the distance of our own sun. Since the intensity of light decreases as the square of the distance increases, it is easy to show that if we were as near to Arcturus as we are to the sun, the earth would be vaporized by the blast of unimaginable heat which would smite it, for Arcturus must exceed the sun in light and heat giving power in the ratio of six thousand to one!"

"At a meeting of the New York Academy of Sciences, Mr. E. L. Thorndike, of Columbia University, gave an account of a long series of interesting experiments on comparative psychology. These experiments were made upon cats, chickens, dogs, monkeys and other animals, and were supplemented by the experience of professional animal trainers. Cats were placed in boxes with doors so arranged that they could be opened from the inside in various ways, in one set of experiments by pressing a latch, in another by pulling a cord, by pulling a hook attached to a cord, or by turning a button. Curves were given showing the rate at which kittens learned the various tricks, the time taken to get out becoming gradually shorter."

"Mr. William Doherty, an American ornithologist and entomologist of reputation, has just returned to this country from the Philippine Islands, via Hong-Kong and San Francisco. His latest distinction was in successfully passing the Spanish customs officers at Manila with the complete plans of the city, the harbor, fortifications and minute details of the armament. It was a dangerous proceeding, but Mr. Doherty carried it out successfully. The plans and drawings were concealed in a newly laundried shirt which was folded, pinned and banded in the usual style and put with other clothing in his trunk. He arrived in Hong-Kong early in April and at once delivered these most important papers to Commodore Dewey on the 'Olympia'."

MAY 1848. "We thought that the revolution in France would have unsettled the Railroads in that country, but it seems not. Our valuable exchange the *Journal des Chemins de Fer et des Mines*, has even come more regular since than before the revolution, and what is not a little pleasing to a republican the *red mark* of royalty has disappeared from the wrapper."

"The atmosphere is an ambient mantle which wraps the earth in its soft embrace. Its direct height from the surface of the earth is calculated to be fifty miles. Although the atmosphere is such a beautiful and transparent substance, yet it is not a simple substance. It is composed of two gases perfectly opposite in their natures singly. The one gas is named oxygen and the other nitrogen. The atmosphere is composed of 79 parts nitrogen and 21 parts oxygen, and although many gases have been discovered and combined, yet no other combination and no single gas will sustain life for any length of time but the air, and bountiful is our Creator who has supplied our earth with such a quantity of it."

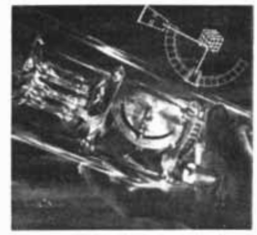
"The Committee of the U. S. House of Representatives appointed to examine into the merits of Whitney's project for a Railroad to the Pacific, have reported favorably, only one of the Committee reporting against it."

"The expedition in search of Sir John Franklin has reached Buffalo, New York, where it is to meet some persons from Montreal, who, together will set out for Hudson's Bay via Detroit, and the Salt St. Marie, in the prosecution of the voyage of exploration. Sir John Franklin set out on this his last voyage of discovery in the year 1845."

"The body of a young man named Bruce has been discovered by clairvoyance in Boston. He had been missing for some time and a Miss Freeman, the clairvoyant, it seems mentioned some singular circumstances relative to his death. There is something essentially wrong in placing confidence in such nonsense. It pains us to think that with all our boasted civilization, so much superstition should still exist."

"An inexhaustible amount of Iron Ore has recently been discovered in Schuyler county within a mile of Illinois River. Samples of this ore were sent to Pittsburgh, and on trial found to yield a rich percentage. A company from Pittsburgh has since visited the ground and in conjunction with citizens of the Schuyler. are making arrangements to erect a number of furnaces with a view of commencing operations at an early day."

"Patent issued. to Charles Goodyear, of New Haven, Conn. for improvement in making hollow articles of India Rubber."



THE COVER

The painting on the cover depicts the apparatus used by C. J. Davisson and L. H. Germer to prove the wave nature of the electron (*page 50*). The diagram above the apparatus shows the path of the electrons which were directed at a crystal to obtain the proof.

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Cover by Stanley Meltzoff

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SCIENTIFIC AMERICAN
Established 1845

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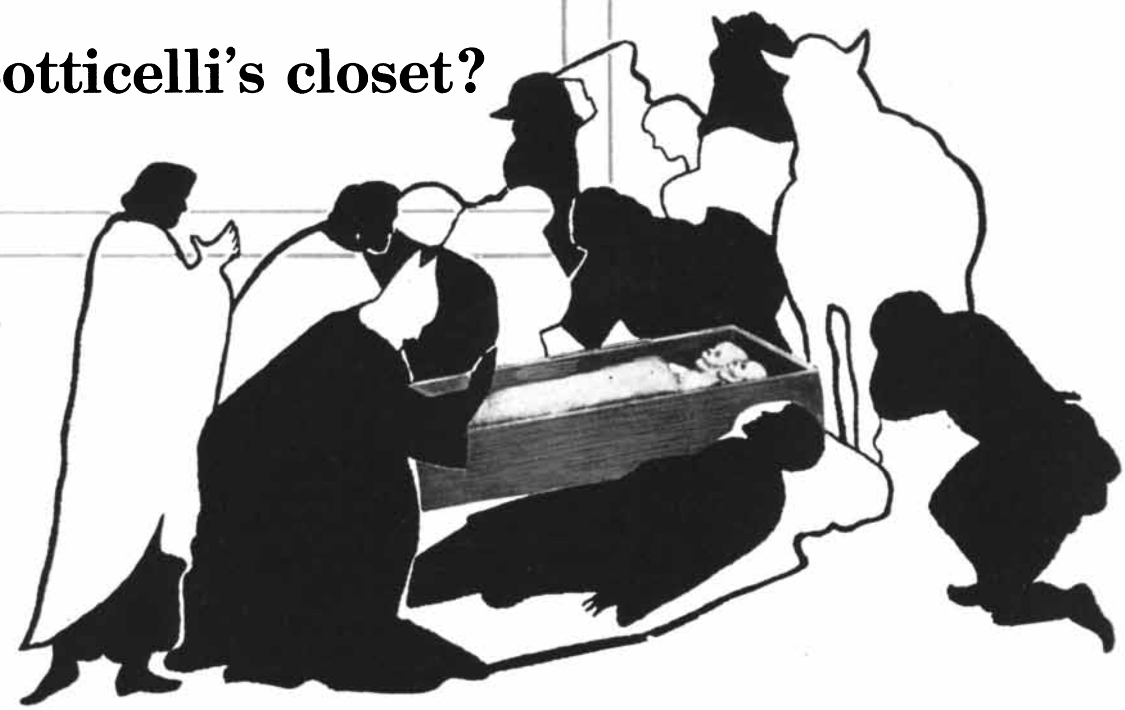
DEPARTMENTS

Who hid the skeletons in Botticelli's closet?

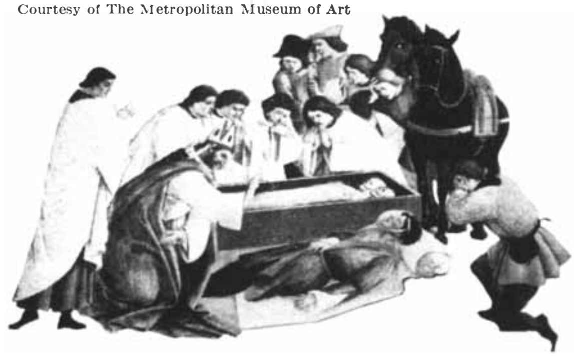


Two skeletons came to light recently when a famous painting was cleaned by the Metropolitan Museum of Art. When Botticelli painted his *Three Miracles of St. Zenobius* in the fifteenth century, the skeletons were conspicuous parts of the central scene. But before the Metropolitan acquired the picture 35 years ago, someone painted over the skeletons and hid them from the eyes of the world.

To disinter Botticelli's bones, museum experts used infrared photographs, X-rays, microscopes, scalpels, and chemical solvents. Acetone and methyl and ethyl alcohol were among the solvents that dissolved the varnish and other resinous substances. They are helpful chemical tools in the delicate work of preserving and restoring art treasures.

CSC acetone and other solvents work for industry on a far larger scale than rescuing skeletons from museum closets. They are of great importance in the mass production of plastics, synthetic fibers, paints, and photographic film. Commercial Solvents serves industry, medicine, and agriculture with more than two hundred fine chemical products.

Courtesy of The Metropolitan Museum of Art



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SCIENTIFIC AMERICAN

MAY 1948 VOL. 178, NO. 5

MAN OF THE AMAZON stands in a swamp on one of the valley's ill-defined river banks. At flood the river is as much as 400 miles wide.

THE FUTURE OF THE AMAZON

Four hundred years of civilized invasion having failed to extract its vast wealth, the Hylean Amazon Institute will now try using the scientific method from within

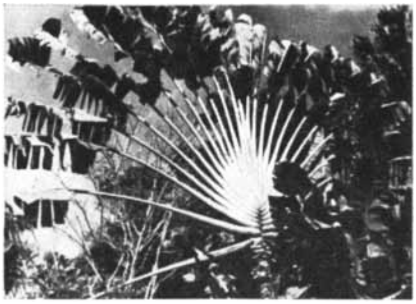
by Peter van Dresser

LAST month a group of scientists representing 10 American nations met in the little town of Tingo Maria, Peru, a garden spot at the headwaters of the Amazon River. There they formally organized an international enterprise. Its objective is to open a new frontier for a hungry world in the vast, unconquered Amazon Basin. The name of this "hemispheric TVA" project is the Hylean Amazon Institute. Its sponsor is the United Nations Educational, Scientific and Cultural Organization. To civilize the wild, rich Amazon and open it to colonization would itself be a gigantic achievement. But the project is perhaps even more significant as the world's first laboratory for international cooperation at the working level. Never before have nations pooled their science and technology to explore an entire subcontinental region and make it bloom for mankind.

The project was proposed just two years ago by a Brazilian biologist, Paulo Carneiro. UNESCO, then in session in Paris, at once warmed to his proposal. At Belem last August, 10 nations—the United States, Brazil, Peru, Venezuela, Colombia, Bolivia, Ecuador and British, Dutch and French Guiana—outlined their plans, and in November UNESCO officially approved them. To start preliminary studies, UNESCO appropriated $100,000, Brazil $600,000 and the eight other Latin American nations will raise about $100,000 more. A headquarters staff of five scientists, temporarily at Belem, the Brazilian seaport at the mouth of the Amazon. is now mapping out the tasks to be undertaken in the various sciences.

The Hylean (from the Greek *hyle*, meaning wood) Amazon Institute is an enterprise of breathtaking scope. Its purpose is not to gouge raw material and food out of the untamed forest. The history of the Amazon River valley is a long chronicle of failure in such endeavors. Wave after wave of expeditions of exploitation has washed up the valley, slaughtering forests, recklessly spending dollars and lives, only to be swallowed up in the overwhelming jungle. The new Institute will try a more thoughtful and subtle approach. It represents basically an attempt to apply the skill and weapons of modern science to making the jungle habitable and fruitful. Its strategy is to study the region's physiography, natural history and ecology (in this case, the relationship between the environment and man) and to evolve a process whereby man will learn to live harmoniously and richly in the environment instead of fighting it.

One of its first tasks will be to disprove the common notion that the Amazon Basin is a hostile, impenetrable wilderness. In part, the conventional view of the area as a steaming tropical jungle is correct. The river valley itself lies dead on the equator. and it is drenched with 100 to 200 inches of rain a year—five times the



A WATER PALM stands alone among hundreds of other species, complicating the problem of forest harvest.

SNOWY EGRET is part of the valley's intricate ecology. But the valley's wealth lies in its botanical life.

PALATIAL RUIN remains of grandeur of Manaos, headquarters of the first great Amazon rubber boom.

annual rainfall of the northeastern United States. Much of the waterway is lined with broad swamps. In the wet season, the swollen river rises 40 or 50 feet and overflows its banks, spreading out in some places to a width of 400 miles. The Amazon Basin's 2.6 million square miles are believed to contain fewer than one million people, although no census-taker has ever ventured far enough from the navigable waterways to count them.

Withal, it is a region of tremendous potentialities. Only a small percentage of the total area is jungle or swampland. This great watershed, which occupies a fifth of South America, is the largest single fluvial region of the globe, and at the same time one of the most richly endowed. Its land area, almost twice that of the Mississippi drainage basin, is nearly as large as the whole United States. It is drained by the most extensive system of watercourses in the world. The central river is navigable by ocean-going steamer for 2,300 miles, a distance equal to the span of the South Atlantic from Cape São Roque to Dakar. Its numerous tributaries—many of them major rivers in their own right—provide many thousands of navigable miles for steamboats and thousands more for smaller craft. Its lands are covered with an incredibly rich and diverse mantle of plant life, ranging from equatorial jungle and treeless savannah to upland forest and prairie. Its mineral deposits are probably at least as extensive as those of the United States; they include metallic ores from iron-rich hematite through the rare alloy elements to silver and gold, economic earths and clays, piezoelectric quartz and industrial diamonds.

FOR over 400 years this world of Amazonia has been known to the West. In 1541 Pizarro's lieutenant Orellana, traveling down the eastern slopes of the Peruvian Andes in search of La Canella—the fabled cinnamon spiceland—launched a crude caravel on the upper Rio Napo. Thus he unwittingly began an epic voyage which did not terminate until he and his ragged troop of men had sailed the three thousand wilderness miles to the broad Atlantic mouth of the *Mar Dulce*, as the river was then called. There they rebuilt their vessel and beat their weary way northward to Cuba. Orellana named the river Amazonas after a battle with a savage tribe whose women, according to his report, fought alongside the men.

In the centuries following, this equatorial world saw other epics of geographic reconnaissance by Spanish and Portuguese adventurers. The great naturalists—Martius, Baron von Humboldt, the Englishmen Bates and Wallace, the revered Agassiz and scores of others—made their pilgrimages there over the course of the nineteenth century. By the twentieth, highly organized expeditions, equipped with wireless, aircraft and the intricate paraphernalia of modern biological and physical science, were carrying on the tradition of exploration in this vast wilderness vivarium of plant and animal life.

It is a strange fact that in spite of this long history of exploration, and an equally long one of attempted colonization and development, the heartland of Equatorial America remains today one of the largest blank spots on the human and economic map. In the centuries during which other migrations to the Western Hemisphere grew from trading settlements to modern states with complex economies and populations in the tens of millions, the enormous alluvial plain of the Amazonian watershed has steadily declined in importance. Its population today, in fact, is probably considerably less than it was a century ago.

The story of the great rubber boom illustrates how ingloriously the Western mercantile world has failed in efforts to achieve a firm foothold in Amazonia. For generations the milky sap of various trees native to the American tropics had been utilized in a crude way for making waterproof garments and vessels. Orellana himself was probably the first Westerner to learn of the properties of these trees, since his homemade boat was caulked with a mixture of wild-cotton fiber and rubber. With the inventions of Goodyear and the rapid expansion of pneumatic-tired highway travel in America and Europe from the 1880's on, the latex of the wild rubber plant *Hevea brasiliensis* was suddenly in demand as a major industrial raw material. An apparently insatiable world crude-rubber market at 50 cents a pound sent a wave of "forty-niners" up the Amazon and on into the Purus, the Acre and the Jurua valleys. Trails were hacked through the wild-rubber territories; strings of trading posts, camps and steamboat landings were set up. Forests along the river banks were felled to fuel the steamboats. Thousands of native and immigrant *seringueiros* patrolled the wilderness, tapping the scattered latex-yielding trees, coagulating the milky sap over the smoke of urucury-nut fires in jungle-clearings, and bringing the great balls of dark gum for weighing in at the trading posts and fazendas.

For a while it seemed that the long-imagined development of Amazonia was at hand. Vast amounts of the white gold flowed down the great yellow river every year. Handsome plantation homes appeared here and there on the banks of remote watercourses. The fabulous city of Manaos, with its three million dollar baroque opera house, its paved streets and water system, sprang up at the confluence of the Rio Negro and the Amazon—trading capital of a million square miles of equatorial wilderness. An English company financed, at gigantic cost, the *tour de force* of the 220-mile Madeira-Mamore railroad.

But the period of the rubber boom

passed and left little permanent mark on the land. When rubber trees transplanted from Brazil to East Indian plantations matured, Amazonia's wild rubber declined sharply in value. Ill-fed and disease-ridden *seringueiros* and *caucheros* living in temporary forest encampments could not compete in output or in quality with the product of organized plantation labor in the long-settled island tropics on the other side of the world. In 1912 the last heavy shipment of crude rubber went down the river. The jungle reclaimed the encampments and trails. The fine plantation homes tumbled to ruin. Spectacular Manaos lost half its population almost overnight.

THE picture today, a generation later, has changed but slightly. Amazon river trade has recovered to some extent.

NATIVE HOMES are nearly lost in the jungle overhanging banks of one of Amazon's uncounted tributaries.

A few forest products such as Brazil nuts, piassava fiber, palm-nut oil, are gathered for export. Steamboats and towboats still ply the river, although in diminished numbers. An occasional mail and passenger plane drones up the valley, linking the interior towns more closely with the administrative and business world of the coast. Here and there a scientific pioneering project, such as the Ford rubber plantation on the Tapajoz, or a medical or sanitation program backed by government, hints of new achievement. But on the whole the Amazon is still essentially the virgin wilderness traversed by Orellana 400 years ago.

One conclusion that may be, and often is, drawn from the evidence is simply: Amazonia is uninhabited because it is uninhabitable. But a strong school of Amazonists, basing their conclusions on a tough and scientific appraisal, reject such pessimism. The total area of uninhabitable swamplands amounts to no more than one per cent of the entire watershed. Some 10 per cent is open savannah, ideal for livestock husbandry, and a big proportion of the forest is well-drained and reasonably insect-free. Though humidity is high, temperatures are moderate, varying from 68 degrees to 93.

What is needed to transform this river-universe into a working part of the civilized world, according to the new school of Amazonists, is a revolution of our attitude toward it. In the past, this, like most other "colonial" regions, has been regarded as a mine from which the raw material required by an alien industrial economy—crude rubber, vegetable oils and fats, fibers—are to be extracted in maximum quantities and at minimum cost, with little regard for the socially destructive by-products of such a process. A new and broader vision must guide future efforts. Amazonia itself must be developed as a well-rounded, integrated economic community.

The drafting commission for the new Hylean Amazon Institute has broken down its unprecedented task of geotechnic reconnaissance into three phases covered by the natural sciences, the social sciences and medical science. During the first year the survey staff is undertaking the preliminary charting of the lines of attack.

The first phases may be thought of as a consolidation and extension of the knowledge gained during the labors of generations of botanists, zoologists and other natural scientists who have worked in the Amazon valley system. The cataloguing of a complete scientific reference library of Amazonia is a formidable project in itself, owing to the immense amount of published material. Martius' great encyclopaedia of Brazilian flora alone fills 40 volumes and required the first half of the nineteenth century to complete.

But this is the simplest first step; from here the agenda projects a program of comprehensive botanic and zoologic exploration. A chain of regional experimental gardens and forest reserves will be established. Specimens of insects and plants must be collected and classified. A "census" of animal species must be made. Extensive ecological studies must be pursued in the field to determine the interrelations of the teeming life of the various subregions.

And of course, underlying the investigation of life phenomena there is to proceed the even more basic study of the land itself—its geology and physical geography, the nature of its myriad soils and their mineral substructures—all to be tied together cartographically by the great new 1:1,000,000 Amazonia map now being prepared by the Brazilian Geographic Council.

The task outlined for the social sciences is equally broad—and perhaps even more interesting. It is generally conceded that the "problem of the Amazon" may be summed up as the problem of establishing and maintaining a vigorous and stable population in the region. Without such a population, "development" in any sense—mercantile, economic or cultural—is impossible. Yet it is just in this task that the methods of Western civilization in Amazonia have so far proved inadequate.

One elemental fact that must be faced is this: any permanent and distinctively Amazonian society must be predominantly forest-dwelling. To think in terms of "clearing the jungle," as the Westernized colonist has been apt to do, and then to attempt to impose upon it a temperate-zone pattern of agriculture, is utterly impracticable. Only by maintaining unbroken the mantle of native climax-vegetation can the fertility of tropical humus be maintained, and the prodigious growth-power of tropical plant life be utilized. The end products of that growth—the wealth of fibers, woods, resins, oils, waxes, fats, fruits, tubers, botanic essences—must form the raw materials of a specialized technology capable of producing in abundance the foodstuffs, the textiles and clothing, the buildings and dwellings, the tools and utensils, of a true Amazon-based society. The members of such a society must know how to live comfortably, and to maintain health and vigor, in the rainforest. They must be master of many arts and skills appropriate to their environment.

It is probable that even the population-density patterns and the modes of exchange and distribution of such a society must be very different from Western norms. One of the most baffling characteristics of the Amazonian jungle, from the point of view of commercial exploitation, has always been the scattered distribution and intermixture of plant types. For example, the valuable hardwoods which are there in abundance never occur in dense stands suitable for mass cutting and lumbering operations. In a square kilometer of heavy forest growth, the same species of tree may not be repeated twice.

To utilize resources of this kind, over a large area, a corresponding diffusion of manpower would seem indicated. The uneconomic cost of mass-transportation facilities—except along waterways—would combine with this factor to suggest a pattern of numerous, well-distributed communities, each largely self-sufficient in the production of the bulk necessities of life, each harvesting the rich and varied crops of the surrounding forest. The populations of these communities would consist largely of woodsmen or "forest farmers," and of craftsmen and technicians trained in extracting, refining and processing the wealth of botanic substances.

What better parent stock for the breeding of such a forest-adapted culture could be found than the 300,000 to 400,000 native Indians in the region? Accordingly, the anthropologists of the new Institute plan a complete study of the patterns of the native cultures, folklore, language and intergroup reactions. They will seek to understand and evaluate the way of living that subdued the ever-present threat of malaria with dietary regime and quinine long before Western medicine was able to cope with it; that worked out a surprisingly subtle empirical chemistry of botanic drugs; that laced the Amazon world with a network of *igarapé* ("canoe-paths") over which native commerce and intercourse flowed constantly. The goal of the Institute's social science program will be to develop a technique whereby the science and skill of Western civilization may be grafted intimately and understandingly into these indigenous folkways.

The native forest agronomy of the interior, with its specialized food plants such as cassava, the plantains, the avocado, the Brazil nut, is to be enriched through the application of principles of plant-breeding, soil chemistry, nutrition, and by the careful introduction of new and suitably adapted food plants. The native fishing practices are to be studied and improved. Native handicrafts and native technology are to be revived, stimulated and gradually extended in scope and power.

An interesting example of this approach is the "pá agronômica" process for hand-coagulating native latex. This process, worked out at the Belem agricultural experiment station, yields rubber comparable to that produced in the industrialized East Indian plantations, yet it may be employed by the native *seringueiro* on his own small holding. It is proposed to redevelop the moribund Amazon rubber industry on a basis of decentralized production on many independent forest-farmsteads, using improved methods and, of course, improved strains of *Hevea* bred at the experiment stations.

To direct this broad movement of grassroots economic maturization, the Institute's directors foresee a network of rural libraries, museums, technical schools, experiment stations and colleges, reinforced by mobile educational teams working with the most advanced visual aids and pedagogic techniques. Native educators and technicians trained in these institutions are to carry their skills into the deepest backwoods. Concurrently, medical science is to work to strengthen the population through the elimination of infectious diseases and the improvement of nutrition.

Along with the pattern of native forest agronomy, there may be gradually evolved a system of extractive industries forming a link with the industrial economy of the West. Rubber, methyl alcohol, acetic acid, glycerine, solvents, soaps, plastics may be obtained from the organic raw materials of Amazonia, once adequate manpower and transport become available. However, in the planning and financing of these industries careful study is required to eliminate the destructive effects which have always accompanied the introduction of the high-energy, high-cost economic operations of the West into an area of less intensive development.

The question of energy sources for such industries (and for extensive river navigation also) presents an interesting related problem. Coal and oil deposits appear to be the one deficiency of the region. Hydroelectric power, while potentially abundant, requires massive investment in structures and equipment that the economy of the valley will probably not be able to sustain for many years to come. Atomic energy may in the not-too-distant future offer an alternative, but it would inject a factor of global economy and strategy whose impact on the region would have to be carefully studied. In the immediate future scientific utilization of fuel wood, either directly under steam boilers or in the form of alcohol or distillation gases, may be possible for specialized enterprises. And for the long run, Amazonia appears to be an ideal territory in which to pioneer in the use of wood as an ever-replenishing source of energy in the form of charcoal, alcohol and the like.

In total, the Institute's program is one of the most challenging ideas on the horizon of science. Up to the present, the impact of Western civilization on other cultures has been disruptive, often to the point of annihilation. Amazonia, although it too has suffered, remains by far the greatest richly endowed region substantially untouched by this process. Even the fabulous period of the wild-rubber boom seems in perspective a mere frenzied hacking at the Hylean wilderness.

THUS the Amazon offers a virgin laboratory in which the sciences and social techniques of our civilization, perhaps grown somewhat more mature, may try their skill. The stakes in this effort are the opening up of a land very nearly the size of the United States—and at least equally endowed in natural riches—in a period of explosive economic dislocations and population pressures. Perhaps even more important, there stands the possibility of working out a pattern for human occupancy of the land which may serve as a model in many parts of the globe.

Peter van Dresser is a city planner and writer.

THE GREAT VALLEY, shown in a spherical projection from the north, covers 2.6 million square miles of the South American continent. It is roughly bounded on the west by the Andes, on the south by Paraguay, on the east by the Atlantic and on the north by the valley of the Orinoco. Rising from Andean glaciers, the Amazon flows 4,000 miles through the jungle to its delta. Its uncounted miles of tributaries are a measure of the valley's natural wealth. They drain away an annual 100 to 200 inches of rain which, together with equatorial sunlight, is a principal element of its botanical environment.


Montevideo
Buenos Aires
URUGUAY
Asunción
PARAGUAY
PACIFIC OCEAN
BOLIVIA
Belém
Amazon
Manáos
FRENCH GUIANA
SURINAM
BRITISH GUIANA
COLOMBIA
VENEZUELA
Orinoco
Bogota
Caracas
Panamá
COSTA RICA
OCEAN
CARIBBEAN SEA
50° W
60° W
70° W
80° W

SKULL of Plesianthropus was found embedded in limestone. The face appears pointed because jaw is missing.

THE MAN-APES OF SOUTH AFRICA

Recent fossil finds reconstruct a possible direct ancestor of man who lived seven million years ago

by Wilton M. Krogman

MAN is known to have existed on this planet for at least one million years. He can trace back his line with fair confidence to *Pithecanthropus* and *Sinanthropus*, the Java and China fossil men, who from the evidence of bones are the earliest known creatures that may be considered truly human. There the trail exasperatingly stops. Beyond the fragmentary remains of these generalized human beings, the genealogy of man and his anthropoid ancestors dissolves into a pathless unknown.

Superficial resemblance has argued since Darwin that man is an offshoot from the anthropoid apes. But the case remains unproved; indeed, the more it is examined, the less convincing it becomes. Between the most highly developed modern anthropoids and the most primitive living men exist differences so basic that the two can be connected only by imagining a series of "missing links" of an unimaginably paradoxical pattern—here progressing, there retrogressing, and in some characteristics suddenly striking off in an unpredictable new direction.

The search for evolutionary links between man and his elusive ancestors, whoever they may have been, is one of the most fascinating in all science. It has engaged the unremitting attention of fossil hunters for a period of more than half a century. Until very recently, however, they had unearthed disappointingly few clues.

Now they have picked up what appears to be a very warm scent indeed. In South Africa, during the past few years, Dr. Robert Broom has discovered fossil bones that have compelled us to recast our thinking as to when and where man made his first appearance on the earth. The bones make up a number of sub-human skeletons. These South African "Man-Apes," of which the best-known is named *Plesianthropus* (from the Greek *plesio*, meaning "close to," and *anthropos*, "man"), are truly astonishing connecting—not missing!—links between man and the ape-like forms from which he arose. Notice that the word is "ape-like." If we adhere to the term "ape-like" or "anthropoid" in describing man's ancestors, we shall avoid prejudging the question of man's exact relationship to the apes.

The Plesianthropus story begins with a dramatic prologue in 1925. Dr. Raymond Dart, professor of anatomy at the University of Witwatersrand, was keeping a sharp eye on the digging in an old limestone quarry near Taungs, in Bechuanaland, where many fossil apes had been found. There, from the solid rock, was dug one day in 1925 a limestone cast of the inside of a skull. Its shape was so unusual that Professor Dart pressed on; soon his diggers unearthed the front half of a skull top and an almost complete facial skeleton, all clearly belonging to the same individual. The skull had a full set of deciduous or baby teeth, plus the first permanent molar. The fossil was therefore that of a youngster about six human years old.

Some parts of this skeleton were definitely ape-like. But others, especially the teeth, were very much like man's. Indeed, if the teeth had been found separately, they would have been pronounced human. The whole skull showed such an amazing blend of anthropoid and human traits that Dart immediately concluded that he had found an important intermediate form. He gave it the name *Australopithecus africanus* (meaning southern ape of Africa).

Dart's find was fascinating but inconclusive. It is hard to be sure about an immature skeleton: the skulls of a young anthropoid and a young child are much more alike than those of adults.

Then, in 1936, Dr. Broom, chief paleontologist of the Transvaal Museum in Pretoria, picked up the track again. At Sterkfontein, in the Transvaal, he found several fossil fragments which fitted together to form part of a skull. It was evidently close kin to Dart's Australopithecus, but this skull was adult. Broom first called his find *Australopithecus transvaalensis*, and later renamed it *Plesianthropus transvaalensis*.

Two years later at Kromdraai, just two miles away, a schoolboy casually picked at a weathered outcrop of fossil-bearing limestone. He stuffed some bits of bone and teeth into his pockets, along with other boyish treasures, and went his way. When Broom accidentally heard of these acquisitions, he tracked the boy down. In his trouser pocket were four priceless teeth, the remains of still another member of the same sub-family as Australopithecus and Plesianthropus. Broom called this third genus *Paranthropus* (meaning man-like) *robustus.*

Now the hunt grew vigorous. It was interrupted by the war, but was resumed last year, with immediate and brilliant success. During the past few months, Broom has found a number of excellently preserved fossils, including a complete skull and an "almost perfect pelvis, femur, tibia, a number of ribs, some vertebrae and a crushed skull" of an adult female about four feet tall.

Broom now has Plesianthropus fossils representing at least 12 and possibly 15 individuals. Plesianthropus is represented literally from head to toe, although no single individual's skeleton is anywhere nearly complete. Paranthropus is represented by most of the palate, the left side of the face with the cheekbone arch, the right side of the lower jaw with most of the teeth, parts of the skull-base, the skull side-wall and fragments of arm, hand and foot bones.

Here, then, is an extraordinarily complete collection of bones, outlining a group of creatures which stand somewhere between ancient anthropoids and man. Now, the first thing the anthropologist wants to know about these bones is their age. To fit them into a family tree, we must place them in time with relation to the other anthropoid (ape-like) and hominid (man-like) fossil remains.

The four most recent geological periods, counting back from the present, are: the Pleistocene (the last million years), the Pliocene (the preceding six million years), the Miocene (the 12 million years before that) and the Oligocene (the 16 million years before that). The earliest men, Pithecanthropus and Sinanthropus, are generally placed in the early Pleistocene. The earliest known anthropoid forms go back to the Oligocene.

The evidence of plant and animal fossils with which Broom's and Dart's finds were associated appears to put them in the Pliocene period. Plesianthropus' bones, for example, were found associated with remains of a fossil baboon, *Parapapio.* Parapapio, in turn, was linked with a fossil hyena whose name is *Lycyaena.* And Lycyaena is definitely dated in the early Pliocene. Recent stratigraphic and physiographic evidence suggests that we had better accept a Pliocene date with some reservations. More precise geologic analysis is necessary.

If we accept the paleontological evidence we may estimate that the South African Man-Apes lived about seven million years ago.

NOW let us look at the bones themselves. The three South African genera—Australopithecus, Plesianthropus and Paranthropus—are grouped as the sub-family *Australopithecinae,* belonging to the family *Hominidae.* Because of their skeletal similarities, we can consider all three genera together.

We start with the size of the brain, the most important single measure in distinguishing man from the other primates. The Australopithecines had a small skull, closer to an ape's than a man's. The brain volume of Plesianthropus ranged from about 400 to 700 cubic centimeters, that of Paranthropus was probably from 440 to 750 and Australopithecus' was from 500 to 800.

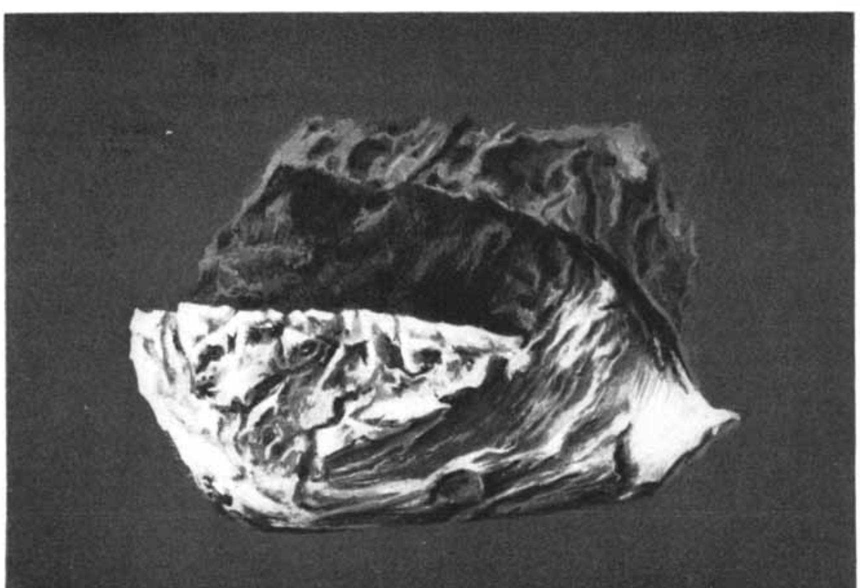
This is an improvement on the apes. Their brain sizes range roughly from 300 to 600 c.c.; the largest ape brain ever found, that of a male gorilla, was 620 c.c. But in brain size Plesianthropus and his fellows were definitely sub-human. The most primitive true man, Pithecanthropus, had a brain of 650 to 1,000 c.c. Neanderthal man, who lived about 50,000 years ago, ranged from 1,070 to 1,730 c.c. Modern man, excluding pathological cases, varies in brain volume from 860 c.c. for a South African Bushman to 2,000 for a European.

It seems clear, then, that the Australopithecines had slightly larger brains than anthropoid apes and overlapped into the lower range of the early hominids. But they did not quite reach the lowest limit of *Homo sapiens.*

The next important clue is the teeth. Because they are the hardest part of the skeleton and hence the last to disintegrate, teeth constitute the principal remains of our paleontological past. It has been said that up to 20 years ago almost 75 per cent of our knowledge of anthropoid and human evolution was based upon fossil teeth.

Without going into precise dental detail, it can be said that the Australopithecines' teeth are unmistakably man-like. The structure and form of the deciduous and permanent teeth, their eruption time and order, their alignment in the jawbones are all human. Moreover, the pattern of toothwear and the way the jawbone is hinged to the temporal bone at the base of the skull suggest that Plesianthropus

LOWER JAW of Plesianthropus has many human characteristics. It has a rudimentary chin and teeth show patterns of wear similar to those in man.



PELVIS is also man-like. Plesianthropus presumably walked upright.

chewed his food with a rotary grinding motion, like man, instead of chomping it, like the anthropoids. (Lil' Abner notwithstanding, human beings are not in the habit of "chompin'" their food.)

What did Plesianthropus look like? His facial profile was relatively man-like; it was losing the anthropoid slope. The bony ridges above his eye sockets were less protruding and he had the beginnings of an arching human forehead. Also like man, he had fairly slender cheekbone arches. The front surfaces of his upper jaw were vertical, not slanting as in apes. The "simian shelf," a characteristically anthropoid platelet of bone on the under side of the lower jaw, had all but disappeared. And on the front of the lower jaw was a little knob—the beginning of a human chin.

Plesianthropus' bones retained many anthropoid features. The side teeth in his upper jawbone, for instance, were arranged like an ape's. The contact-line, or "suture," between the two bones of the hard palate, which in man usually closes at birth, appears to have delayed in closing, as with an ape.

Below the neck, Plesianthropus looked like an incompletely developed biped. His elbow joint did not flex as freely as man's; his arms seem to have been permanently bent. His anklebone, intermediate between a human and an ape-like form, indicates that the ankle may have been designed for weight-bearing, as in an erect man, but that the foot may still have possessed a grasping big toe. The bone in the center of his palm suggests a hand freed from locomotion but with limited flexibility for manipulation. His thighbone and hipbone, in the opinion of some, were mechanically adapted for standing, walking and running in the erect position.

Did Plesianthropus actually walk upright? All the evidence points to the likelihood that he did. One significant sign is the position of the foramen magnum and the occipital condyles. These structures form the joint where the skull rests on the backbone. In anthropoids, this joint is far back on the skull-base. But in man, it is in the middle, so that his skull is balanced squarely on the spinal column. Plesianthropus was well-advanced toward this balanced position. His foramen magnum was much farther forward than that of the anthropoids, but not as far forward as man's.

As to the quality of Plesianthropus' brain and his abilities, we have little evidence. The casts of the inside of his skull do not show his brain configurations in any accurate detail. They tell us only the approximate size of regions in his brain. From his study of the brain casts and skeleton, Broom's associate Schepers concludes:

"These fossil types were capable of functioning in the erect posture, of using their hands in a limited sense for skilled movements not associated with progression, of interpreting their immediately visible, palpable and audible environment in such detail and with such discrimination that they had the subject matter for articulate speech well under control. . . . They were also capable of communicating the acquired information to their families, friends and neighbors, thus establishing one of the first bonds of man's complex social life. With all these attributes, they must have been virtually true human beings, no matter how simian their external appearance may have remained."

In contrast with this extreme interpretation is the more conservative—and more acceptable—view of the English anthropologist W. E. Le Gros Clark. The endocranial casts suggest to him "that the mental powers of the Australopithecines were probably not much superior to those of the chimpanzee and gorilla." Nonetheless, on the basis of another piece of evidence, Le Gros Clark concedes that their intelligence was "definitely in advance" of that possessed by the modern apes. In the same cave with some remains of Australopithecus were found the crushed skulls of baboons, suggesting that the mental powers of Australopithecus were great enough to enable him to hunt and kill monkeys.

FRONT of Plesianthropus' skull shows small brow ridges and arching forehead of man-like anthropoid.

What does our evidence on the Australopithecines add up to? It is this: that in the Pliocene period, about seven million years ago, there lived a form that was intermediate between anthropoid and man. He had a brain near the anthropoid, a dentition practically human, and a general skeletal build well-adapted to the human upright position and locomotion. The Australopithecines fulfill almost every requirement of a real connecting form. Moreover, they show that the rate of evolution differs in various parts of the body: thus dentition is ahead of long bones, and long bones are ahead of brain.

We are certainly not sure of the precise evolutionary position of the Man-Apes. The problem is: were they a link in the direct line to man, or were they abortive offshoots of an attempt by an ape to make the grade to man's estate? The first alternative seems to me the more likely.

ANY chart of human and anthropoid evolution must be tentative and speculative. Let us draw one picturing a set of reasonable possibilities. We can start (we must start somewhere!) with *Propliopithecus,* a fossil anthropoid found in an Oligocene formation of Egypt which is about 30 million years old. He was not an ape, mind you, but most likely a common ancestor of apes and man. From Propliopithecus may have come *Dryopithecus* and *Sivapithecus,* anthropoids of the Miocene and Pliocene of Europe and India. They in turn, still according to our hypothesis, were ancestors of Plesianthropus and his cousins. The evidence of Plesianthropus' teeth strongly suggests that he and his fellows may have been ancestors of the first true men, Pithecanthropus and Sinanthropus. (*Gigantopithecus* of Java may fit into the line here, but there is some doubt whether he was anthropoid or hominid.) From the Java and China men, in turn, via Solo man of Java and Neanderthal man of Europe, finally came Homo sapiens.

Where do the apes fit into this picture? There is increasing conviction that the modern anthropoids (gibbon, orangutan, chimpanzee and gorilla) have arisen independently of man. Somewhere in the Oligocene or the Miocene, their ancestors split off from the common trunk to form separate branches. They may have split off from Propliopithecus or, more likely, Dryopithecus and Sivapithecus.

This chart represents only one of several plausible possibilities. The Australopithecines may, indeed, have been an offshoot from some still undiscovered ancestral form. The modern apes and anthropoids may each have come from a different ancestor. But the chart offers a tenable present view. If its chain of reasoning be true—and I suggest that it is reasonably so—then human evolution is almost a straight-line parallel of anthropoid evolution, with a basic split-off of the several lines in the Oligocene period 30 million years ago, ± a few million.

It is the South African Man-Apes who have pointed the way to this conclusion. In effect they have emancipated man from a presumed simian ancestry. "Family tree" may be a misnomer. Perhaps we never were brachiators, *i.e.,* swingers-through-the-trees-by-our-arms. It is entirely possible that for millions of years we've walked erect, striding head up toward our evolutionary destiny, whatever it may be.

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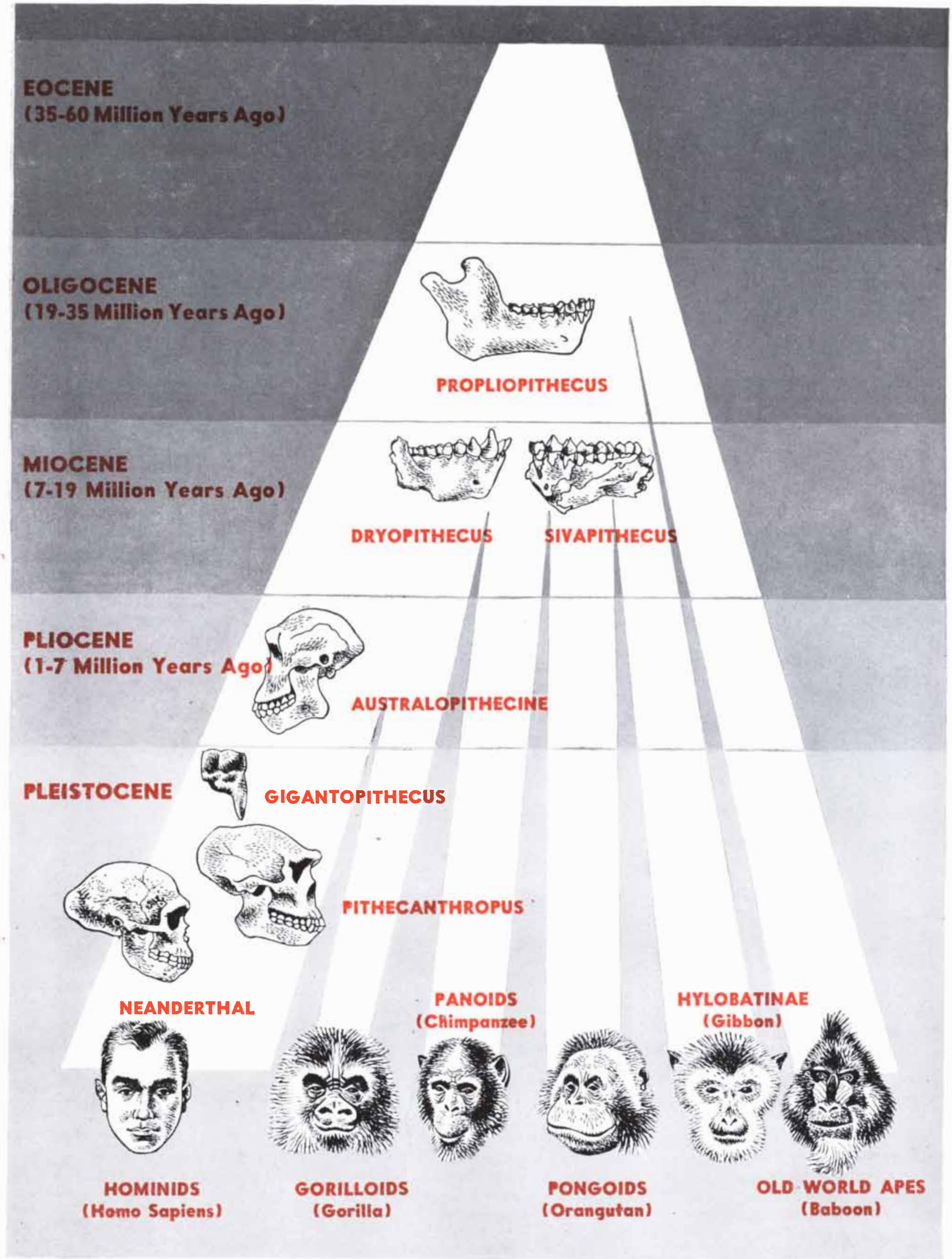
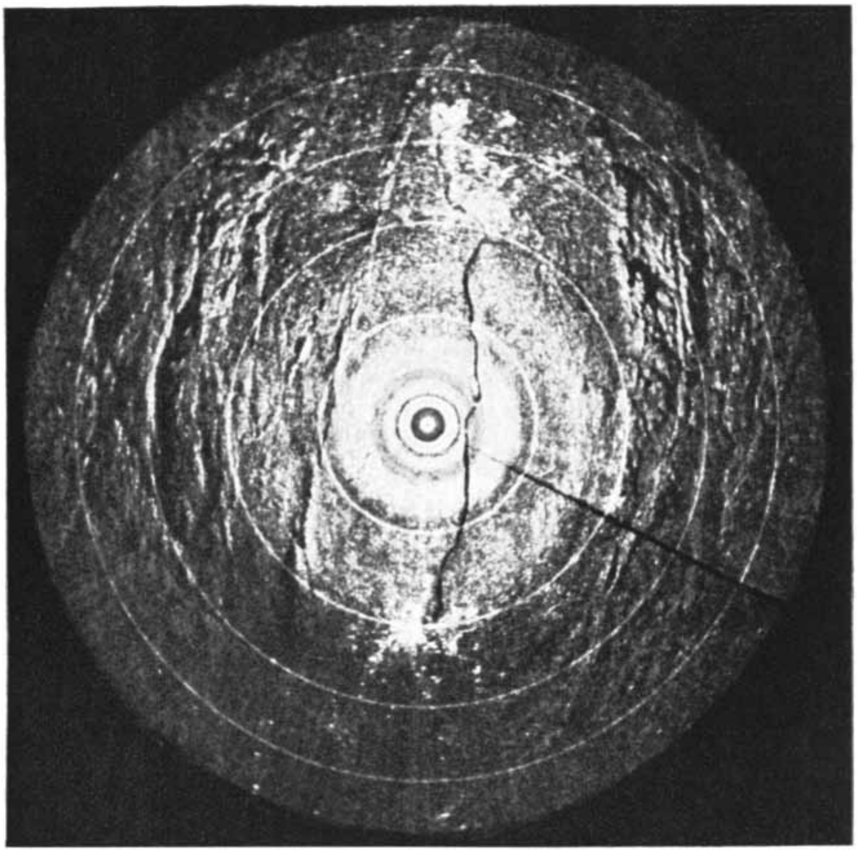


EVOLUTION of man and apes appears to have proceeded from common ancestors in the Miocene and Oligocene periods. Here the Australopithecines are in the direct line of human descent. Complete fossil skulls are shown where reconstructions have been made. Incomplete fossils such as Gigantopithecus are not drawn to scale.

CONCERNING "SOCIAL PHYSICS"

The quotation marks indicate that it is not an accepted science, although it may well become one. Its principal concept: the behavior of people in large numbers may be predicted by mathematical rules

by John Q. Stewart



RADAR PROJECTION of an American countryside is a crude visual expression of one rule in social physics. Here an airplane flying between Hartford, Conn. (*bottom*) and Springfield, Mass. (*top*) sweeps the ground with a beam of microwaves, translating the reflected signals into an image on a cathode-ray screen. Since areas where many buildings are concentrated reflect the signals better than those with fewer buildings or no buildings at all, the most densely populated areas appear as the brightest spots on the screen outside of the overexposed central part. This imperfectly depicts the fact that people tend to concentrate by an inverse-square relationship like that of gravity. The formula used in social physics, explained in text, is Pp/d.

A GIANT observer who himself was as big as the earth could easily consider a man as being no more than a molecule. From such a vantage point, an observer equipped with appropriate devices for measuring population densities and movements might discover that, like molecules in a gas, groups of men obey certain simple physical laws. The point of view would be favorable for formulating an exact social science—a "social physics."

Molecules are unable to study themselves with such detachment. Nevertheless, man is strongly tempted to try to find some mathematical order in human relations. More than one investigator has sought to apply the analogies and precision of physics to the study of societies. The term "social physics" is at least as old as the nineteenth century French philosopher Auguste Comte, although he contributed nothing to the subject but its name. Today social physics is still only a science in the making. It still has far to go before it is ready for uncritical acceptance. But already its barrier-breaking results unite demography (the study of populations) with phases of economics, and both of course with physics.

But what has physics to do with people? Men, after all, are more than molecules. Can we advance the study of human relations by forgetting that they are human? Or, to put it another way, can we roughly approximate satisfactory over-all solutions of mass sociological problems by an analysis that averages the conflicting desires and the varied characteristics of individuals into a uniform mathematics?

I am confident that we can. People can be counted. They exist in space and time. Their distances apart can be measured. Their activities are subject to mechanical limitations which can be described. True, an individual human being is a complex, often unpredictable organism. But the physics of atoms is subject to similar uncertainties. The famous indeterminacy principle, stated by the German physicist Werner Heisenberg, means that the motions of individual corpuscles cannot be described with indefinitely great precision. The behavior of an individual particle is exceedingly hard to predict. Nonetheless the physicist makes progress because the *averaged* motions of a group of corpuscles conform to mathematical formulas or "laws." In the same way, human behavior can be averaged.

When the physicist attempts to study people in their societies by comparing them to molecules in fluids, his difficulty is not that there are too many people but too few. If reduced to the size and density of molecules in normal air, the entire world's population would comprise a cube only a thousandth of an inch on a side. To reduce the planet to this size, our physicist must be a coarse-grained giant of astronomical dimensions. Little wonder that professors of history, politics and economics are likely to oppose the notion of loosing such a bull in such a china shop. But he was already there, even before Hiroshima.

Here we should pause to define our subject. Social physics examines human relations in terms of space, time and number. In brief, it is the quantitative study of society. Its raw material is statistical observations about people. Whenever appropriate, it draws on mathematical physics for suggestions and analogies which seem usable as guides for discovering and organizing social concepts. It also uses such generally-accepted and well-tested sociological information as already exists. It includes, for example, the subject of econometrics, which is a union of mathematics, statistics and economics.

Thus much suitable material lies ready to hand. Indefatigable social statisticians, especially in recent years, have accumulated hundreds of shelves of numerical observations. For example, the sixteenth census of the United States, made in 1940, runs to more than 60 volumes and cost 50 million dollars to compile and publish.

WHEN analyzed, this material reveals some astonishing mathematical relations. George Kingsley Zipf of Harvard University has found, for example, that the number of telephone calls between any two cities in the United States is roughly proportional to the product of their populations divided by the distance between them. The same relation holds true for the number of bus passengers between cities and the number of railroad tickets sold. The enrollment of students from a specified state in any given privately endowed, "national" university or college tends to be proportional to the population of the state divided by its distance from the campus. Attendance at the New York World's Fair in 1940 from each state was proportionate to the population of the state divided by its distance from Flushing, Long Island. The number of obituaries from specified cities in the New York *Times*, the number of news items from other cities in inside pages of the Chicago *Tribune*, and the circulation of the St. Louis *Star-Times* in counties outside the city all show surprising agreement with the population-divided-by-distance rule.

The task of the social physicist is to invent new systems of concepts which fit such observational situations. In doing so, he is guided and encouraged by the glorious history of physics itself.

The present state of social studies may be estimated as little superior to that of physics at the time of the seventeenth century astronomer Johann Kepler. It was only three centuries ago that physics learned to supplement words with numbers. The entire body of knowledge of physical principles accumulated up to that time would not make a single lesson assignment now for a high-school freshman. Modern physics had its beginning in celestial mechanics. It advanced through three successive stages, typified by the names of three astronomical investigators: Tycho Brahe (1546-1601). Kepler (1571-1630) and Isaac Newton (1642-1727).

Tycho Brahe over laborious years accumulated many reasonably accurate observations of the positions in the sky of the planets, in particular of Mars. Because precise observation was far from being a routine requirement of science at that time, this Danish nobleman was a great pioneer. Kepler became his secretary and inherited his sheaves of observations. Kepler deserves an even higher place among the founders of modern science than he usually is accorded. He had a fanatical faith in number as a means of insight into physical phenomena. To modern scientists that seems no faith but obvious common sense—until someone suggests that number is equally important for social phenomena! Kepler made trials, errors, retrials—many of them cockeyed—before he succeeded in stating the last of his three "laws" on the orbital motions of the planets. These are not general laws of nature but empirical statements of mathematical regularities which apply only to planetary motions. But when Newton sought to reduce all motion everywhere to orderly description, he needed only to think of Kepler's short mathematical statements, instead of having to essay the impossible task of carrying in mind many thousands of separate measurements. Newton, without much trouble, because he was "a giant who stood on giants' shoulders," carried mechanics to its third stage of rational interpretation of all known motions.

The phenomena with which social physics must deal are less tractable, and more intricate, than the harmony of the spheres. As already indicated, this is partly because we view them from the microscopic rather than the macroscopic level, being ourselves "molecules." What the student of the kinetic theory of gases calls a minor fluctuation in pressure may represent a terrific series of bumps to a lot of molecules.

In the modern study of society, no single individual has been a Tycho nor a Kepler, and no one investigator is likely to repeat the role of Newton. Thanks to the labors of the social statisticians, however, the Tychonic stage is unmistakably here. And the Keplerian stage is in progress.

The available numerical data on society include censuses of populations, vital statistics, tables of geographical areas and distances, rents, prices, wages, dividends, interest rates, studies of business cycles, public opinion polls, psychological tests relating to social behavior, quantitative observations in philology. So far only a very small proportion of this grand observational array has been reduced to concise mathematical regularities. The workers in this field are few, and fewer of them are sociologists or economists. Outstanding are the contributions of Professor Zipf of Harvard, whose original field was philology.

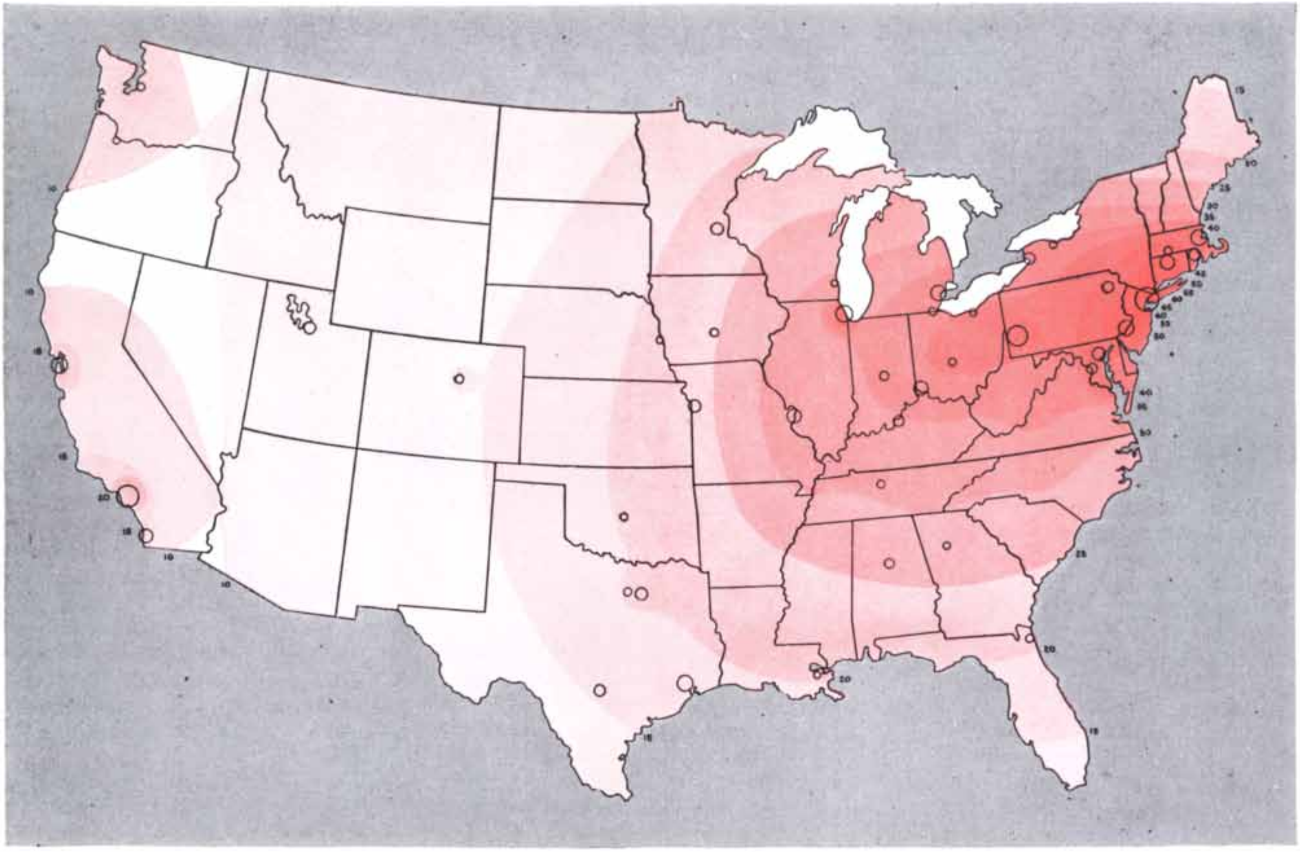
Professor Zipf has emphasized particularly the "rank-size rule." This rule shows a definite mathematical relation between the relative rank and size of institutions in a series. As applied to cities, for example, it determines that the second largest city in a certain group has $1/2^n$ as many people as the first; the third largest has $1/3^n$ as many as the first, and so on—n being a constant depending on the series considered. With $n=1$, this rule has applied with remarkable regularity to the populations of cities in every United States census since 1790.

THE writer cannot discuss all the empirical regularities that have been announced for social phenomena. But enough regularities exist to establish the conclusion that certain types of human relations, *on the average and only on the average*, conform to mathematical formulas resembling the primitive "laws" of physics.

When we come to the Newtonian stage of theoretical interpretation, we encounter our major difficulty. Scientists are prone to believe that every branch of study has its own peculiar relationships, most of which are not duplicated elsewhere. In this view, principles of physics could have no meaning in social study. This conventional view was emphatically opposed, however, by Gottfried Wilhelm Leibnitz, who was Newton's great contemporary and rival in mathematics, physics and philosophy. Leibnitz believed thoroughly in the transferability of ideas and relations from one field to another. A hundred years after both savants were dead, Newton's own law of gravitation became an instance of such transfer. A principle of exactly the same mathematical form as his law was found to hold in electrostatics, and again in magnetism.

Now the same mathematical form serves to organize a wide range of observations about people. To see how it does, let us consider the principle in some detail. Newton stated his law in terms of the force between two attracting masses. The force varies as the product of the two masses divided by the square of the distance between them. It is often more convenient to state the same principle in terms of mutual gravitational energy instead of force. Force is a directed quantity—a "vector"—and therefore forces have to be added by trigonometry. Energy is a non-directed quantity—a "scalar"—and scalars add by mere arithmetic. Thus the gravitational energy between two masses varies as the product of the masses divided not by the square but by the first power of the intervening distance.

This important difference makes pos-



"POTENTIAL" in social physics is a measure of the influence of people on people. The influence of a city at a distance (example: the number of telephone calls made from it) is represented by its population divided by the distance. In this map New York City has the greatest potential. Its strength is indicated by number at the edge of each contour. The influence of other cities (*circles*), save those on the West Coast, is merely local.

sible the elegant solution of problems when several gravitating masses interact, as in the solar system. Joseph Louis Lagrange, the eighteenth century French mathematical physicist, was the first to appreciate this convenience. His method describes the influence of a body at any separated point in space as the body's "gravitational potential" there, and this potential, V, is proportional to the mass of the body divided by the distance. Thus the potential of the sun, whose mass is designated by M, at a certain point at distance d away from it, is M/d. If a planet, of mass m, is located at this point, the mutual gravitational energy of sun and planet would be Mm/d.

When there are several distant masses, the potential produced by each at any given point is computed as though the other masses did not exist. To obtain the total potential at that point, the separate potentials of all the masses are added up. This same pattern of related equations and concepts (and others not mentioned here) holds not only for gravitation. but also in electrostatics and in magnetism. In electrostatics, the symbols for mass, M and m, are replaced in the equations by the symbols for electric charge, E and e. In the theory of magnetism, we use pole strengths instead of charges or masses. Although the symbols refer to very different things, the equations are the same.

Now let us apply these equations to populations. In the place of mass or charge we substitute "population density." This term is actually derived from the physical concept of surface density; the analogous unit in electrostatics would be the amount of surface charge per unit area of the charged body.

Pursuing the analogy, we may take the density of population in a given area—say a city—as a measure of that population's influence, or potential, at distant points. By the equation we considered above, the influence of one city upon another would be proportional to the product of their populations divided by the distance between them, or Pp/d.

DOES this relation hold in fact? It does indeed, for a surprising variety of phenomena, as we have seen in the case of telephone calls and many other items of human commerce. There now exists a considerable collection of interesting statistics to confirm the "Pp/d hypothesis."

The population-divided-by-distance formula was originally used in connection with the geographical distribution of college undergraduates. Its close analogue with physics suggested the concept of a "potential of population" corresponding to gravitational potential. This in turn suggested study of the mutual "demographic energy" between cities. A diagram of energies between cities is very similar to one illustrating mutual gravitational energies between bodies in the solar system.

From census data on the distribution of people, a map can be computed showing potentials of population at all points. Such a map, like a topographical one, has contours outlining levels of equal potential. In the United States, potentials in general rise toward New York, except west of the Sierras. In Europe, Asia and South America, they likewise rise toward the great coastal cities; in Africa, toward the major river valleys.

As everyone knows, the proportion of city-dwellers in the United States has consistently increased. Should the total United States population ever reach 260 million, the indication is that the rural population, except doubtless for a small, stubborn remnant, will have disappeared. All the people would be living in 10,400 cities, and the largest city, probably New York, would have a population of 26 million. If the total population were to go on increasing beyond that highly problematical level, the larger cities would begin to eat up the smaller ones, and finally everyone would live in a single great city whose population works out as 6,250 million. But these extreme extrapolations had better be regarded as just a little fun with arithmetic.

The map of potentials of population, however, is much more than a mathematical exercise. A completely accurate map, which must exhibit not only the major influences such as New York City but also local loops of potentials surrounding every sizable city, is laborious to compute and construct. When carefully done, it is highly rewarding, for it gives us some significant social quantities.

State by state, and even county by county, population averages along contours of equipotential run remarkably true to form. This is true, for example, of population densities in the region embracing the 28 states east of Colorado not including the deep South, *i.e.*, principally the Middle West, Middle Atlantic and Northeast. The density of rural population tends to remain constant along any given contour. When we move to a higher contour (*i.e.*, a higher potential) in the direction of New York, rural population density increases according to the square of the increase in potential. But densities of the rural non-farm population (*i.e.*, in villages) increase as the cube of the potential.

As the potential rises, the death rate, suicide rate and the median age in rural areas also tend to rise, while the birth rate falls. Especially interesting is the relation of economic statistics to the contours. In the 28 states, average non-farm rents rise as the first power of potential, while values of farmland per acre tend to rise as potential squared. Differentials in potential from one population to another are significant for problems of business, labor and economic planning.

These correlations and counter-correlations had better be regarded as only empirical, for the time being. A system of equations is under test which, if successful, will serve as a general rational interpretation of most of them. This system of explanation, in addition to using the concept of demographic gravitation, brings in the "human gas."

The gas analogy, or some equivalent concept, is necessary to explain the resistance of human beings to social gravitation. We know that there is a long-term drift of people toward the principal gravitational centers. Were it not for the expansive force of the human gas, representing the need of individuals for elbow-room, the center-seeking force of gravitation would eventually pile everyone up at one place.

Once a potential map has been made, the total demographic energy of all the people with respect to one another can be computed. To compute the demographic energy of a nation, the population of each area is multiplied by the potential there, and half the sum of all these products is the total energy. We must divide by two to avoid counting the same energy twice; for example, to compute the mutual demographic energy of New York and Chicago at both places would be a duplication. The unit of energy is formed by two average Americans one mile apart. There are so many possible pairs among the 140 million people that the total Pp/d sums to hundreds of billions.

The trend of applications of Pp/d to social activities suggests that economic wealth is related to demographic energy. Direct evidence to support this hypothesis can be found in the income and census figures for the past century. The annual income of the United States increased from one billion dollars in 1829 to nearly 69 billions in 1939. During the same period the nation's "demographic energy" rose from decade to decade in about the same proportion—from 300 billion units in 1829 to 25,000 billion in 1939. If we divide the total income in any year by the number of units of demographic energy, the income per unit of energy comes to an average of a quarter of a cent. In other words, two average Americans one mile apart create by their free mutual relations an average of 0.25 of a cent per year. This ratio fluctuates with the boom-and-bust phases of the business cycle, reflecting the effects of inflation and deflation. The present annual income is estimated at 200 billion dollars and the demographic energy at 30,000 billion units, which indicates that the income per unit is 0.67 of a cent and that the present cheapening of the dollar is the greatest on record.

It is an attractive hypothesis to assume that Pp/d is a measure of the number of effective human relations between a group of P people and another group of p people who are d miles away. If each person in the P group is paired with each one in the p group, the number of pairings is P x p. It is common sense to assume that distance reduces the number of effective relations between the two groups, and evidence of many sorts indicates that the factor 1/d takes care of this. So demographic energy tentatively may be interpreted as a measure of human relations—leaving exactly what we mean by that to be defined by further observational tests.

Perhaps the crass materialism of this treatment of human beings can be relieved by taking to heart Leibnitz's philosophy of the monads. The monads, you will remember, are units of life which are characterized by possession of a soul. They do not push one another about as molecules do, but act through inner sympathy. When social physics advances to the quantum level, it may appear that the separating effect of distance is only external and statistical, and that one person can come into contact with another through impulses which make nothing of space and perhaps nothing of time also.

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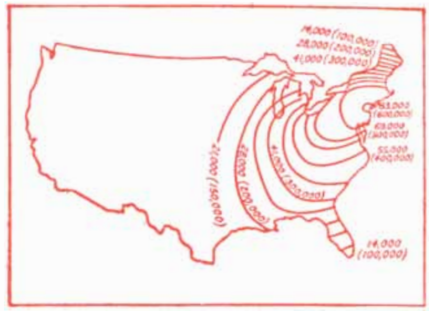
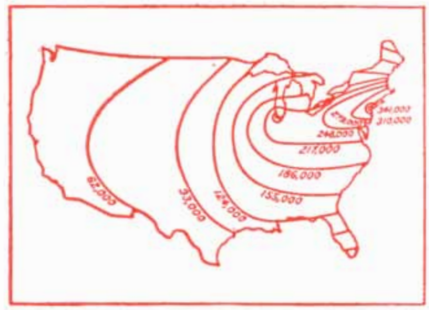
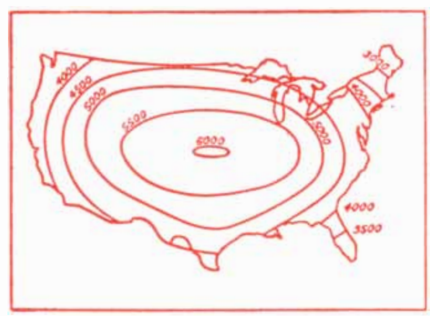


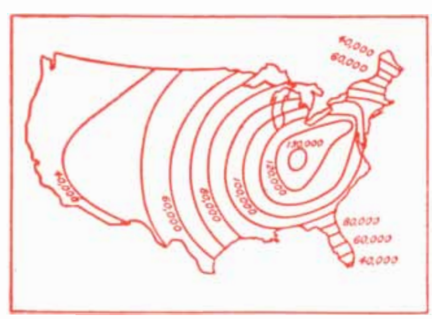
1840 POTENTIAL, compared in parentheses with 1930 potential, shows potential relationships change very little with population growth.



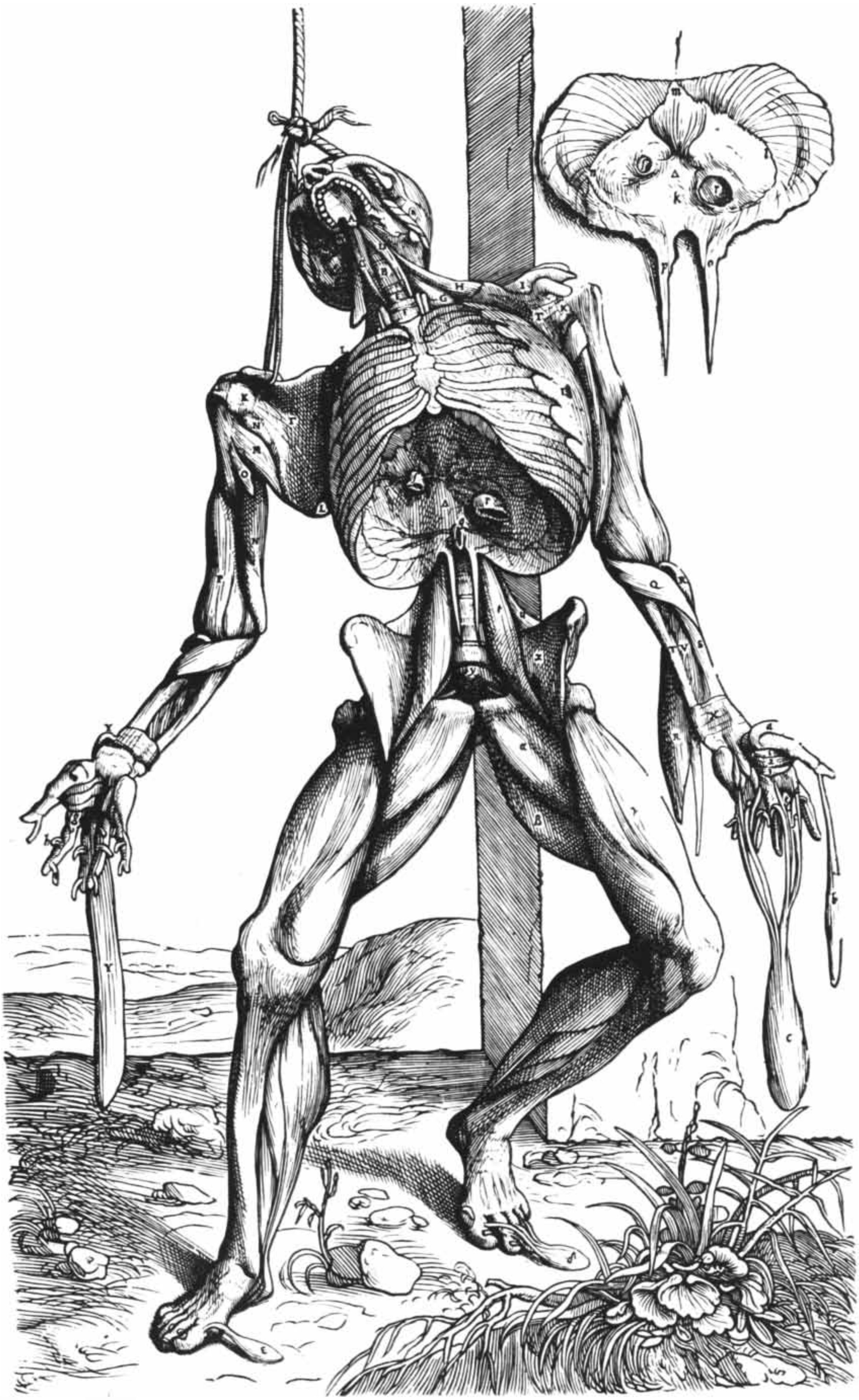
1900 POTENTIAL is shifted westward. The potential numbers on this page are larger than those on opposite page because units are smaller.



UNIFORM DENSITY of population would cause potentials to center in Kansas, illustrating how demographic and actual geographic centers differ.



RURAL POTENTIAL, *i.e.*, that outside of incorporated places, is less centered on New York. Peak potential is near Cincinnati and Louisville.



DISSECTED CORPSE in one of Jan Stephan van Calcar's woodcuts for Vesalius' *Fabrica* is hung by a rope passing through the eye sockets and around the base of the skull. On the wall at upper right is the diaphragm.

VESALIUS: DISCOVERER OF THE HUMAN BODY

His great De Humani Corporis Fabrica, which founded modern anatomy, is also an unsurpassed work of scientific art

by Martin Gumpert

ON July 17, 1903, in Baltimore, young Harvey Cushing received the following post card from the Isle of Guernsey: "I have bagged two 1543 *Fabricas!* 'Tis not a work to be left on the shelves of a bookseller." The card was signed by the great physician William Osler. A week later came another message: "Besides the two '43 *Fabricas* I have just ordered a third. We cannot have too many copies in America & no medical library is complete without one."

By autumn the three copies had grown to six, among them an imperfect first edition discovered in a Rome blacksmith's shop by another of Cushing's peripatetic friends. When Osler returned to Baltimore, the two bibliophiles spread their loot on his dining room table. It was a solemn and happy moment. From the obscurity that sometimes attends greatness, the two friends had retrieved six first editions of a treatise which Osler called "the greatest medical work ever printed."

Osler distributed his precious volumes to medical libraries with missionary enthusiasm. For Cushing, the moment in Osler's dining room was the beginning of a lifelong labor of love. His copy of the *Fabrica* grew into the world's most complete collection of works by its author, Andreas Vesalius. It is now in the Historical Library of the School of Medicine at Yale University. Today one need not hunt abroad for a copy of the *Fabrica*. The New York Academy of Medicine has even sponsored the publication of a modern edition from the original Vesalius woodcuts.

This sixteenth century work, *De Humani Corporis Fabrica*, written by the founder of modern anatomy, is indeed one of the most daring, creative and beautiful adventures ever undertaken by the human spirit. No one who can be moved by genius should die without seeing it. For medical men, whose work so often leads to a final attitude of cynicism, it has the power to turn cynicism into enthusiasm.

It is regrettable that all young doctors are not made familiar with the life and work of Vesalius. This, however, is an unhappy by-product of the fact that even the best medical schools neglect the teaching of medical history. The anatomy textbook of today is a medical Sears, Roebuck catalogue. The anatomy of Vesalius is a testament of passionate devotion to medicine. Any doctor who has made the acquaintance of this powerful book will be better prepared for the practice of medicine and its deep and dangerous beauty.

The *Fabrica* is more than a milestone in the history of medicine. It is a great work of creative art. Curiously, it is not notable for literary quality. "As a book," Cushing once observed, "the *Fabrica* has probably been more admired and less read than any publication of equal significance in the history of science." But its text, like the libretto of an opera, has become merely scaffolding for the great music of its illustrations.

These illustrations depict man's first clear and accurate knowledge of human anatomy. Even now, after four centuries, the *Fabrica's* drawings show the freshness and enthusiasm of original discovery. In its perfect unity of format, print, picture and scholarship, the *Fabrica* is comparable to the great creations of early religious literature. Indeed, its perfection could have been achieved only through a reverence for the exquisite architecture of the human body.

The book was the joint product of a scientist—one whom Cushing ranked with Hippocrates, Galen, Harvey and Lister among the five great discoverers in medicine—and an artist, Jan Stephan van Calcar. A pupil of Titian, Calcar drew the anatomical features which Vesalius laid bare.

Great books and great discoveries are always dangerous, and the *Fabrica* was no exception. It was as daring as the later heresies of Galileo. It radically revised concepts of the structure of the human body which men had been taught for centuries. In its precise identification of all the organs, it seemed to leave no room for the "seat of the soul"—a perilous omission. The fury of the attack launched against the *Fabrica* was not reduced by the circumstance that Vesalius was only 28 when it was published.

Vesalius was a Belgian, born in Brussels on December 31, 1514. He came of a long line of illustrious physicians. His great-grandfather was doctor to Maximilian I of Burgundy. Grandfather Eberhard wrote a commentary on a famous textbook by Rhazes, the renowned medieval Arab physician. Vesalius' father was apothecary to Emperor Charles V of the Holy Roman Empire.

Vesalius' interest in anatomy began early. As a boy he dissected mice, moles, cats and dogs. These experiences possibly are reflected in the drawings of fat little cherubs performing dissections which decorate the initial letters of the *Fabrica's* chapters. By the time he had begun his medical studies at the University of Louvain, and soon afterward in Paris, his interest had become a passion. He obtained his first skeleton by robbing a gibbet.

VESALIUS' ardor for dissection did not please his instructors. In the sixteenth century it was regarded as indecent for a professor to take a knife in his own hand for dissection. At lectures this odious task was performed by barber surgeons. Vesalius reported of his teacher Guenther von Andernach, known as Guinterius, that he never saw him with a knife in his hand except at the dinner table.

The earnest young scientist soon became impatient with his teachers. Instruction in anatomy consisted of lectures, an occasional glimpse of a butchered dog and an annual dissection of a human corpse by the rude, ignorant hands of the barbers. Never did he see a nerve, an artery, a vein; never did he dare to take a bone in his hand.

So Vesalius began his own independent study of anatomy. He prowled about Paris churchyards and places of execution for subjects. At the cemetery of St. Innocent and at Montfaucon, dumping ground for the bodies of criminals, he was a constant visitor. Sometimes he fought with wild dogs for the corpses he dragged home to dissect in the quiet of his room. Soon he could recognize every bone with his eyes closed, just by touching it. His skill gained him the privilege of acting as the barber at demonstrations. While he was still a student at Louvain he shocked his teachers by conducting a demonstration in which he lectured and dissected at the same time. It was the first public dissection at the university in 18 years.

At 22, Vesalius escaped this barren environment for the stimulating intellectual atmosphere of Venice. In this period Venice was the focus of the Catholic revival. Amid contrasts of luxury and pestilence. culture and filth, the serenity of Greek theology and groans of hunger, the Renaissance was drawing to a close. Vesalius threw his useful talents into the crusade of brotherly love launched by Ignatius Loyola and his new order of Jesuits. He helped the Jesuits care for the dying, the prisoners and the lepers. He bled patients, set leeches to work and tested the wonderful healing powers of quinine, recently brought from Peru by sailors.

Presently, just before his 23rd birthday, Vesalius was appointed professor of surgery and anatomy at the University of Padua. Now he had the means to realize his great dream—to get on with the science of anatomy. He began at once to reorganize the system of instruction. One of his first ventures was a full-dress public dissection. From all over Europe, hundreds of physicians, philosophers and theologians came to see and hear his demonstration. It lasted for three weeks of all-day sessions. Vesalius dissected dogs and other animals, displayed sections of human anatomy and climaxed his lecture by exhibiting a complete human skeleton.

In the midst of the revolutionary sixteenth century, anatomy was still dominated by the second century Greek physician Galen. European medicine. emerging from the medieval spell of Arabian science, was on the crest of a surge of neo-Galenism. The revival, moreover, was led by two of Vesalius' old teachers—Guinterius and Jacobus Sylvius, the latter the most renowned medical lecturer in Europe. Vesalius himself, as he began his work at Padua, was still a loyal Galenist.

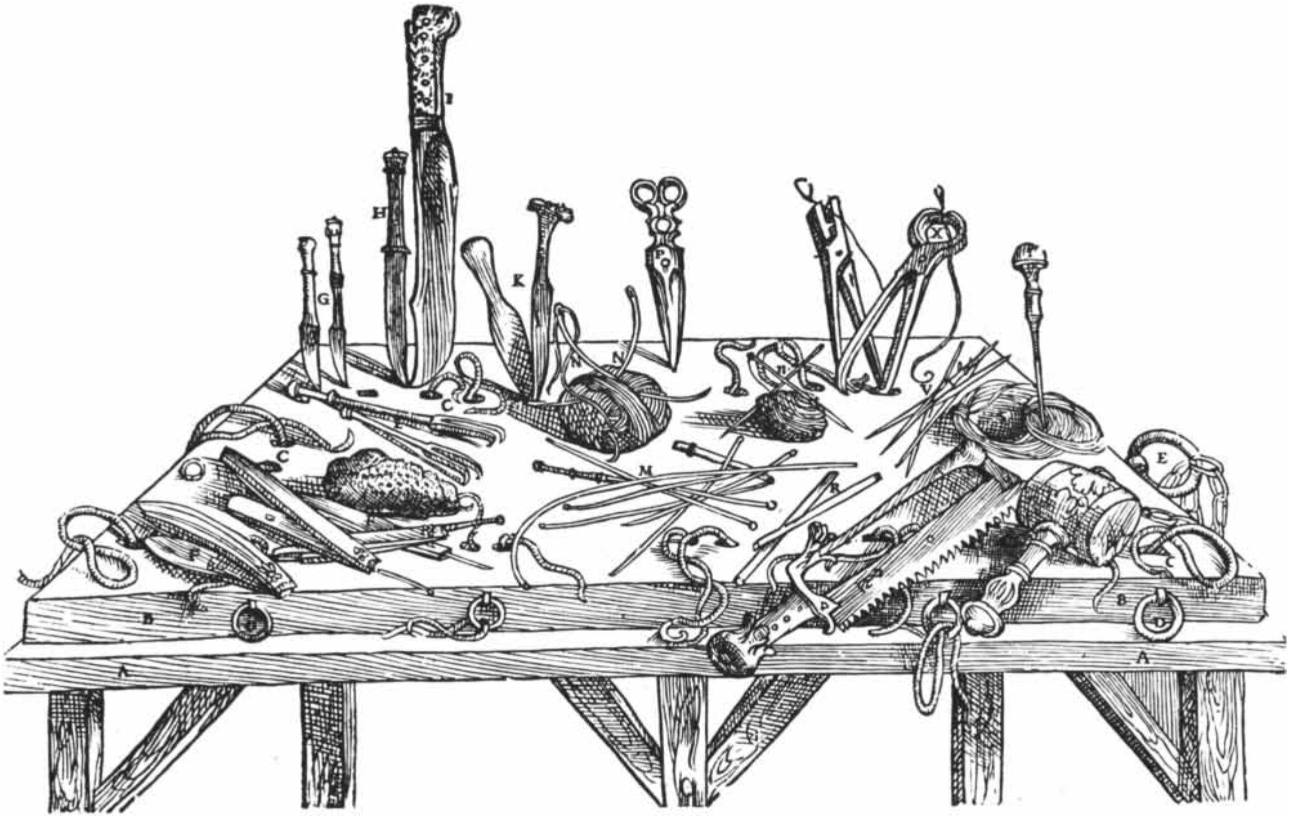
BUT already Vesalius had begun to discover errors which had been committed by the master. His dissections showed, for example, that the actual course of the azygos vein, running up through the diaphragm to the vena cava, was entirely different from Galen's description. As a result, Vesalius published a little treatise called *Letters on Vein-Cutting*, suggesting a new blood-letting procedure based on his discovery. This work was shortly followed by Vesalius' first anatomical publication, an outline of his lectures which he called *Tabulae Anatomicae*. It is fascinating to study these first anatomical sketches of Vesalius—three drawn by himself and three by Calcar. The correction of Galen's errors is already under way. But some glaring ones still remain: the liver is still shown with five lobes, the breastbone still has seven parts, the uterus is shaped like a bubble, the heart is inaccurately sketched, the pelvis is falsely situated.

Vesalius did not yet dare to challenge Galen's basic anatomy. He hunted assiduously but vainly for organs which Galen had mentioned. The *plexus mirabilis*, which Galen had described in minute detail, he could find in sheep but not in man. Then, in the year 1540, Vesalius was enlisted in a project which was to become the turning point of his studies. This was the translation of Galen's collected works into a magnificent new Latin edition. Vesalius edited the parts on the dissection of the nerves and blood vessels, especially one of Galen's most important works, *De Anatomicis Administrationibus*.

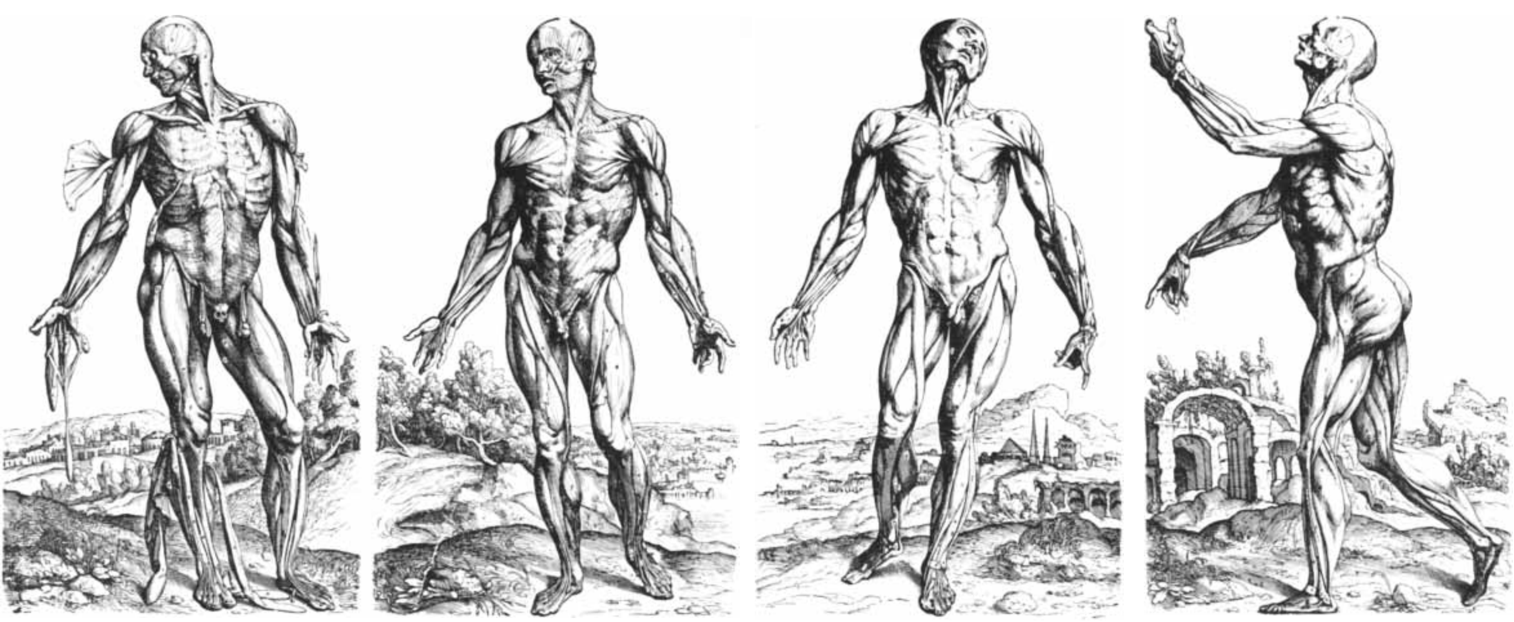
As he worked on this translation, Vesalius was delivering a course of lectures at Bologna, during which he reconstructed the skeletons of a man and a monkey. When the work was finished, he compared the two. In the monkey he found a lumbar vertebral process which was described in Galen's anatomy but which apparently did not exist in the human skeleton.

A great revelation dawned upon Vesalius. He realized, with sudden, shocking

ANATOMICAL FIGURES make a monumental panorama when the *Fabrica's* folio pages are laid side by side. This series of eight tortured illustrations begins at the far right on the opposite page, proceeding through stages of dissection to the limp skeleton at the left. The illustrations are arranged in this order to show that Calcar placed his figures on an almost continuous landscape, identified as that of the Euganean Hills, near Padua. The figure at the far right shows the body from the side with the skin and some superficial tissue removed. Second from the right is the same figure from the front. The third figure shows the body with the mus-



THE ANATOMIST'S TOOLS were drawn by Calcar as they appeared on a table used by Vesalius to dissect living animals. Also on the table is a wooden slab fitted with holes and rings to fasten the ropes that held the animals motionless. The tools are various razors and knives (noted by Calcar with the letters F, G, H, I and K), hooks (L), styluses and a siphon (M), needles and stout bookbinding thread (N and n), a saw, a pair of scissors (P), a wooden mallet, reeds for inflating the lungs and other organs (R), copper wire for joining bones (S), pointed instruments for piercing bones (V), pincers for tying and cutting twine (X).



cles laid bare of superficial tissue. In the fourth figure several of the muscles, mainly those controlling the tibia and the fingers, have been laid back and left to hang down. In the fifth the muscles of the thigh and other parts have been cut away. In the sixth the head is thrown back and the lower jaw split in half. The seventh, which also appears on page 24, shows the body suspended by a rope with the viscera removed. The shoulder blade is also suspended lest, as Vesalius wrote, it fall down like a broken wing. In the eighth figure the breastbone and rib cartilages have been cut away and placed on the ground at left, leaving the skeleton almost stripped.

FABRICA'S FRONTISPIECE, discussed in the text of this article, is a symbol of the anatomical revolution begun by Vesalius. Here Vesalius stands by the cadaver performing the dissection himself. Before it had been done by barber surgeons. Calcar drew himself as the man with the book to the left of the seated skeleton.

perception. that Galen had never dissected the human body. Galen's anatomy was that of the ape! The obscure and erroneous details that had bothered him for years were cleared up at a stroke. His long. frustrating search for the imaginary organs mentioned by Galen was at an end. Vesalius' reaction to his astonishing discovery was characteristic: he was ashamed of himself. He wrote: "Ipse meam stupiditatem et nimiam in Galeni aliorumque Anatomicorum scriptis fidem haud satis demirari possum"—"I could not get over wondering at my own stupidity and overconfidence in Galen and the writings of the other anatomists."

THAT day in 1540 marked the birth of modern anatomy. Vesalius now went to work to present the first accurate description of the structure of the human body.

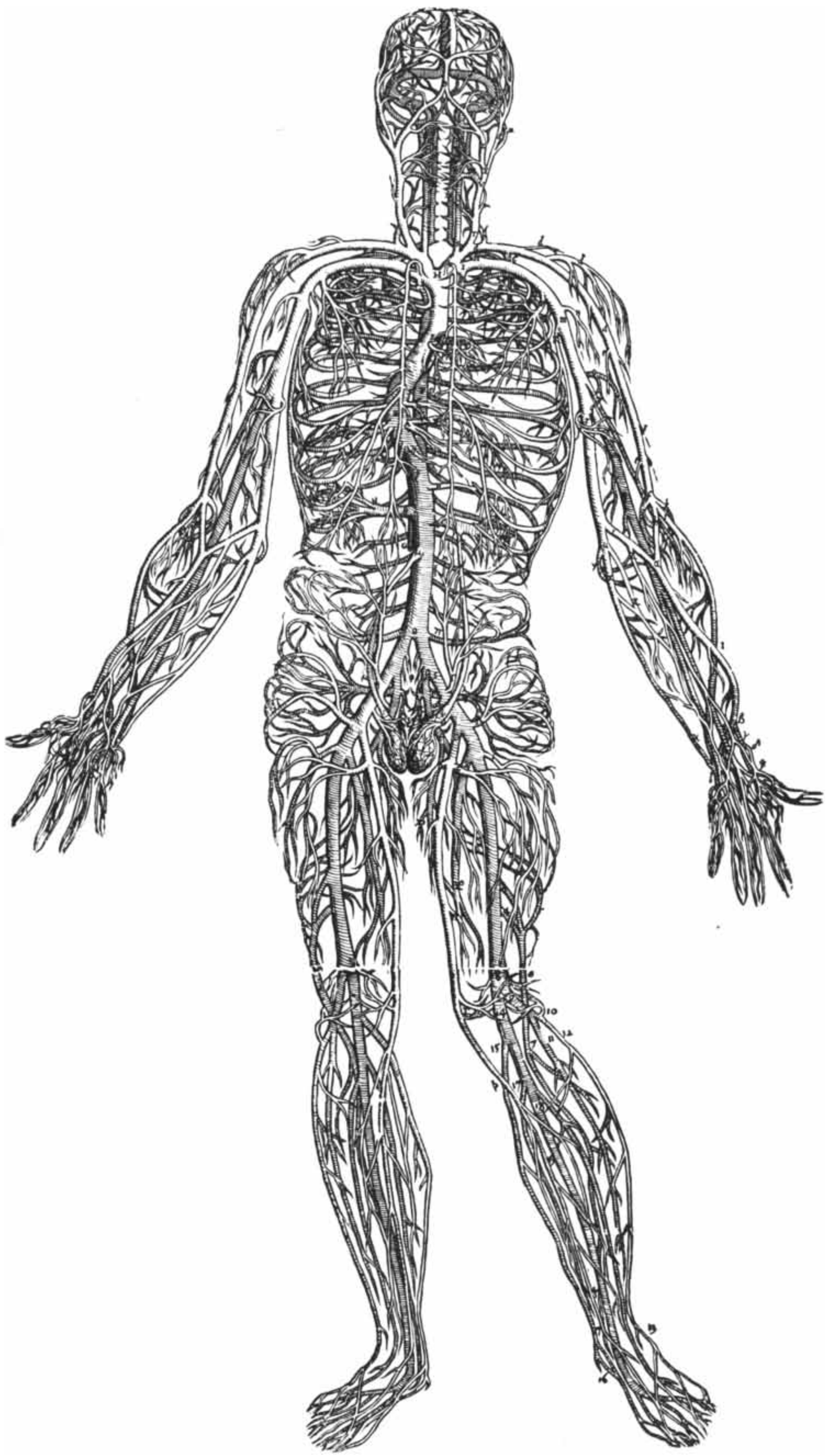
It took him only two years to complete the *Fabrica*. Meanwhile, he also undertook the dangerous task of removing Galen from his shrine in scientific opinion. His public dissections took on the character of turbulent mass meetings. He was greeted with both praise and bitterness as he destroyed the legend of Galen by citing more than 200 errors in his anatomy. "Thou. Galen." he declaimed. "who hast been betrayed by thine apes!"

On August 1. 1542 his work was finished. He took the huge manuscript to Venice and shipped it, with all the woodcuts and minutely detailed directions. to his publisher Oporinus in Basel. Vesalius soon followed to supervise the printing personally. But even while attending the birth of his masterpiece. he went on with his dissections. On May 12. 1543. a criminal named Jakob Karrer was beheaded. Vesalius promptly seized upon his body to perform the first dissection that had been witnessed in Basel in 12 years. For four centuries the skeleton Vesalius constructed from the bones has outlasted Jakob Karrer's misdeeds, whatever they were. Today it is still treasured by the Vesalianum in Basel as the oldest preserved anatomical specimen in the world.

In June of 1543 the great book finally appeared. Actually it was two books. Besides the exhaustive *Fabrica*. Latin and German editions of an *Epitome* were published for laymen. This was an outline of the new science and a safeguard against unauthorized condensations and translations.

In the woodcut which appears on the first page of the *Fabrica* one may see a portrait of Vesalius at 28—a bold. eager man with curly hair, piercing eyes. a high forehead. an upturned nose and a small birthmark over the right eyebrow. On the table before him are the flexor muscles of a cadaver's right forearm laid bare. Vesalius. grasping the hand. is supposedly exhibiting one of Galen's errors.

The frontispiece of the *Fabrica*, a panoramic view of Vesalius' dissection theater.



THE VENOUS SYSTEM is delicately traced in another of Calcar's woodcuts. Although Vesalius knew the existence of capillaries, he did not know the circulation of the blood. This was not discovered by Harvey until 1616.

boldly symbolizes his defiance of tradition and his devotion to science. At the center, Vesalius, scalpel in hand, stands beside a table upon which lies a woman's nude body with the viscera laid open. Every detail in the picture is a deliberate rebuke to the academicians. At the conventional medical lectures of the time the professor sat high on a kind of throne, reading a chapter from Galen. Below, the demonstrator, a physician, pointed with a wooden staff at the organs to which the reading referred. Even lower, in the pit of the theater. the barbers cut up the body, or rather, hacked at it with clumsy hands. In the *Fabrica* a skeleton occupies the throne of the professor, while Vesalius stands and lectures in the midst of his students. Underneath the table two squatting barbers disconsolately brandish their razors. Flanking the picture at the bottom are an ape and a dog—the rejected subjects of traditional dissections. At the left, braced against a column, is a naked figure which illustrates the play of living muscles. The bearded figure at the right, directing a servant to quiet the dog, is believed to be Realdus Colombo, Vesalius' assistant. At the top of the picture, upheld by naked little angels of anatomy, is Vesalius' family coat of arms—three fleeing weasels. And packing the theater to the doors is a throng of fascinated students, watching the dramatic event with the taut faces of men trembling with excitement.

The frontispiece falls short of being an artistic masterpiece, but it is a masterful illustration of Vesalius' place in the history of medicine. This is the birth of anatomy, firm foundation of the art of healing and of all scientific investigation of the human body.

THE principal illustrations of the *Fabrica* are its anatomical drawings, imprinted on folio pages by woodcuts. These fall into a narrative which unfolds like a great voyage of discovery. Calcar's massive figures are almost supernatural beings, each animated by an intellect. In attitudes of monumental suffering, their giant forms rise from a continuous landscape, identified as a section of Petrarch's countryside in the Euganean Hills near Padua. From page to page the giants shed their muscles like tall trees shedding their leaves in autumn, the landscape suffering with them. The narrative proceeds with the structure of great drama: in the final pages the figures stand on naked rock, stripped of every connection with life—poor remnants of humanity sinking on their knees, leaning against a wall or hung up by cords. From this has the study of anatomy sunk to a mere pedantic exercise!

The *Fabrica* was to revolutionize surgery and to found a new era of physiology from which was to grow the discipline of modern medicine. But it broke upon its time like the first nuclear chain reaction. Vesalius' old professor, Sylvius, called him a "madman," an unprincipled upstart who had disgraced his teaching. Guinterius turned against him. Even Vesalius' assistant, Colombo, a gifted but unscrupulous careerist, did his best to discredit him in his own stronghold of Padua.

Vesalius lacked the toughness that often accompanies genius. The attacks discouraged him. Within a year, during a fit of depression, he burned most of his notes and scientific papers and fled his university and his science. He began an entirely new life as court physician to Charles V in Madrid. He accompanied the emperor on military campaigns and to conferences throughout Europe. He also married Anna van Hamme, the daughter of a royal councillor in Brussels. In his bitter *Letter on China-Root* (quinine), which he wrote to a friend, he exclaimed: "Never again will I procure scientific material for myself and my pupils with such labor and danger as once I did in Paris, Louvain and Italy. In my youthful enthusiasm for science I endured this willingly and easily. Now I am through with the passion for writing." Vesalius was 31.

FABRICA'S ALLUSION to the legend of the Greek Poet Arion almost foretold manner of Vesalius' death.

In 1556 his life took a minor turn. When Charles V gave his throne to his son Philip II, Vesalius entered Philip's service in Spain. This was probably the period when the portrait of Vesalius ascribed to Titian—now in Florence's Palazzo Pitti—was painted. It shows Vesalius with thinning hair and the high, pale forehead of a man growing old. A graying, slightly ruffled beard melts into the enormous breadth of his heavy body. His right hand holds a pair of spectacles. His left holds a book, an index finger between the pages. His wise, resigned eyes gaze past the beholder over some melancholy vista. It is Vesalius—without goals, lost in the darkness and corruption of the Spanish empire.

But the last spark had not quite been extinguished. While he was in Spain Vesalius received a book entitled *Observationes Anatomicae*, by Gabriele Falloppio. whose name is commemorated by the Fallopian tubes. Falloppio of Modena had been through an early career much like that of Vesalius. At 24 he was a professor in Ferrara, and he succeeded to Vesalius' chair in Padua after the treacherous Colombo resigned. In a clear, forthright script, every line of which breathed respect, Falloppio advised Vesalius of a few errors in the *Fabrica*, described the organs of hearing and gave an exact anatomy of the uterus, the ovaries and the clitoris.

For Vesalius, Falloppio's manuscript was a trumpet call. He read it in a fever of interest and in a few days wrote his last work, *Comment on Falloppio*. He sent the manuscript to Falloppio. but before it could be delivered Falloppio had died. Vesalius' book was published two years later in Venice.

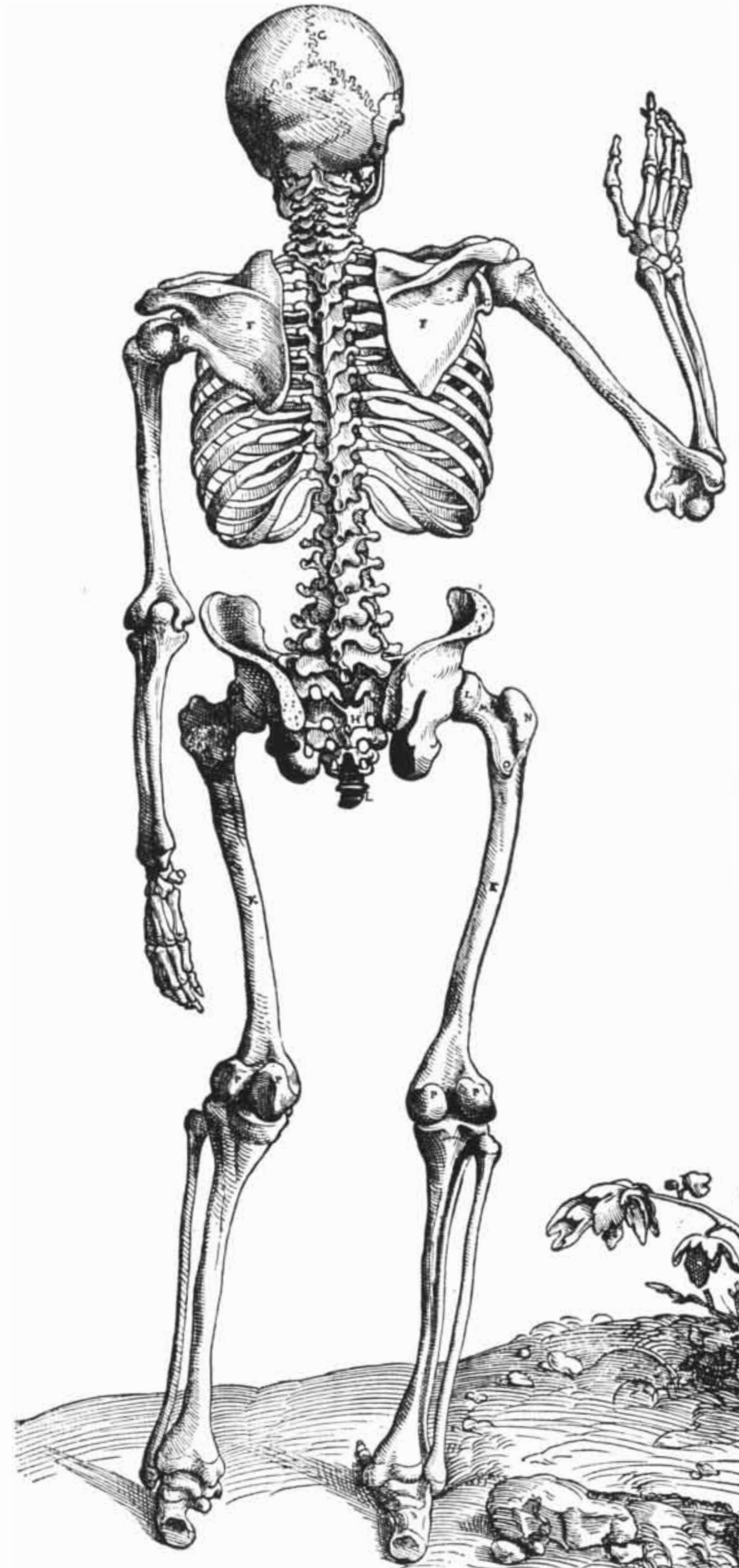
In the spring of 1564 Vesalius set out on a pilgrimage to Jerusalem, from which he was not to return alive. The reason for this journey and the circumstances of his death have never been completely clarified. According to a letter written by a Paris physician in 1565, Vesalius had a distinguished patient in Spain who died of an unknown sickness. "When he believed him dead," wrote the Parisian, "he asked the relatives for permission to perform an autopsy. This was granted, but when he opened the chest. the heart was still beating. The relatives accused Vesalius of manslaughter and Godlessness before the Inquisition. Since the killing was proved, the Inquisition wanted to sentence him to death. Only with difficulty was the king able to free him from great danger. Finally he was released on condition that for the expiation of his crime he should go on a pilgrimage to Jerusalem and Mount Sinai."

On Vesalius' return journey from Jerusalem, according to another report, his ship was wrecked on Zante. one of the Ionian Islands to the west of Greece. There he lay dying, untouched by the inhabitants because they thought he was a victim of the plague. Shortly before he died he was found on the beach by a visiting Venetian goldsmith. There, at 50, Vesalius was buried in an unmarked grave.

If this account may be accepted, there is a strange parallel between the end of Vesalius and the end of his great book. On the last page of the *Fabrica* is a concluding illustration, said to have been chosen by Vesalius himself. It is a picture of Arion, the poet and musician of Lesbos, who during a voyage was robbed and driven into the sea by Corinthian sailors. Vesalius had almost predicted his own death, and had chosen his monument

Martin Gumpert is a practicing physician and a writer on medical subjects.

ΣΚΕΛΕΤΟΝ A TERGO DELINEATVM



Naturalis capitis figurę, ad oblongę sphęrę similitudinem confabricatę, ῥαφαὶ, suturę, מחוברים mechubarim, Complosa.

A Per sinciput στεφανιαῖα; coronalis quod coronari soleat, כתרי cethari: in alia figura apparens.
B Per occiput, à litterę Λ figura λαβδοειδὴς, הבית haleth, Laude.
C A medio posterioris suturę per verticem ad anteriorem: ὀβολιαία, quòd telum refert dicta, החץ hachets, Sagitalis, Nerualis. Hęc aliquando frontē ipsam secans inter supercilia finitur, quod omnibus mulieribus & nullis viris accidere, falsum est.
Hę tres suturę in tribus non naturalibus capitis figuris pro perditarum, aut remanentium eminentiarum ratione, variant.
D Ad tempora duę κροταφίαι, temporales, Corticales, λεπιδοειδῆς, squammęformes, סחוס schechusi, commissurę potius quàm suturę nuncupandę.
Reliquę potius harmonię quàm suturę sunt, vna à λαβδοειδεῖ, altera à coronali vtrīq; ad os cuneiforme protensę: ab huius extremo per medias oculorum sedes ad nasi summum vsque vna: ex cauis temporum per inferiorem oculorū ambitum vna, hinc rursus in oculi cauo tres exiguę: tres narium ossa discernentes. Quę verò ad caninos dentes à Galeno deferri scribūtur, hactenus parte exteriori mihi visę non sunt. Vna quę per medium palatum procedit, aliáque transuersa idem palatū ad narium foramina secans, hic delineari nequeunt.
E Lapidosa, petrosa, λιθοειδῆ ossa, nullā propriam circumscriptionem habent, sed illa pars quę ad caluarię basim est quà spinalis medulla excidit, ita propriè nominatur: licet nonnulli temporum ossa eo nomine significauerint.
F Scapula, ὦμον, ὠμοπλάτη, Latinis aliquando humerus, scoptulum opertum, scoptula, כתף cathep, Spatula.
G Ceruix seu collum scapulę in acetabulum desinens.
Ῥαχίς, spina dorsi, שדרה schedra, σπονδύλοις, vertebris, חוליות chuliotb viginti quatuor constat: τραχήλου, colli, מגרון megaron septem: νωταίου, dorsi, metaphreni, thoracis, הגב hagab duodeci: ὀσφύος, lumborum, העצה heatze, Renū, Alchatinm quinque. Hactenus dorsi vndecimam, non decimam vidi vtrinque suscipi, & posteriores processus quas spinas & Simenia vocant, sub decima obscurè admodū, aut potius non ascendere, solamq; duodecimā (quod & Arabibus placuit) transuerso processu destitui.

H Os ἱερόν, sacrum, πλατύ, latum, amplum, עצלה alagas, Osanium, Alchauis, Hagit, lumborum vertebris subiectum, tribus vertebris in libro de ossibus, quatuor verò in libro de vsu partium Galenus conformari prodidit.
I Coccygis, עקצון bakaton, Caudę, Albosos tribus Galeno ossibus constituitur, eius in li. de vsu partium non meminit, sicut in lib. de administrationibus anatomicis & libro de ossibus. Verum Galeni Medicinę principis descriptiones etiam parū sibi constantes, his duobus ossibus non conuenire subinde obseruauimus, reperimus enim nouem ossa, pauciorâque quàm sc ibit foramina.

K Μηρός, fœmur, fœmen, פחד הירך pachad haiarech, Os coxę omnium corporis ossiū maximum. L superius caput. M ceruix. N. N inferiora capita quibus tibię dearticulatur. O τροχαντὴρ magnus, quē & γλουτὸν appellant, Malum granatum testiculorum. P τροχαντὴρ paruus & interior.

CAVTVM EST DECRETO PAV. III. PONT. MAX. ET SACRATISSIMAE CAESAREAE MAISTATIS Illustrissimiq; que Sena. Vene. ne quis has Andreę Vuesalii Bruxellensis tabulas aut imprimat, aut alibi excussas diuendat, sub penis grauissimis in priuilegiis expressis.

EARLY WORK OF VESALIUS was a lesser book called *Tabulae Sex*, also illustrated by Calcar. As indicated by the scroll on the stump at the right, this was printed in 1538, two years before the publication of the *Fabrica*.

SCIENCE

Science Foundation

A NATIONAL Science Foundation seems likely to be enacted this month. A new bill resolving the disagreements which blocked the establishment of the Foundation last summer has been introduced in both houses of Congress with bipartisan sponsorship.

The bill is designed to meet the objections that impelled President Truman to veto last year's measure. The new bill, like the old, places control of the Foundation in a governing board of 24 members, who are to elect an executive committee of nine. But the Foundation's program of research contracts, grants, fellowships and scholarships will be administered by a director appointed by the President instead of by the Foundation committee. This was the feature of last year's bill to which the President objected most strongly.

There are three other important changes in the bill: 1) it replaces the proposed defense division with a military liaison committee, so the Foundation will undertake military research only at the request of the armed services; 2) it omits the previous plan for a committee to coordinate U. S. Government science activities, since the President has already set up such a committee independently; 3) it permits the Foundation board to create whatever divisions it chooses, instead of restricting it to a specified list. The bill specifically directs the Foundation, however, to form "for as long as [it] may deem necessary" commissions for research in cancer, poliomyelitis and degenerative disorders.

Research Budget

A RECORD sum for research and development will be appropriated in the Federal budget for the fiscal year ending June 30, 1949. Although the final figure will not be determined until June, it appears that the appropriation will be more than $900 million—$150 million more than in the current year. New defense bills calling for additional military research may raise the total still higher.

The budget includes $15 million for the National Science Foundation's first year of operation. Some two thirds of the total is for Army, Navy and Air Force research and for the military projects of the Atomic Energy Commission. The armed services are to receive $550 million, of which $40 million is for the Office of Naval Research, whose contracts support much basic research. The total allotment to the Atomic Energy Commission is $118 million, two fifths of which is for laboratory construction.

Virtually all government departments will receive increased appropriations. Their tentative research budgets, in millions of dollars, are: Department of Agriculture, 56; National Advisory Committee for Aeronautics, 48; Bureau of Mines, 22; Geological Survey, 16; Bureau of Standards, 8.25; other Department of Commerce, 7.5; Public Health Service, 32.7; Tennessee Valley Authority, 5.

Synthetic Fuel

EXPERIMENTS looking toward the establishment of a synthetic liquid fuel industry have been given a boost by Congress. Because of the developing oil shortage, the Bureau of Mines has had a large-scale synthetic fuel research and development program under way for three years. The O'Mahoney-Case law, passed in March, extends this program for three more. It also authorizes the Bureau to build a demonstration plant for converting coal to liquid fuel by the German-originated Fischer-Tropsch process.

This plant will be built at Louisiana, Mo., by mid-1949. It will react coal with steam and oxygen to produce carbon monoxide and hydrogen, which in turn will be converted into liquid fuel.

Other processes also are under test. The Bureau of Mines has one plant in operation and a second under construction. The first, at Rifle, Colo., is producing 50 barrels of bunker oil a day from shale. The second, which will be near Louisiana, Mo., is to produce liquid fuel by the Bergius process for the hydrogenation of coal.

Atomic Energy

THE question of civilian *v.* military control of atomic energy is again in dispute. Several weeks ago Senator Kenneth S. Wherry of Nebraska introduced a bill to transfer functions of the Atomic Energy Commission to the Department of the Army. When Army Secretary Kenneth C. Royall disapproved the bill, it was laid aside. Another bill before Congress would authorize Senate members of the Joint Congressional Committee on Atomic Energy to order investigation of future nominees to the AEC by the Federal Bureau of Investigation. Although some doubt its constitutionality on the ground that it permits legislative interference in an executive department (in this case the FBI), the bill is expected to pass.

Health

THE National Health Assembly meets in Washington early this month to consider the nation's health and the prospects of an unusually large crop of health bills that have been introduced in Congress. The prospects of the bills are doubtful. One that seems likely to pass is a measure creating a National Heart Institute in the Public Health Service. The others, all of which appear unlikely of enactment, are: the Wagner-Murray health insurance bill; the Taft bill for grants to states in behalf of the "medically indigent"; the Saltonstall-Cordon bill for rural public health units; the Lodge bill to supply drugs, X-rays and diagnostic tests free to "such persons as may require them"; and a dental research bill.

The World Health Organization, having obtained ratification by more than the necessary majority of United Nations members (26), came into permanent existence last month. The United States is not yet a ratifier or participant. The Senate approved the WHO charter last year, but ratification has been tabled indefinitely by the House Rules Committee.

U. S. participation in WHO would consist chiefly of cosponsorship of research and educational projects and a contribution to its annual budget. Since the expected U. S. contribution in the first year, $2 million, represented one third of WHO's total budget, U. S. nonparticipation will require a curtailment of the organization's program. But few doubt that the U. S. will eventually join the organization.

UNESCO in the Field

BESIDES launching the Hylean Amazon Institute *(see page 11)*, UNESCO's Natural Sciences Division soon will open a new Field Cooperation Office, the fourth of its kind. Last year it established field offices in Cairo, Nanking and Rio de Janeiro whose purpose is to funnel scientific information into technologically backward areas. The fourth, to be in operation by the end of this year, will be in New Delhi.

This year will also see the start of work on the No. 1 project of UNESCO's Social Sciences Division: a study of tensions affecting international understanding. The study is the largest of its kind ever undertaken. Arrangements for American sections of the investigation were made at the February meeting of the U. S. National Commission. liaison body between UNESCO and U. S. scholars.

"Physics Today"

A NEW magazine covering the entire field of physics in a nontechnical manner appeared this month. *Physics Today*, edited by David A. Katcher, is published by the American Institute of Physics. Its basic circulation is the Institute's 8,500 members, but it is intended also for non-physicists who are interested in the subject.

Biological Institute

AN American Institute of Biological Sciences has been organized to serve as a clearing house for activities in biology. It will perform the same function in that field as the American Institute of Physics in the physical sciences. Formed with the assistance of the National Research Council, it already has 12 other societies as members: The American Physiological Society, American Society for Horticultural Science, American Society of Parasitologists, American Society of Plant Physiologists, American Society of Zoologists, Botanical Society of America, Genetics Society of America, Limnological Society of America, Mycological Society of America, Poultry Science Association, Society for the Study of Development and Growth, and Society of American Bacteriologists.

International Congresses

SCIENTISTS traveling abroad this summer will find more international scientific meetings in session than at any time since before the war. Besides the World Health Assembly in Geneva. the European schedule includes:

In London: International Rubber Technology Conference, June 23-25; Tropical and Subtropical Soils Conference, June or July (date not available at press time); International Congress on Mental Health, August 11-21.

In Stockholm: Eighth International Genetics Congress, July 7-14; Society for Radio Technique and International Consultative Committee for Radio Telephony, July 12-31; International Association of Entomologists, August 9.

Meetings in June

SOCIETY of Automotive Engineers. Summer meeting. French Lick Springs, Indiana, June 6-11.

American Medical Association. Annual meeting. Chicago, June 21-25.

American Physical Society. Sectional meetings. Madison, Wis., June 21-23. Pasadena, Calif.. June 24-26.

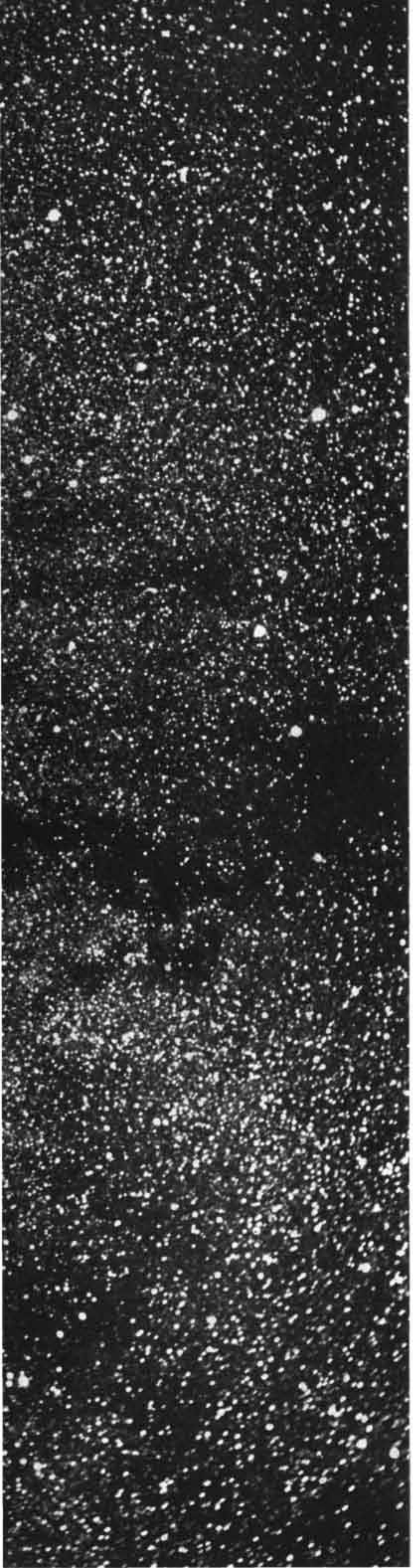
THE DUST CLOUD HYPOTHESIS

The vast distances of interstellar space are filled with huge amounts of dust and gas, the study of which has led to a new theory accounting for the origin of stars and planets

by Fred L. Whipple

IF the earth should disappear some day in a chain-reacting cloud of dust, a possibility which is mentioned half seriously in these deranged times, philosophers on another planet might find a certain poetic symmetry in its birth and death. Recent astronomical studies have given us reason to surmise that the earth was born in a cloud of dust. This Dust Cloud Hypothesis, as it is called, suggests that planets and stars were originally formed from immense collections of submicroscopic particles floating in space. Although it is still being developed, the dust cloud hypothesis possesses a plausibility that other theories about the origin of planets and stars have lacked.

The beginnings of our physical universe are necessarily beclouded in the swirling mists of countless ages past. What cosmic process created the stars and planets? Are new ones still being formed? Or were all that now exist made in one fell swoop? And if so, when did that happen? Scientists are making progress in their study of these fascinating questions, although they still cannot answer them with certainty.



EMPTY SPACE, according to the evidence of this photograph, is far from empty. It is shot through with masses of loose material. The photograph shows a region of the Milky Way north of the star Theta Ophiuchi, the bright object near the bottom. The original plate was made by the great observer Edward Emerson Barnard with his 10-inch Bruce refracting telescope. Barnard, who died in 1923, collected his photographs of dark markings in a catalogue. One of the most famous markings is Barnard 75, the S-shaped object above and to the left of Theta Ophiuchi. Below Barnard 75 is a string of small globular dust clouds, the significance of which is discussed in this article.

The study begins logically with the earth itself. The earth's present composition tells little about how it was formed. But like an oldster's brittle bones, the earth's crust does yield evidence of its age. This evidence consists of traces of the products of radioactive disintegration within the earth's oldest rocks. Over vast intervals of time, radioactive uranium and thorium in the rocks break down into other elements. In five billion years half of the atoms in a given amount of uranium disintegrate. The products of this disintegration are helium and a stable isotope of lead, both of which are trapped in uranium-bearing rocks. (Thorium disintegrates in the same way, but more slowly.) By careful measurement of these minute traces of helium and lead, the age of the rocks can be determined. In this way the English scientist F. A. Paneth has shown that the oldest earth rocks have existed much as they are today for some two billion years. So we may take it as well-established that the earth's crust solidified about two billion years ago.

How long the planet had been in existence before it solidified we do not know. There is strong astronomical evidence, however, that the entire universe in its present form is not much older than two billion years. The spiral nebulae—galaxies outside our own Milky Way, each of which is made up of hundreds of millions of stars—appear to be receding from us and from one another at speeds that increase in proportion to their distance. If they have been expanding at the indicated rate throughout their history, about two billion years ago all of the known universe must have been concentrated near one point.

It is well to remember that this expansion concept may be wrong. Perhaps some fundamental error creeps into our calculations when we project our theories so far back in time from our present observations. We may be deceived in thinking that the universe is expanding. Perhaps we are observing some strange effect that space and time exert upon light rays which have been traveling for hundreds of millions of years.

In any case, our problem is to explain how the spinning sphere on which we live came into being some two billion years ago. Many possibilities have been explored. But one by one the old, familiar theories have been shown by astronomers to possess weaknesses that make them implausible. The dust cloud theory also may be wrong, but it does seem to fit the facts as we know them better than the others.

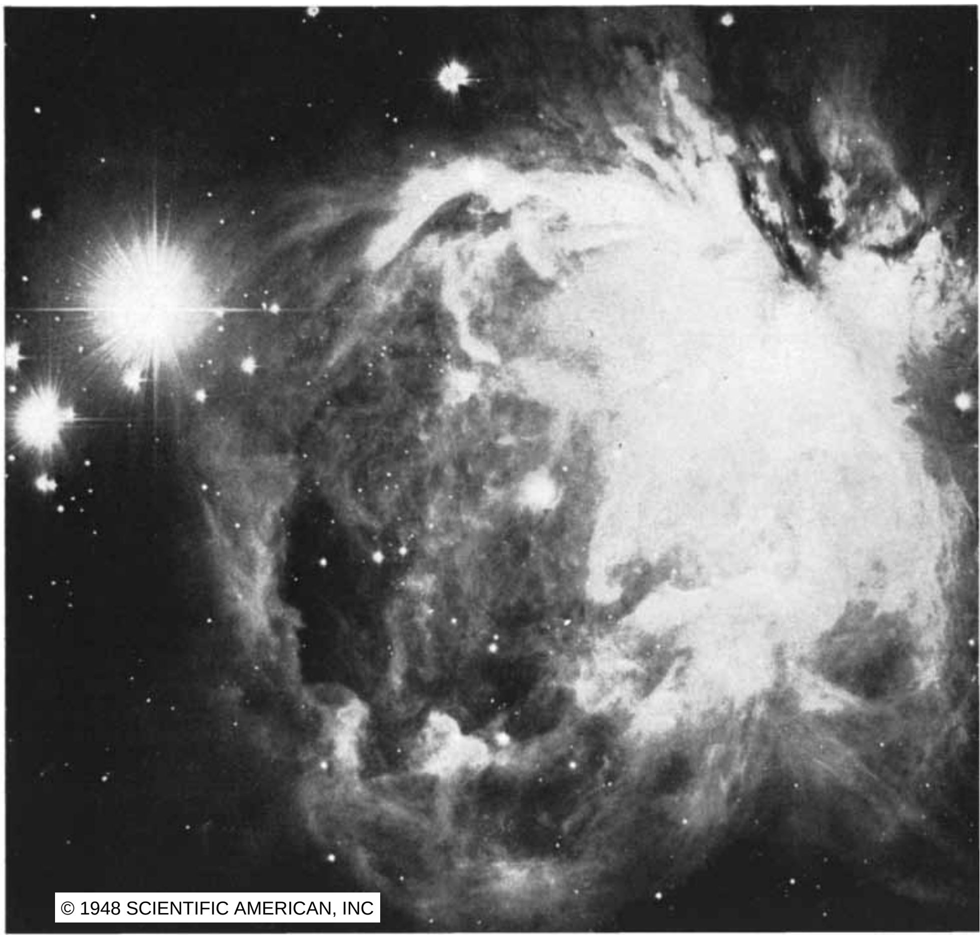
THE dust cloud theory begins with the fact that there are gigantic clouds of dust and gas in the abyss of space that lies between the stars. Observations by the world's astronomers during the past 20 years have proved the existence of these clouds. Interstellar space, formerly supposed to be empty, is now known to contain an astonishing amount of microscopic material. Jan Oort of the Netherlands, the present president of the International Astronomical Union, has calculated that the total mass of this interstellar dust and gas is as great as all the material in the stars themselves, including all possible planet systems. In other words, for every star there is an equal amount of dust and gas dispersed in space. The immensity of this quantity of material is beyond the grasp of human imagination. In the Milky Way alone, it comes to 300 million million earth masses. Yet interstellar space itself is so vast that this dust and gas is scattered more thinly than in the highest vacuum that can be created on earth.

We have a good deal of information about the composition of this nebulous star dust. The gases that we can detect are the ordinary elements with which we are familiar—hydrogen, helium, oxygen, nitrogen, carbon, and so on. Dutch astronomers have recently shown that these gas atoms slowly coalesce into chemical combinations and dust particles. While the structure of the dust particles is uncertain, it appears that most of them are very small—of the order of a fifty-thousandth of an inch in diameter. Evidence of their size and of the fact that they actually are dust particles is afforded by the way in which they scatter the light from distant stars. This scattering produces dark clouds on a photographic plate. The small amount of starlight that filters through these dust clouds is red-

HORSEHEAD NEBULA in Orion is example of dense dust cloud. Photograph by 100-inch at Mount Wilson.

LIGHT AND DARK nebula in Carina, visible only from the Southern Hemisphere, shows how tiny dust

GREAT NEBULA in Orion demonstrates the huge winds of light pressure which blow through interstellar space. This nebula is a cloud which is apparently being scattered by radiation from several hot stars that are em-

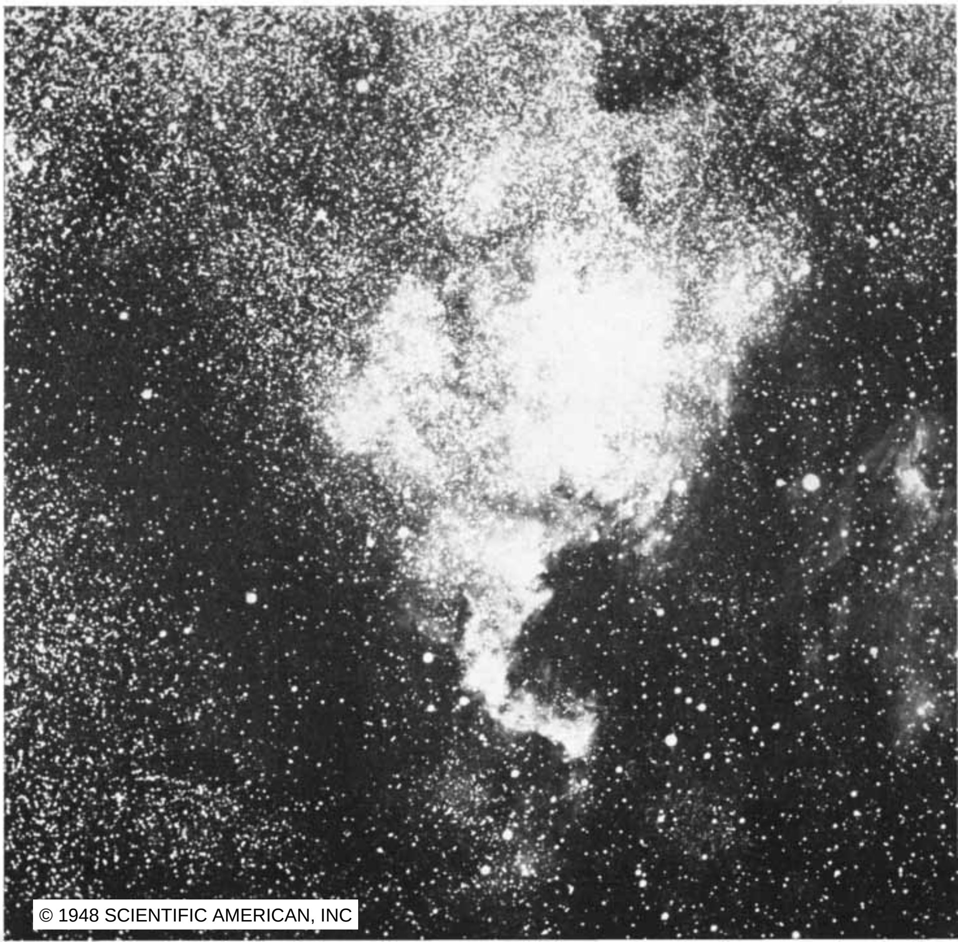


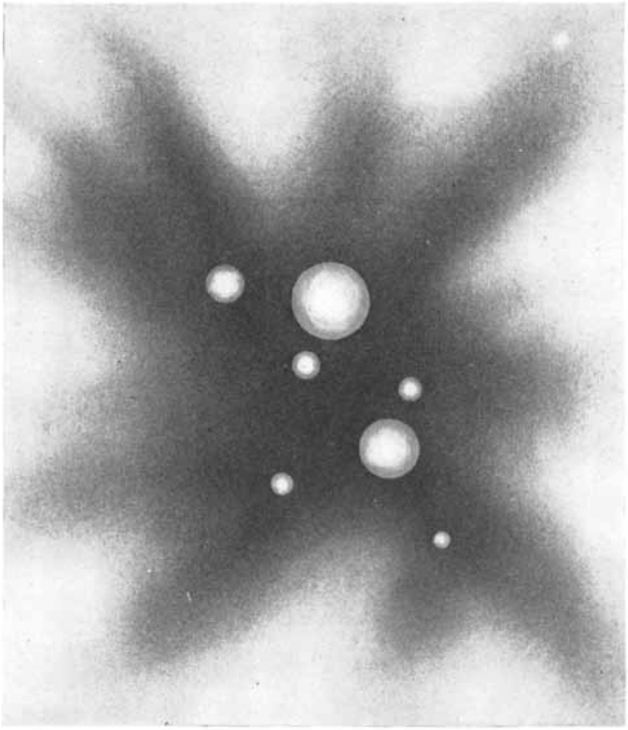
clouds may be studied when they are projected against a luminous mass. Picture by 60-inch at Bloemfontein.

DIFFUSE NEBULOSITY about the star Auriga illustrates why dust clouds do not condense in the vicinity of a hot star. Light pressure literally blows the dust away. Photograph by 100-inch Mount Wilson reflecting telescope.

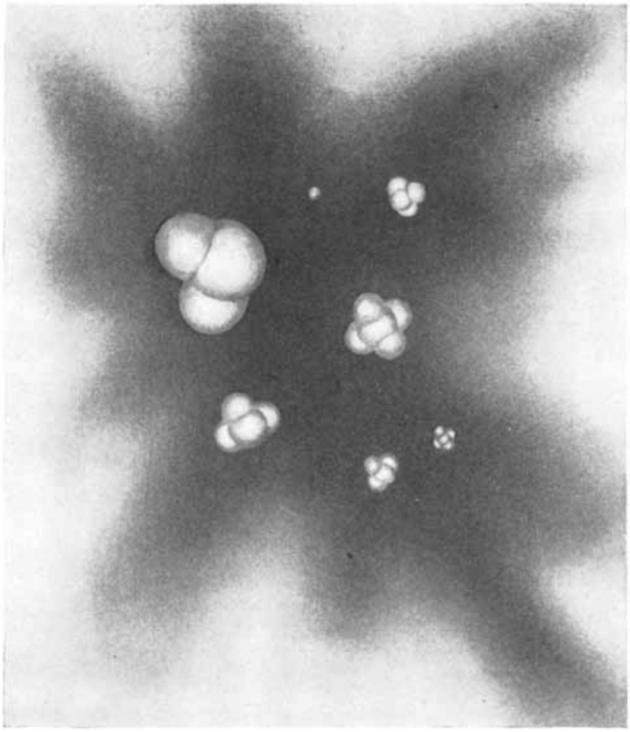
bedded in it. Photograph by N. U. Mayall and H. W. Babcock with the Crossley reflector, Lick Observatory.

NORTH AMERICAN nebula, named for its resemblance to the outline of the continent, shows vast quantity of the raw material from which smaller clouds may condense. Part of this nebula is bright, the rest is dark,





DUST CLOUD FORMATION begins with individual atoms floating in space. Absorbing quanta of light from the stars about them, the atoms are set in thermal motion. Here their closeness has been greatly exaggerated.



CHEMICAL COMBINATIONS of commoner elements is the next stage. When atoms of hydrogen, carbon and nitrogen collide, they form simple molecules such as cyanogen (CN), methane (CH_4) and ammonia (NH_3).

dened—for the same reason that the sun appears reddened during a dust storm: the long waves of red light are less scattered by small dust particles than are the shorter waves of other colors.

What collects these dust particles into clouds? Lyman Spitzer, formerly of Yale and now at Princeton, suggested that it might be the pressure of light. The pressure of light, which is so exceedingly small that it cannot ordinarily be observed, is strikingly demonstrated in comets' tails, which are formed by the pressure of sunlight forcing fine material away from the head of the comet.

THE writer, following the approach suggested by Spitzer, found that under rather unusual, but possible, circumstances the light from stars would tend to force interstellar dust into larger and larger clouds. The process is illustrated in the accompanying drawings. In the starlight of space, each dust particle casts a shadow. The shadow is minute. Nonetheless, it results in less light shining from the direction of one particle on another nearby, and vice versa. Hence the two particles tend to attract each other, by a force varying inversely as the square of the distance between them. The mathematics of this principle is similar to that of Newton's law of gravitation.

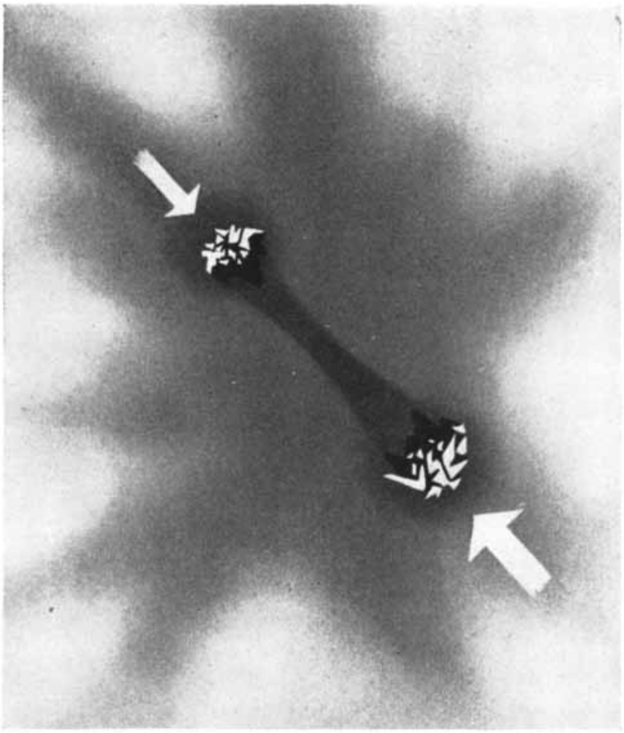
After a few particles are collected into a small cloud, the cloud casts a larger shadow in the starlight on the particles in its neighborhood. These particles are drawn into the cloud, making it larger and larger. If such a cloud is not too much stirred by its motion through other banks of dust and gas, and if too bright a star does not pass through it and scatter the particles by its light pressure, the cloud will continue to draw in dust. Finally it will attain a mass and density sufficient for gravity to become stronger than light pressure. The cloud will then begin to contract. Calculations show that for a dust cloud with the same mass of material as the sun, the two forces would be about equal when the diameter of the cloud was some 6,000 billion miles. This distance is 60,000 times the distance of the earth from the sun. It has been further calculated that such a cloud might develop and collapse into a star in less than a billion years.

These calculations were made before any dust clouds of this nature had actually been observed. During the war, Bart J. Bok of Harvard, while musing one day over some familiar photographs of the Milky Way, noticed some very small, round, dark patches that had not seemed important before. He studied a number of photographs of each region in the Milky Way and found the same dark patches in all the photographs. These were not photographic blemishes but truly dense, dark clouds in space! When Bok estimated their distances and calculated their diameters, he found that the smaller clouds in this group were about the same size as the hypothetical dust cloud for which gravity equals the light pressure on dust. Many were larger but few much smaller.

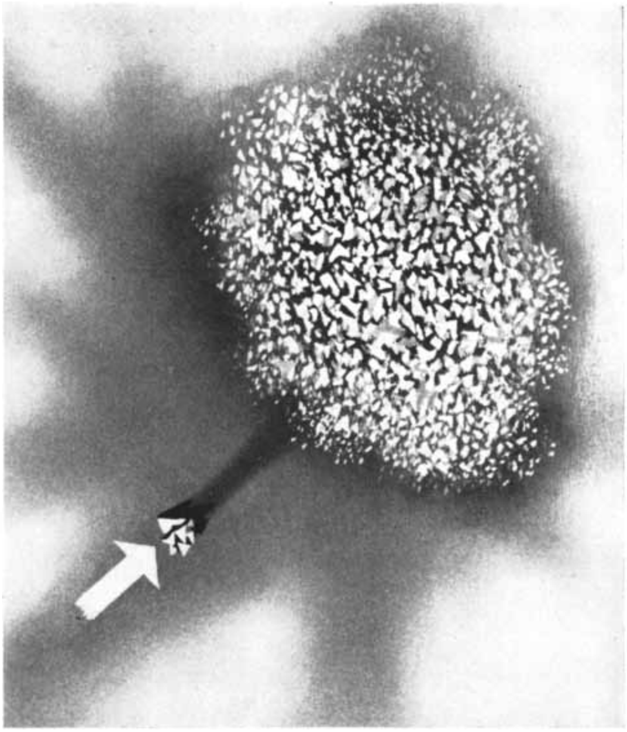
Bok's discovery suggested the fascinating possibility that the small dark clouds might be stars in the making. That new stars are constantly being formed from cosmic dust seems more than likely. There is no other reasonable explanation for the brightness of certain stars. A star's intensity of radiation, which shows how fast it is burning up its energy in nuclear reactions, indicates its maximum age. Some stars are so brilliant that they could not have radiated for two billion years, the minimum time we can allow since the "beginning." Hence they must have been born later than the solar system.

If we could measure the amount of matter in the Milky Way dust clouds, we might have a means of checking the dust cloud hypothesis and of estimating whether and when new stars are likely to be formed. Such measurements must depend on future observations, possibly with the new 200-inch telescope on Mount Palomar or other large instruments. The discovery of these clouds, however, encouraged the writer to study the possibility that not only a star but also a system of planets might condense out of such clouds.

LET us consider our solar system, therefore, as a case study of the formation of a star and its satellites. We have a huge dust cloud, as described above, which has begun to condense under gravity. There



DUST PARTICLES made up of many molecules are brought together by the gentle pressure of light from thousands of stars. Particles attract one another because light pressure in tiny shadow between them is low.



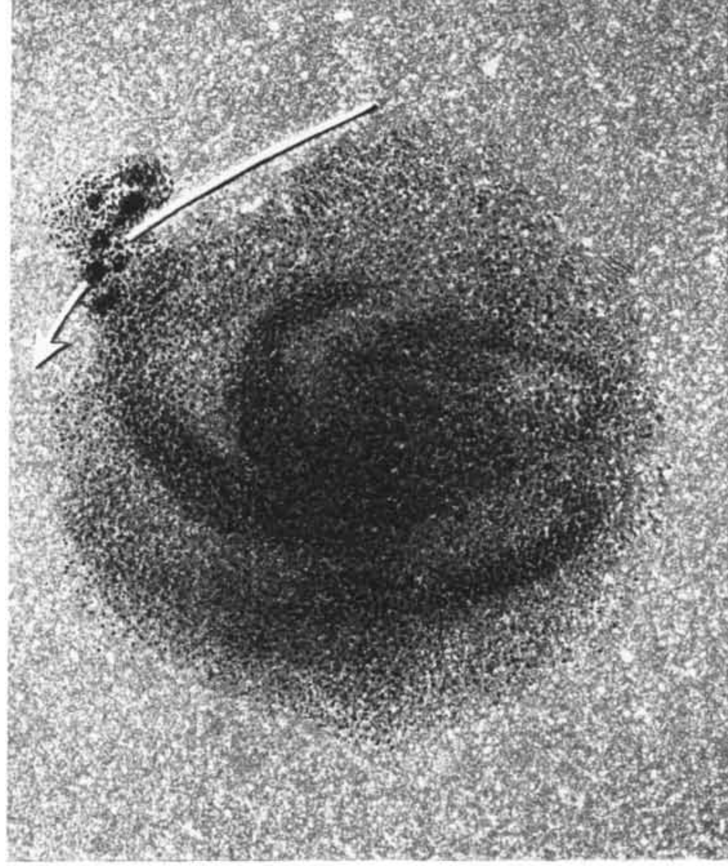
LIGHT PRESSURE also tends to propel individual particles towards larger aggregates. Thus dust clouds slowly grow bigger and bigger until they have sufficient mass for gravitational forces to take effect *(see next page)*.

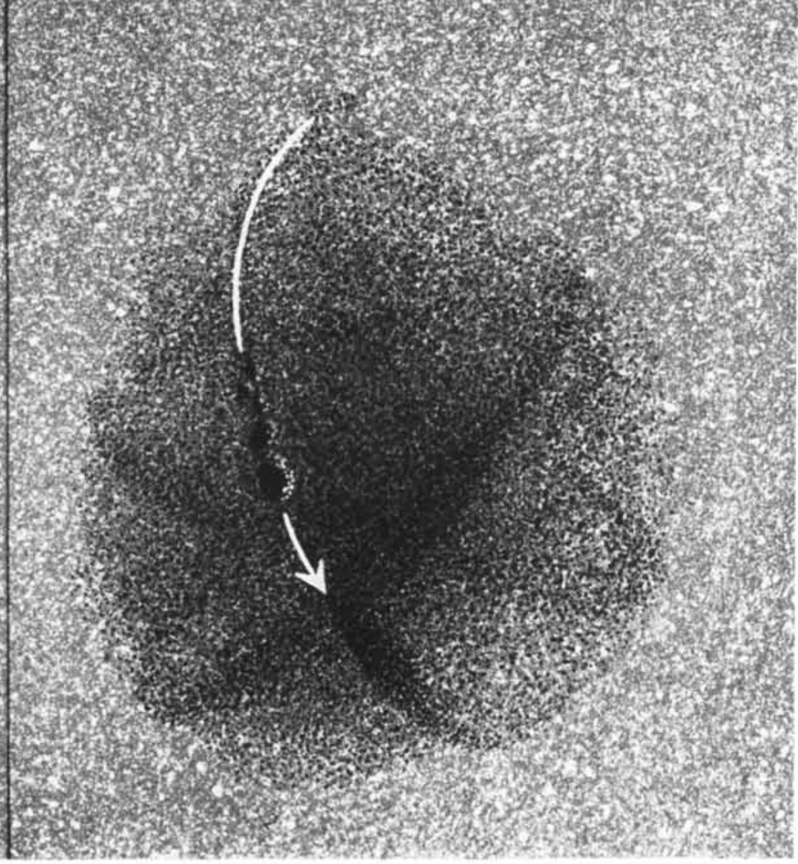
will be minor turbulent motions of the material within it—sub-clouds, or streams of dust—that slide by each other or collide. But these motions cannot all be in the same direction. In order to explain the present slow rotation of our sun, we must assume that the motions of the streams in the original dust cloud canceled each other and that the cloud as a whole did not rotate. This point can be illustrated by a well-known parlor game. The victim is persuaded to sit on a piano stool with his arms outstretched and holding some books. The stool is started turning slowly. Its occupant is then instructed to draw in his arms and the books. He now spins so rapidly that he may fall off the stool. The same principle is illustrated by a whirling figure skater who speeds up her spin when she pulls in her outstretched arms. This phenomenon demonstrates the law of "conservation of angular momentum," or what might be called "rotational obstinacy." Angular momentum, or rotation around the center, may be variously distributed among the parts of the system, but the total momentum for the system as a whole remains constant. The principle applies in any system that is not acted upon from outside. All rotation that exists in the whole system in the beginning will remain there forever, and the rotation becomes more rapid if the system shrinks in size. Thus if the great dust cloud from which the sun was formed had had any appreciable rotation to begin with, after its collapse the condensed sun would have rotated with great speed. But actually our sun turns very slowly; it takes nearly a month to make a complete rotation. Consequently the original dust cloud must have been almost stationary.

This, by the way, would not necessarily be true of other dust clouds in our galactic system. The Milky Way itself rotates; hence we might expect many coalescing dust clouds within it to possess a great amount of rotation. In that case, according to our theory, they could not condense into single stars but would form double stars or even clusters. As a matter of fact, most stars *are* double or multiple, so that in this respect the dust cloud hypothesis is consistent with observations. The sun can be considered a somewhat unusual case.

Having accounted for the sun's slow rotation, let us go back to the original dust cloud. Under the force of its own gravity, it has begun to condense. At first it collapses very slowly, because the motions of its internal currents and streams resist its contraction. A group of moving particles is of course harder to collect and compress than one which is standing still. But in the course of millions of years the random motions of the streams within the cloud are damped out by collisions and friction. Meanwhile the cloud contracts more and more powerfully as it becomes smaller, because as its density increases, the force of gravity among the particles increases. The net result, with resistance diminishing and gravity increasing, is that the cloud collapses faster and faster. Its final collapse from a size equal to that of the solar system (*i.e.*, the diameter of the orbit of Pluto, the farthest known planet) would require just a few hundred years. Due to the increased pressure in the contracting cloud, its temperature rises enormously. In the last white-hot phase of its collapse, the sun would begin to radiate as a star. Its central temperature, due to contraction, would become great enough to start the cycle of nuclear reactions among carbon, hydrogen and helium which keeps the sun radiating, but no detailed theoretical study of this phase has yet been made.

NOW we must account for the evolution of the planets from the same great dust cloud. We return to the cloud before it has begun to shrink appreciably, and follow the largest stream in the cloud. If the dust in this stream is sufficiently dense, the stream condenses into minor clouds. They may be strung out in a series, as shown in the drawing on page 40. As these clouds drift along together, roughly in the same direction, they will pick up material less compact than themselves; hence they will grow slowly, feeding on portions of the great cloud. As they grow, the minor clouds, now "proto-planets," begin to spiral slowly in towards the center of the main cloud. They have gained in mass but not in angular momentum, so they move towards the center of gravity, somewhat as a whirling ball on a rubber string, if no force is exerted to keep it whirling,



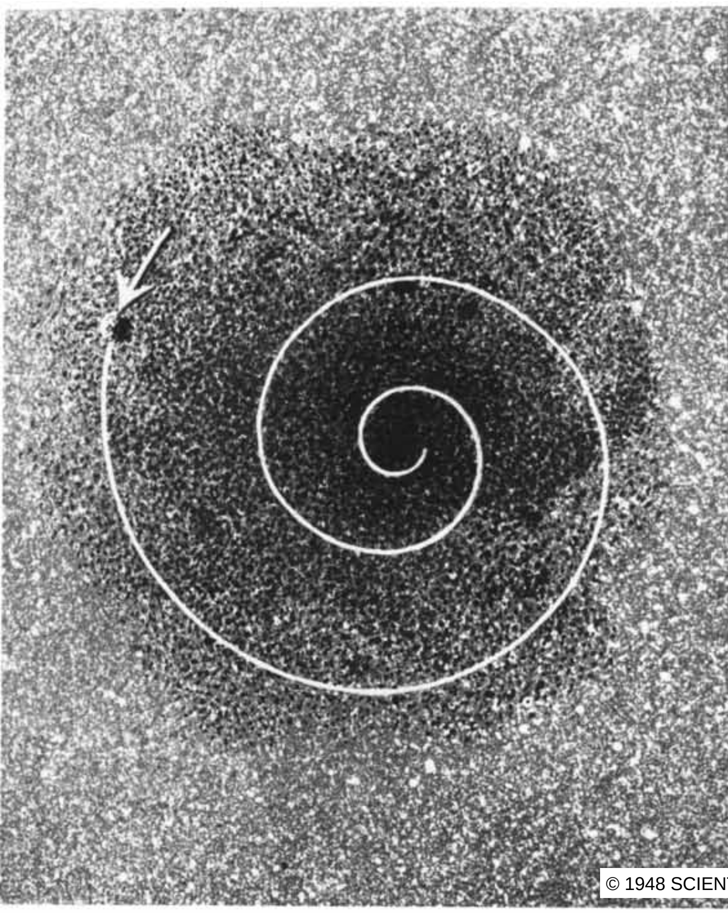


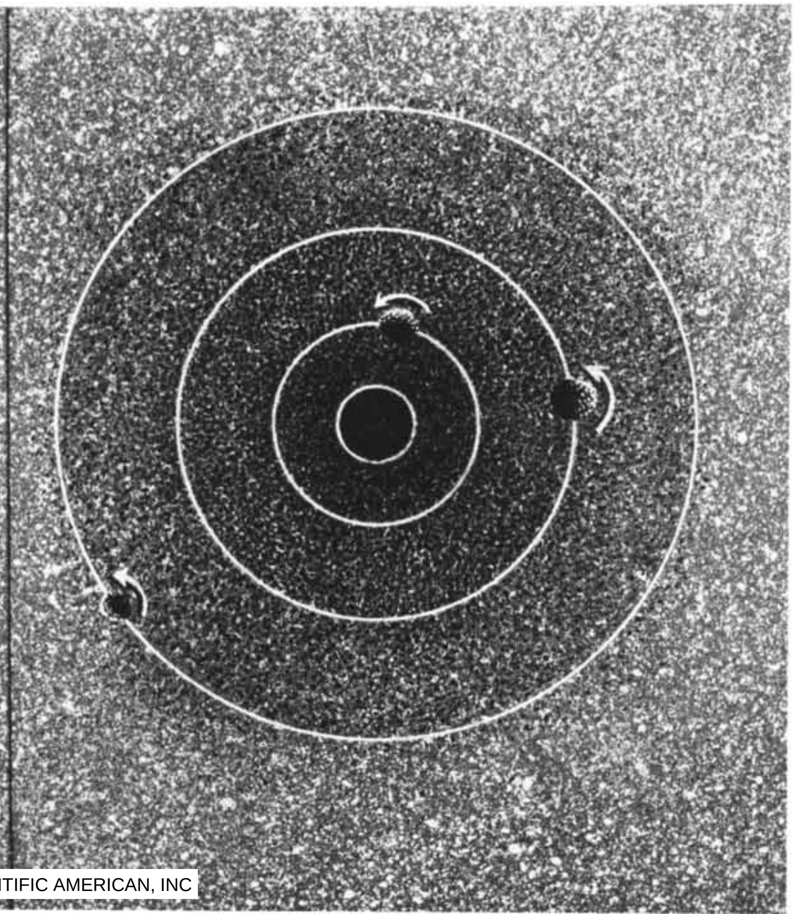
HUGE DUST CLOUD, after formation by light pressure, begins to develop gravitational eddies. A small, dense cloud (*left*), moving at many miles a second, might have been pulled in by the larger cloud's mass.

SPIRALING toward the center of the cloud, the proto-planets are separated by various effects but still remain in the same plane. At this stage the entire dust cloud has also begun to contract at a much faster rate.

PLUNGING INWARD, "proto-planets" in denser cloud are strung out by friction with dust in the larger cloud. At this point larger cloud would be some 60,000 astronomical units, or five and a half trillion miles in diameter.

FINDING STABLE ORBITS, the planets circle within the collapsing cloud. Since the dust toward the center of the cloud is denser, each of the planets is spun in the same direction by picking up more dust on one side.





spirals in an ever-narrowing circle as its motion is slowed by friction. Some of the proto-planets move in more rapidly than others, their rate depending on their size and on chance encounters with other streams.

If the great cloud remained spread out forever, all the proto-planets would eventually wind up at its center. But long before some of them have completed their spiral, the main cloud collapses and forms the sun. Its rapid final collapse leaves a number of proto-planets stranded in their orbits, outside the collapsing cloud. Some are trapped too near the center and are pulled in or destroyed in the sun's heat. Others are far enough away to remain intact. They condense and become planets. Some of them may be at enormous distances from the sun. For all we know, there may be planets in our system beyond Pluto, the farthest one that we can see. Even a great planet like Jupiter, the largest in our group, would almost certainly have escaped discovery if it had been at a distance from the sun fifteen times that of Pluto. Pluto itself, which is about the earth's size, is barely within the range of probable discovery.

When first formed, the planets are hot, perhaps hot enough to be in a molten condition. But since they are relatively small, their heat of contraction is not sufficient to start the nuclear reactions that would make them radiate permanently like a star. Gradually they cool off.

We have described, then, how the dust cloud hypothesis accounts for the origin of the solar system. Now let us see how well our theory accounts for the system's peculiarities.

Any theory about the evolution of our planetary system must explain certain striking characteristics: 1) The planets all move in the same direction and very nearly in the same plane as the earth's orbit, called the plane of the ecliptic. 2) Their orbital paths around the sun are nearly circular. 3) Almost all the planets rotate, or spin, on their axes, in the same direction in which they revolve about the sun. 4) Most of them have moons or satellites—Jupiter has 11—which usually revolve about the planet in the plane of its rotation and in the same direction.

Thus the theory must account for a great deal of regularity in the system. But it must also explain some irregularities. For example, the orbit of Uranus and its system of five satellites, including probably the one recently discovered by G. P. Kuiper at the McDonald Observatory in Texas, is tipped up roughly at right angles to the plane of the ecliptic. Neptune's single satellite revolves backwards, as compared with the rest of the solar system, although Neptune itself turns in the forward direction and is thus properly oriented. Some of the satellites of Jupiter and Saturn also are contrary.

To begin with, the theory explains why the planets generally revolve in the same direction and in nearly the same plane. Their plane and direction are determined by the motion of the original stream from which they were created.

The planets' circular paths around the sun are accounted for by the spiraling phase of their evolution. Spiraling reduces the orbit of a revolving body more and more to the circular form. This principle can be demonstrated mathematically beyond question.

The spacing of the planets at their present distances from the sun is not explained by the dust cloud hypothesis. This spacing, as every astronomy student knows, follows a regular mathematical relationship known as Bode's Law. It is possible that the planets' distances from the sun were determined by gravitational effects over a long period of time rather than at the very beginning. The great mathematical astronomer Ernest W. Brown, of Yale, doubted that the planet distances could have remained constant for more than 100 million years or so.

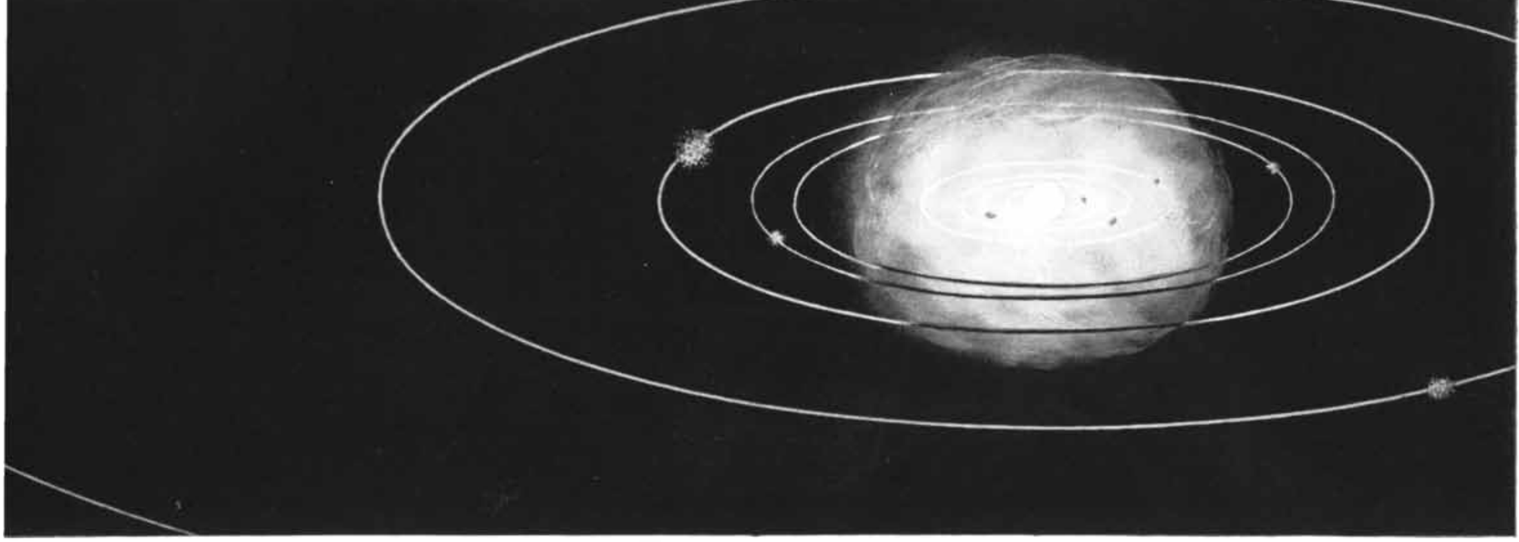
The planets' rotation or spinning is adequately explained by the dust cloud theory. As the great cloud condenses, it is denser towards the center than in its outer regions. Thus a proto-planet, when it spirals in, tends to pick up more material on the side that faces towards the center than on the side away from it. This process produces a result something like the rolling of a snowball. The side that picks up more material becomes heavier and is slowed up. The outer side of the planet, being lighter, travels faster and moves forward. Thus the process imparts a forward spin to the whole planet.

On the assumption that the planets actually gained all of their rotation in this fashion, we can estimate how large they must have been when they condensed. The size of a planet when it started to rotate can be calculated from its present speed of rotation and its mass. The results of these calculations are very encouraging to the dust cloud hypothesis, for the calculated diameter of each proto-planet figures out to about the same or a little more than the diameter of the orbit of that planet's farthest present satellite. This indicates that the satellites were formed while the planets were still distended as clouds. When a planet-cloud collapsed, the outer material collected into satellites or fell to the surface of the planet. Thus the satellites developed in just about the same way as the planets did when the sun-cloud collapsed.

Our theory that the satellites condensed from outer sections of the planet-cloud is further supported by the fact that, with one exception, every planet is very much more massive than all of its satellites combined. The exception is the earth-moon system; the earth weighs only about 82 times as much as the moon. The British astronomer Sir George Darwin suggested that the earth and moon really constitute a twin system, or "double planet," and that the moon was once much closer to the earth than it is today. In fact, the moon may actually have been in contact with part of the earth. The earth, during the early stages of its history, probably rotated so fast that its day was only four or five hours instead of 24. Then, according to Darwin's calculations, the friction of its tides slowly separated the moon from the earth and lengthened the day.

We have no difficulty in accounting for the rapid revolutions of the satellites around their planets. The planets themselves rotate rapidly. We would also expect the satellites to revolve in the same direction as their planets' rotation and in the plane of the equator. In most cases, as we have seen, they do. But what about the exceptions? Neptune's only satellite, the three outer ones of Jupiter and one of Saturn's revolve in a direction opposite from all the others and generally in planes different from those of their planets' equators. The answer is probably very simple: the maverick satellites were not a part of these planets' initial systems but were captured later, when they could no longer be completely controlled. Very likely there were originally many dense minor clouds, or potential planets, which did not develop into full-fledged planets. Some of these were small and outside the main stream. If a small cloud of this sort ran into a planet-cloud before the planet had collapsed, it would be captured and become a satellite. Normally the planet-cloud's rotation would carry the captured cloud along in the same direction, and would reduce the size of the satellite's orbit. But a satellite that was captured by a planet's gravity after the planet had collapsed would be less strongly influenced. If it was revolving backwards when it was captured, it would continue in a retrograde orbit, even though held a prisoner by the planet's force of gravity.

OUR hypothesis has another major irregularity to explain. Why are some of the planets so much larger than others, and why are the large planets so much less dense than the earth? The average density of Jupiter, for example, is only a little greater than that of water, while the earth is five and one-half times as dense as water. Saturn, if it could be put into a huge sea, would actually float. The explanation of these differences probably lies, as Henry Norris Russell of Princeton has suggested, in the fact that the giant planets were bigger to begin with. Their size gave them a huge gravitational attraction so that they could hold the light gases, such as hydrogen and helium, which would float away from a less massive planet. Their ability to attract and hold light elements would have a double result: they would grow rapidly, and they would be relatively light in proportion to their volume. On the other hand, a smaller proto-planet such as the



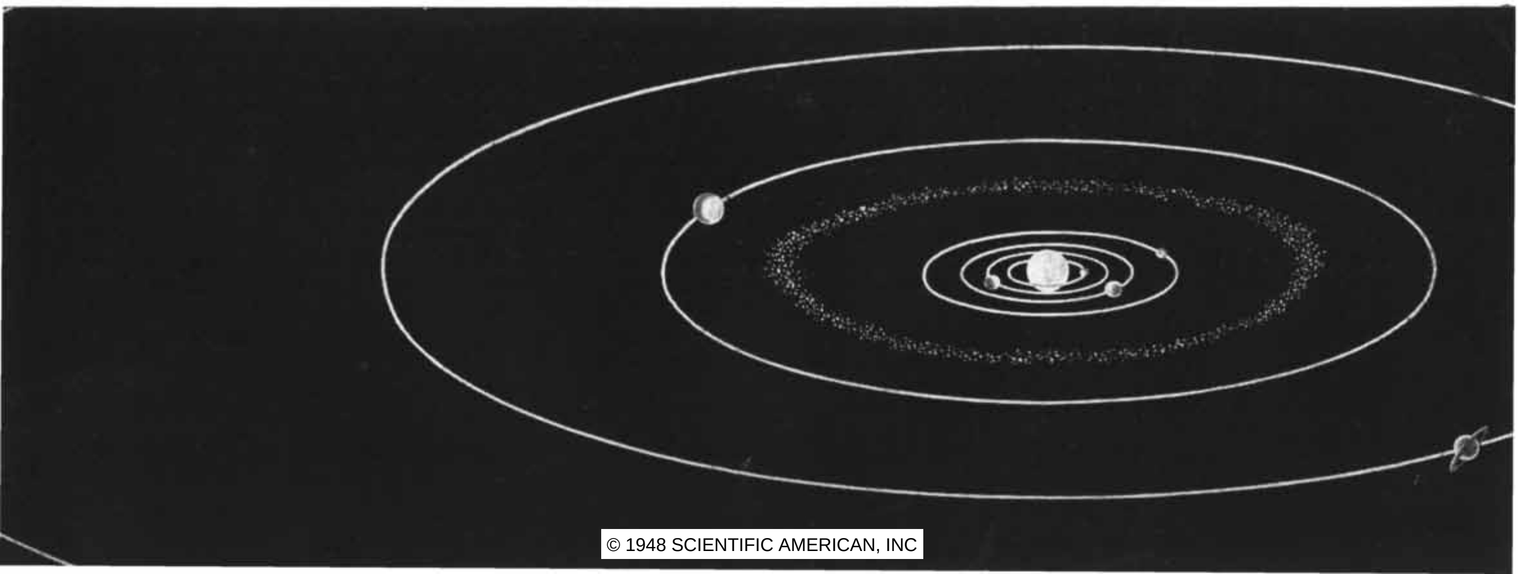
STAR FLARES UP when the heat and pressure at the center of the collapsing dust cloud are sufficient to set off a nuclear reaction. The central sun, however, is still surrounded by a fiery cloud of dust and gas. Here the solar system has been placed in this situation. Reading outward from the sun are the four inner planets: Mercury, Venus, the Earth and Mars. Beyond Mars there might have been two other planets which are now ex-

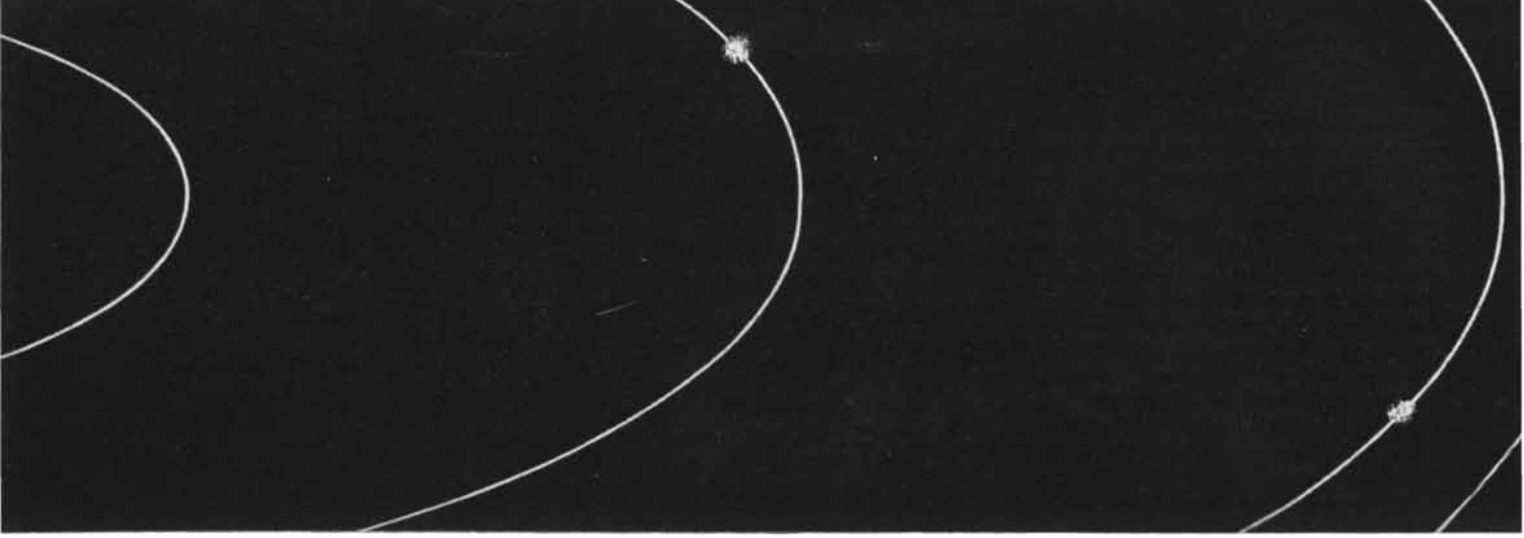
earth, which has less ability to hold hydrogen or helium, would soon reach the limit of its growth. Lyman Spitzer has recently shown that hydrogen and helium are escaping from the earth's atmosphere even today. We have every reason to believe that hydrogen and helium are relatively more common in the universe as a whole than on the earth; they are much more abundant than oxygen, nitrogen, carbon and other elements which seem more prevalent to us. About one-third of the sun, for example, is hydrogen, and it also contains a large amount of helium. Thus hydrogen and helium are major building blocks of the universe, and it is entirely possible that many of the other elements were made by nuclear synthesis from these two gases.

THERE is still another odd peculiarity of the solar system that the dust cloud hypothesis seems to explain quite well. This is the fact that the planets which are closest to the sun have relatively few satellites and comparatively thin atmospheres. The explanation is this: When the sun was collapsing to its final form, the energy released by its contraction made it hot. The inner planets—Mercury, Venus, the Earth and Mars—were then in a fairly dense region of the condensing sun. As a result, their atmospheres and surfaces were heated to very high temperatures. Most of their satellites would boil away. Fortunately for the theory, this boiling period was very short—perhaps a few months or years—else the planets would have boiled away also. As it was, the earth and moon probably were not entirely spared by this "bath of fire"; both may have been appreciably reduced in size by the evaporation of their outer rocks. The outer planets, being outside this bath of fire, would not have been much affected, which accounts for the fact that they still have thick gaseous envelopes and a comparative abundance of satellites.

One other puzzling phenomenon, perhaps the most fascinating of all, remains to be explained. This is the great collection of asteroids, or minor planets, found in the region between Mars and Jupiter. There are at least 1,600 of these "flying mountains," ranging from a mile or two to three or four hundred miles in diameter. All revolve in the same forward direction and near the plane of the ecliptic, although not as close to it as the planets. Their grouping suggests that the asteroids had a common origin. Are they the building stones of a planet that was stillborn, or the debris of one that was smashed? Present opinion favors the latter possibility. The proof, though not yet complete, is fairly convincing. Harrison Brown at the University of Chicago and Carl Bauer at Harvard have recently shown that meteorites—pieces of interplanetary material that fall on the earth as shooting stars—must be fragments from a broken planet. Other studies by C. C. Wylie in Iowa indicate that these shooting stars or fire-balls swing about the sun in orbits resembling those of some asteroids. Though the chain of evidence at this point is weak, we may reasonably accept the tenta-

SOLAR SYSTEM TODAY is the reality which theories of its origin must explain. Its principal unifying characteristic is that the planets and their satellites, with a few exceptions, spin on their axes and rotate about the sun in the same direction and in the same plane. The dust cloud theory has been able to account for this better than previous theories. In this drawing another recent idea has been added to the dust cloud theory.





tinct, a possibility which is discussed in the caption below. After these come Jupiter, Saturn, Uranus, Neptune and Pluto. The dust cloud theory proposes that the orbits of the inner planets were inside the incandescent sun cloud. This might account for the fact that they have thinner atmospheres and fewer satellites than the outer planets. Most of their satellites and atmospheres might have boiled away in heat of the new sun.

tive conclusion that meteorites are baby asteroids, and that the asteroids, in turn, are broken pieces of a once completely formed planet. Harrison Brown calculates that the planet was about the size of Mars.

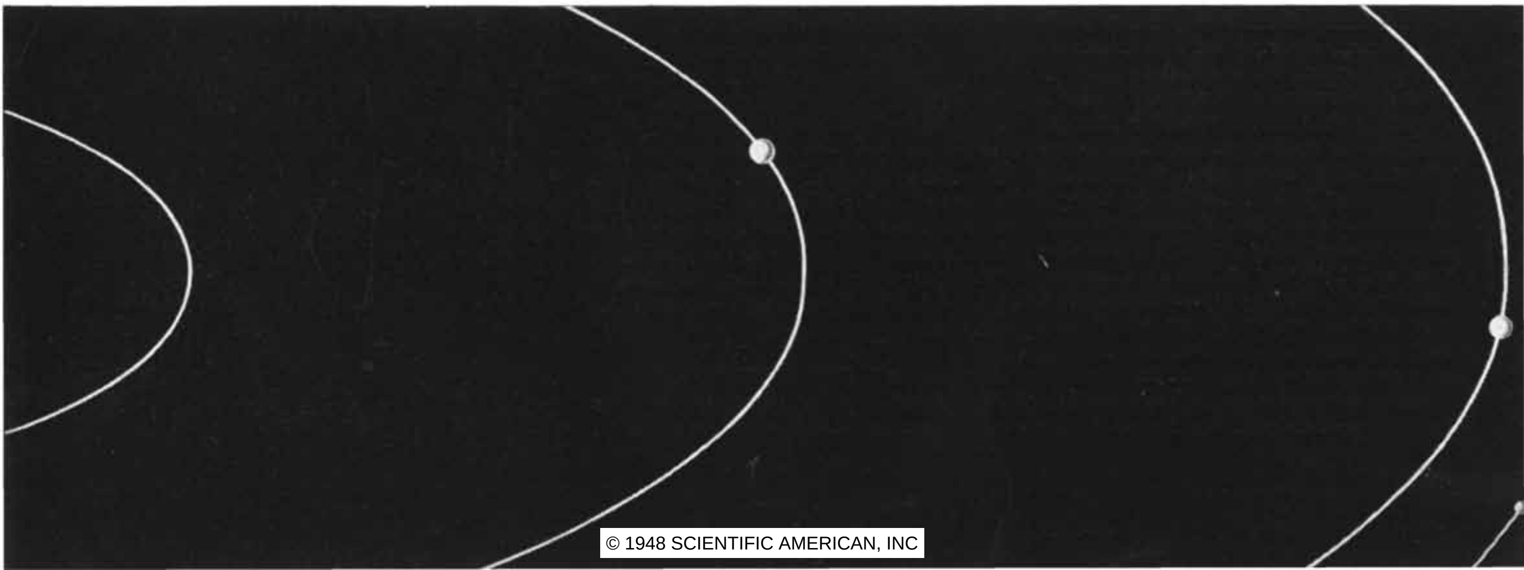
How was the planet smashed? Probably by collision with another planet; there may even have been more than two planets involved. On the dust cloud theory, we can easily assume the formation of an eccentric planet which would cross the path of one in the main stream. If it did, sooner or later we would expect the two planets to collide. The resultant cosmic explosion would produce the scattered asteroids. (An explosive collision between one of the large asteroids and the earth, that might destroy a continent, is an ever-present possibility. The famous mile-wide crater in Arizona, and the tremendous explosion that flattened a forest in Siberia in 1908 are believed to have been caused by small asteroids.)

It is interesting to speculate about the possible effects that the asteroid-planet's destruction may have had upon the earth. The collision must have occurred after the planets had cooled considerably. If it came within the period of geological history—that is, the last billion years—the effects on the weather of the planets must have been tremendous. After the explosion, interplanetary space would have been filled temporarily with a cloud of fine dust and gas. Contrary to what one might assume, this dust, though it obscured the sun, would not make the earth colder. A calculation by Donald H. Menzel of Harvard shows that if the earth were enveloped in an obscuring cloud, sunlight would be scattered or reflected by the cloud in such a way as to fall on the dark side of the earth as well as on the side facing the sun. Consequently the earth's nights would be much brighter and warmer. The long polar winters would be milder, and ice caps would melt. The result would be a great rise in the earth's average temperature. There is no geological proof of this theory, but it may explain certain phenomena that have puzzled geologists. It is conceivable, for example, that this process caused a prolonged heat wave that eliminated dinosaurs from the face of the earth.

WE have seen, then, that the dust cloud hypothesis accounts for a great many of the facts about our solar system. The chief difficulty in the theory has to do with the question of how the proto-planets maintained themselves during the early stages. At that period the dust clouds had to be very rare, their average density being more nearly a vacuum than the vacuum in a Thermos bottle. Yet they had to hold together sufficiently to pick up material from the rarer spaces between them, and had to be massive enough to grow and to spiral in towards the sun. Such a situation is difficult to imagine, but there is some theoretical evidence that it is possible.

We must now consider whether the dust cloud theory is more convincing, or has fewer weaknesses, than other theories that have been proposed. The famous Nebular Hypothesis of the French mathematical

This concerns the two extinct planets shown in the drawing above. Recent studies of meteorites have indicated that they and the asteroids are shattered fragments of one or more extinct planets. One possibility is that two planets between Mars and Jupiter collided to form what is now the asteroid belt. In this drawing the size of the planets has been exaggerated. Satellites, except for the rings of Saturn, have also been omitted.



astronomer, the Marquis Pierre Simon de Laplace, suggested that the sun and planets derived from a great revolving nebula, or cloud. In this respect Laplace's theory sounds somewhat like the present one. But he assumed that the planets were formed from rings of matter left behind when the dish-shaped nebula collapsed. The nebular hypothesis meets with the overwhelming difficulty that it requires that most of the solar system's rotation be carried by the sun. As we have seen, the slowly rotating sun actually contains only a small percentage of the system's total rotation or angular momentum, while Jupiter contains more than half. It is not possible to account for the observed motions by Laplace's theory.

ANOTHER famous and extremely important theory, known as the Planetary Hypothesis, was proposed by the geologist T. C. Chamberlin and the astronomer F. R. Moulton, of the University of Chicago, early in this century. They postulated that the planets were formed as the result of a near-collision between the sun and another star. The star came very close to the sun, perhaps even grazing its surface. Huge tides were raised on the sun and great quantities of material were torn from it. This material is then supposed to have condensed into droplets which eventually coalesced into planets. The planetary hypothesis has many attractive features, and has dominated thinking in this field for many years.

One of its principal difficulties, which is also common to other theories that require a stellar collision or near-collision, was pointed out by Henry Norris Russell and proved by Lyman Spitzer. Let us consider the physical state of the hot, gaseous material which, according to this theory, is to be removed from beneath the surface of the sun very rapidly, say within an hour or two. While this gas remains in the sun, it is held by the sun's enormous gravity, some 28 times that of the earth. If it were not extremely hot, the gas would collapse into a very dense mass. It is kept distended by solar temperatures which range from 10,000 degrees F. at the surface to some 40 million degrees at the center. Suppose, then, that we scoop enough material out of the sun to make the planets, allowing for a considerable loss into space. We are drawing out gas at a temperature of perhaps 10 million degrees. At the instant when it is released from the sun's great gravity, the explosive pressure of this superheated gas is fantastically great. Released suddenly, the gas expands in an explosion of almost inconceivable force. Most of the gas is lost forever from the solar system. Furthermore, it is very difficult to conceive of a process whereby the remaining gas would cool and condense into droplets, or collect in masses as large as the planets.

Recently the German physicist C. F. von Weizsäcker has developed a new mathematical theory for the evolution of planets from a gas-and-dust cloud rotating about the sun. His theory can be made to predict the Bode's Law relationship of planet distances from the sun. There is still some question, however, whether the Weizsäcker theory really works. Moreover, it leaves wide open the question as to how the gas cloud came into existence and into motion about the sun. Whatever its value as an explanation of the origin of planets, Weizsäcker's theory is of great current interest to physicists and astronomers because of its wider applications in the theoretical study of large masses of gas.

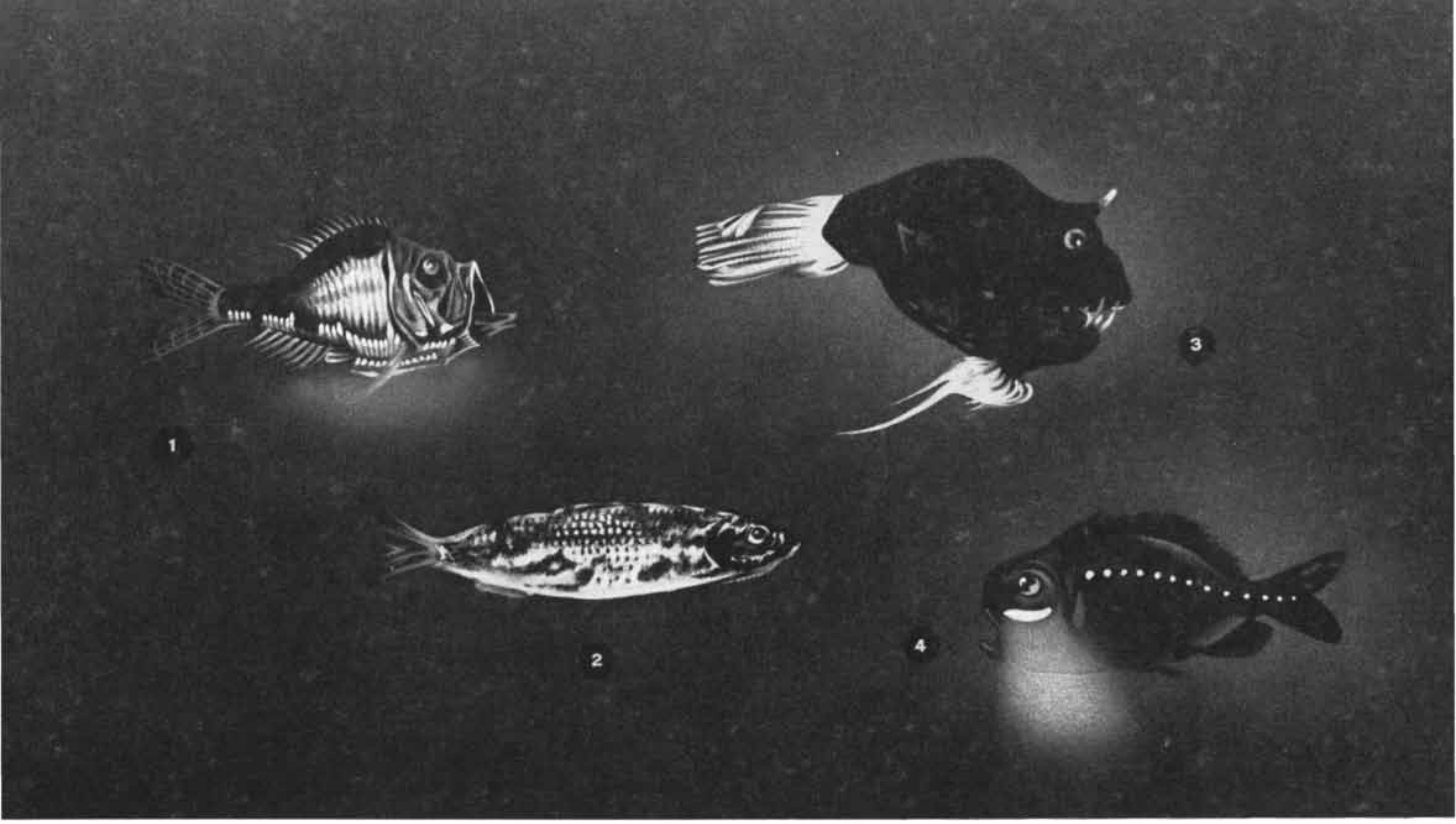
All of the current theories about the birth of the stars and planets leave much to be desired. The evolution of the solar system remains foggy, which may be fitting, considering that the system may actually have been formed in a dusty fog. The truth is that we are still groping in the haze of a poorly illuminated and ancient past. Perhaps an entirely new advance in science will be required to light our way. On the other hand, it is possible that we have already stumbled on the correct path but cannot see clearly enough to recognize its worth.

In any case, the dust cloud hypothesis revives an old and intensely interesting speculation: Are there other living planets like ours? If the planets in our system developed from an encounter of the sun with another star, we should expect other planetary systems to be exceedingly rare, for the odds against such encounters are very high. But if the solar system developed at the "beginning of things" by some general but yet mysterious process, or later by condensation of dust clouds, other planetary systems are likely to be numerous. The dust cloud theory thus suggests a possibility that worlds with human or intelligent life may be fairly frequent throughout the universe.

The consideration of such questions no longer belongs only in the realm of "science fiction." If intelligent beings exist on other planets, we may some day establish radio contact with them. Conceivably we may be able to send ships into space to cruise among planetary systems belonging to other stars in our neighborhood. There our descendants may find strange types of intelligent beings—or at least settle the argument.

Fred L. Whipple is associate professor of astronomy at Harvard University.

TINY DARK SPOTS made visible against a huge luminous nebula are possibly dust clouds at the beginning of their evolution into stars and planetary systems. The nebula is Messier 8, in the constellation of Sagittarius, the Archer. Photograph was made by the 60-inch reflecting telescope at Mount Wilson Observatory.



LUMINESCENT LIFE is found among 40 orders of animals and two groups of plants. At the far left (1) is the hatchet fish, *Argyropelecus.* The herring (2) is not naturally luminous, but here illustrates a culture of luminescent bacteria which often grow on dead fish. *Linophryne arborifera* (3) has a thin luminescent tail and ventral fin. *Photoblepharon palpebratus* (4), a fish of the East Indian Banda Sea, harbors

THE LUMINESCENCE OF LIVING THINGS

The soft, cold light given off by a host of plants and animals is an engaging mystery, especially for writers and scientists. Herewith a biologist presents a brief essay on what is known of bioluminescence

by E. Newton Harvey

THE luminescence of living things has charmed and mystified mankind from earliest times. The phrase at once suggests the firefly and the glowworm, described by Aristotle and Pliny mentioned by writers on nature throughout recorded history, famed in song and poetry. Shakespeare wrote:

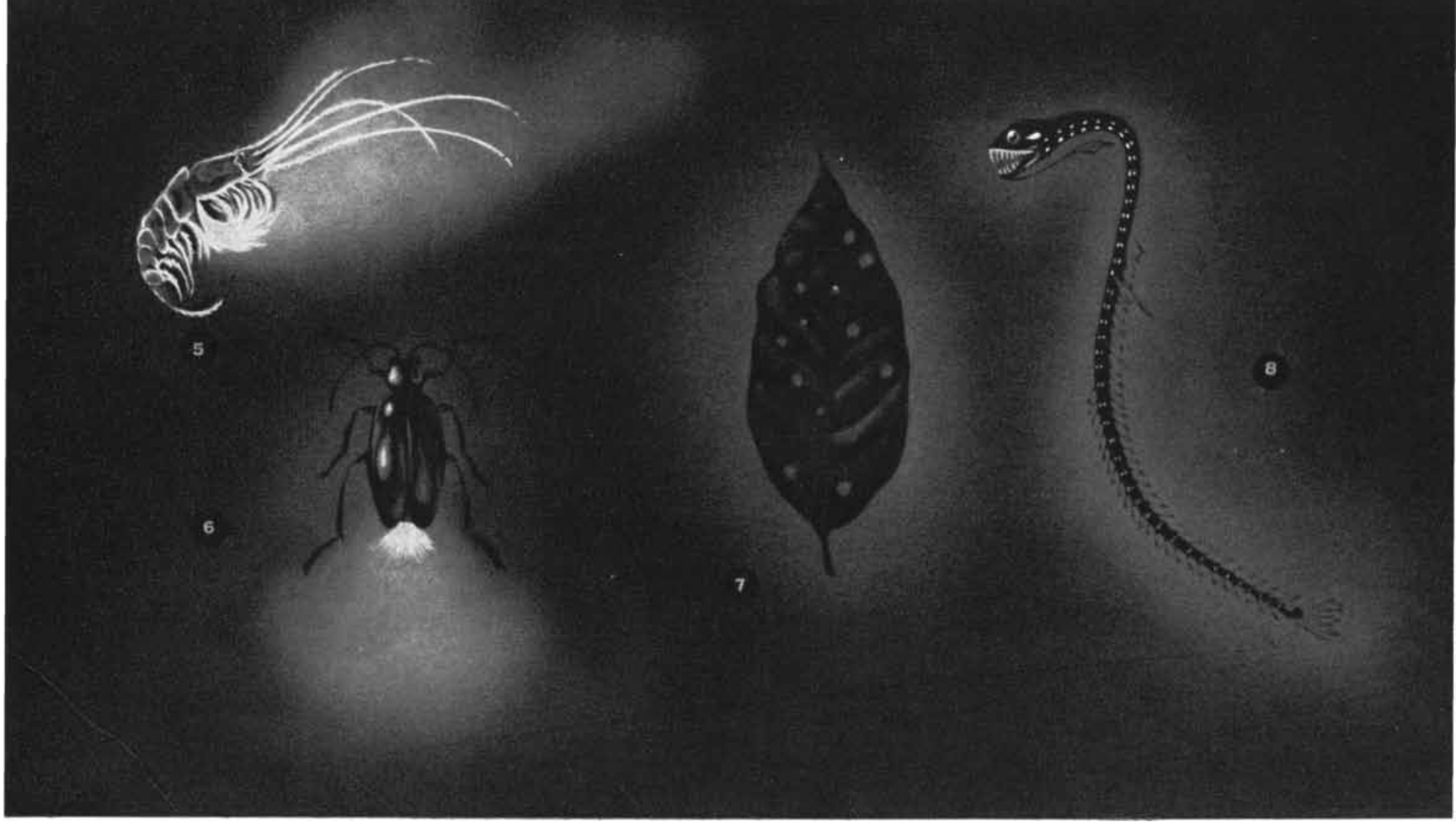
"Like a glowworm in the night,
The which hath fire in darkness,
none in light."

Who has not thrilled at the myriad sparkling lights to be observed on almost any night in late spring as, in the words of James Russell Lowell:

"The fireflies o'er the meadow
In pulses come and go"?

Here is not only a spectacle but a fascinating scientific problem. The firefly and the glowworm emit "cold light," as it is commonly called. How is it possible for a living thing to produce a light without at the same time producing heat?

This problem of bioluminescence is less of a mystery at present than it was 50 years ago. We are now accustomed to lighting houses and offices by a form of cold light: the fluorescent tube. One need merely touch the glass wall of a fluorescent lamp to realize that the light is actually cold. On the inner wall of the tube there is a thin layer of white powder. When it is "excited" by invisible ultra-



under each eye a culture of luminescent bacteria which it can turn on and off. *Acanthephyra purpurea* (5), a deep-sea shrimp, squirts a luminous fluid when it is frightened. *Photurus pennsylvanica* (6) is a species of firefly common to the U.S. *Omphalia flavida* (7), a luminescent leaf spot fungus, here grows on a coffee leaf. *Idiacanthus fasciola* (8) has a double row of luminescent spots which run the full length of its sinuous body.

violet radiation, generated by current passing through the tube, the powder fluoresces, that is, it absorbs the energy of the radiation and converts it into visible light with practically no loss as heat. This process, a very efficient one, is called a luminescence to distinguish it from an incandescence, in which the light is emitted as a result of high temperature—a very inefficient process.

Many different kinds of luminescence are known, classified according to the kind of energy that is converted into light. When the exciting energy is chemical, the process is called chemiluminescence. The problem is to find out what chemical is involved and the mechanism by which the chemical reaction takes place.

Although we may not always be able to isolate and purify the chemical compound concerned in a biological process, it can at least be given a name. Sometimes the name is "substance X" or "factor Q," sometimes A, B, C or D, as vitamins were named before their chemical constitution was known. In the case of the firefly, the light-emitting material is called luciferin, meaning "light-bearer."

We know that oxygen is necessary for light emission by the firefly. The luminescent process is an oxidation. In addition, like practically all biological processes, the luminous oxidation of luciferin proceeds only with the aid of an enzyme, in this case one called luciferase. Research in bioluminescence is concerned with the isolation and purification of luciferin and luciferase and with the complete series of reaction-steps, not only during the oxidation of luciferin, but also during its formation from some precursor in the luminous cells.

An important question immediately presents itself: What species of luminous animal is most favorable for chemical work? There is a large number to choose from. More than 40 orders of animals and two groups in the plant kingdom have developed the ability to luminesce. These vary from the simplest known organisms, the luminous bacteria, to so complicated a vertebrate as a deep-sea fish. For chemical study, by far the most valuable form is a marine crustacean less than an eighth of an inch long called Cypridina.

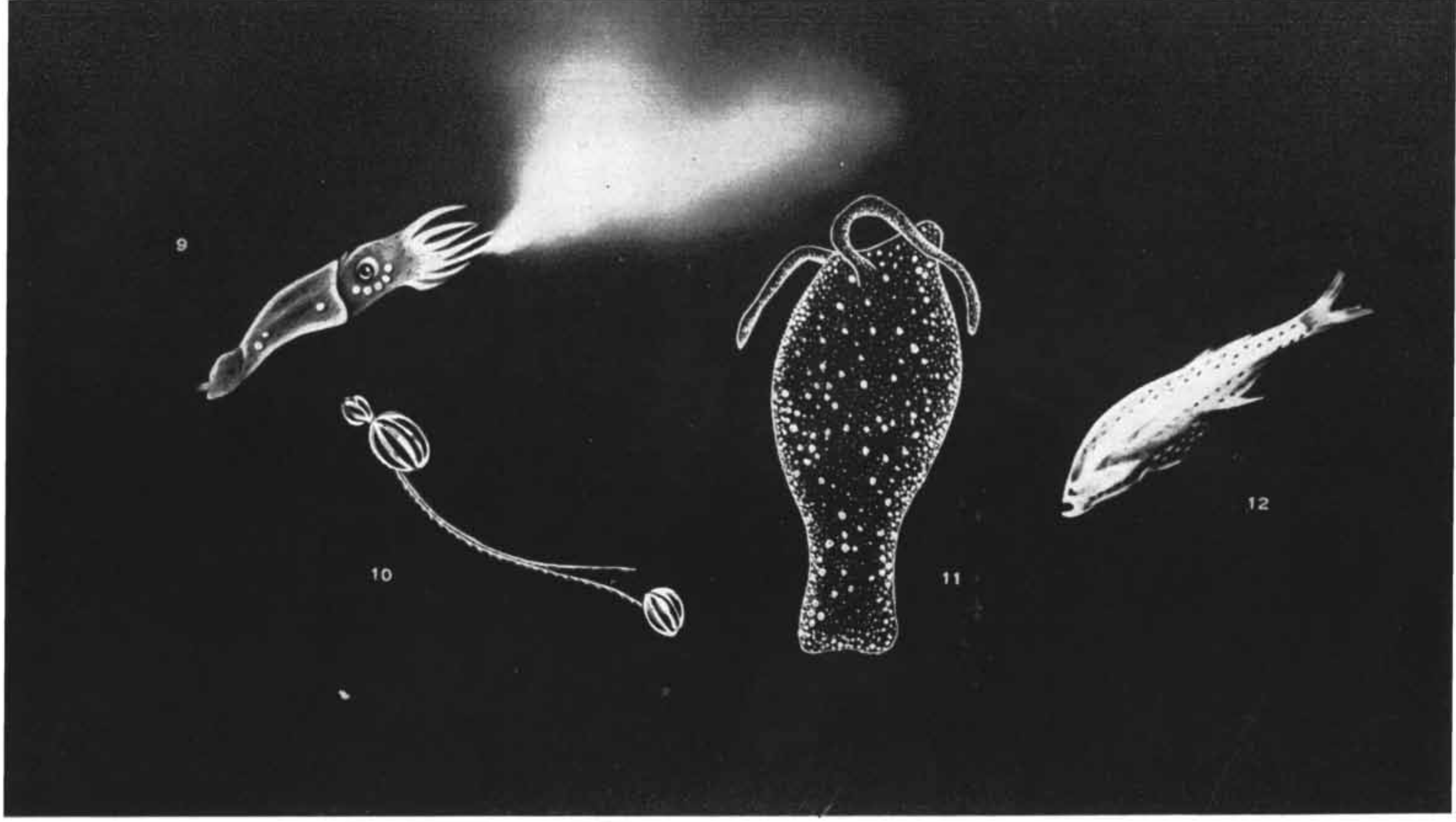
Curiously enough, all the 40 orders containing luminous species are either terrestrial (like fireflies and other insects; earthworms and myriapods) or marine (such as flagellates, jellyfish, sea pens, comb jellies, marine worms, crustacea, molluscs, squid, brittle stars and ascidians). No fresh-water luminous species has been found. The reason for this is still unknown.

BIOLUMINESCENCE is responsible for the phosphorescence of the sea, a phenomenon that not only amazed and mystified the older voyagers, but inspired some of the most flowery descriptions to be found in scientific literature. Like the firefly and the glowworm, phosphorescence of the sea has fascinated the poet, from the first century Roman poet Martial, who referred to the sparkling skin of women sea bathers, to Lord Byron's Corsair, one of whose characters:

> "Then to his boat with haughty gesture sprung.
> Flashed the dipt oars, and sparkling with the stroke,
> Around the waves phosphoric brightness broke."

Not until many years after the perfection of the microscope was it realized that all marine phosphorescence came from living animals, some of it from millions of minute protozoa entirely too small to be detected with the naked eye. These organisms glow intermittently when they are stimulated by breaking waves or other mechanical disturbance.

We cannot consider here each of the 40 groups of luminous organisms. A few have been of particular value for physico-chemical study; others are of interest for the remarkable biological adaptations that they exemplify. Among luminous bacteria, for example, three distinct types are found: saprophytic, parasitic and symbiotic. The saprophytic type live on dead fish or meat in refrigerators, making the whole surface luminescent. This was the light that astonished Robert Boyle in 1672 and that in 1944 frightened a citizen of Mexia, Texas. Rushing into a police station, the latter exclaimed, "My meat,



EIGHT OTHER SPECIES begin with *Lycoteuthis diadema* (9), a deep-sea squid which squirts luminous fluid, as opposed to the dark fluid squirted by most squids. The comb jelly *Pleurobrachia* (10) is responsible for most of the larger flashes of luminescence seen in the sea at night. *Phillirrhoe bucephala* (11) is a luminous snail which has no shell. The pale round mouth, *Cyclothone braueri* (12), has a body which

it's all lit up!" This particular instance of "mystery meat," due to luminous bacteria, was widely reported in newspapers and magazines.

Robert Boyle tested the shining meat and also shining wood, whose light is due to threads of luminous fungus, in his air pump to see if the light would disappear when air was removed. He found that it did and thereby performed a crucial experiment showing that luminous bacteria (and fungi) require air (meaning oxygen) for luminescence. Boyle did not know that the light was due to luminous bacteria or that oxygen was the necessary gas withdrawn by his pump. Nevertheless he deserves much credit for the first important work on bioluminescence.

WHEN luminous bacteria attack a living animal, as they sometimes do, they are said to be parasitic. The unfortunate victim comes down with a luminous malady. Several instances are known among insects and crustacea. One example is the sand flea that hops about on beaches, especially near piles of dead seaweed. These animals may become infected or parasitized by the bacteria. They invade the sand flea's muscles so that its whole body becomes luminous. The sand flea gradually weakens, its movements become feeble and it finally dies, we might add, in a blaze of glory.

By far the most remarkable luminescent animals are those that permanently harbor luminous bacteria. This is an example of symbiosis, and it is found in certain fish. Such cases are not mere infections, for the fish have special luminous organs in which the bacteria live without harming their hosts. One striking instance is a fish of the Banda Islands in the Dutch East Indies. It cultivates the bacteria in gland-like cells, forming a special oval structure just under the eye. Luminous bacteria, in contrast to the small marine organisms that cause phosphorescence in the sea, glow continually. But the Banda fish has developed a method of turning its bacterial light on and off. It has a black fold of skin, like an eyelid, which it can draw over the luminous organ—hence its name: Photoblepharon (from the Greek words meaning light and eyelid).

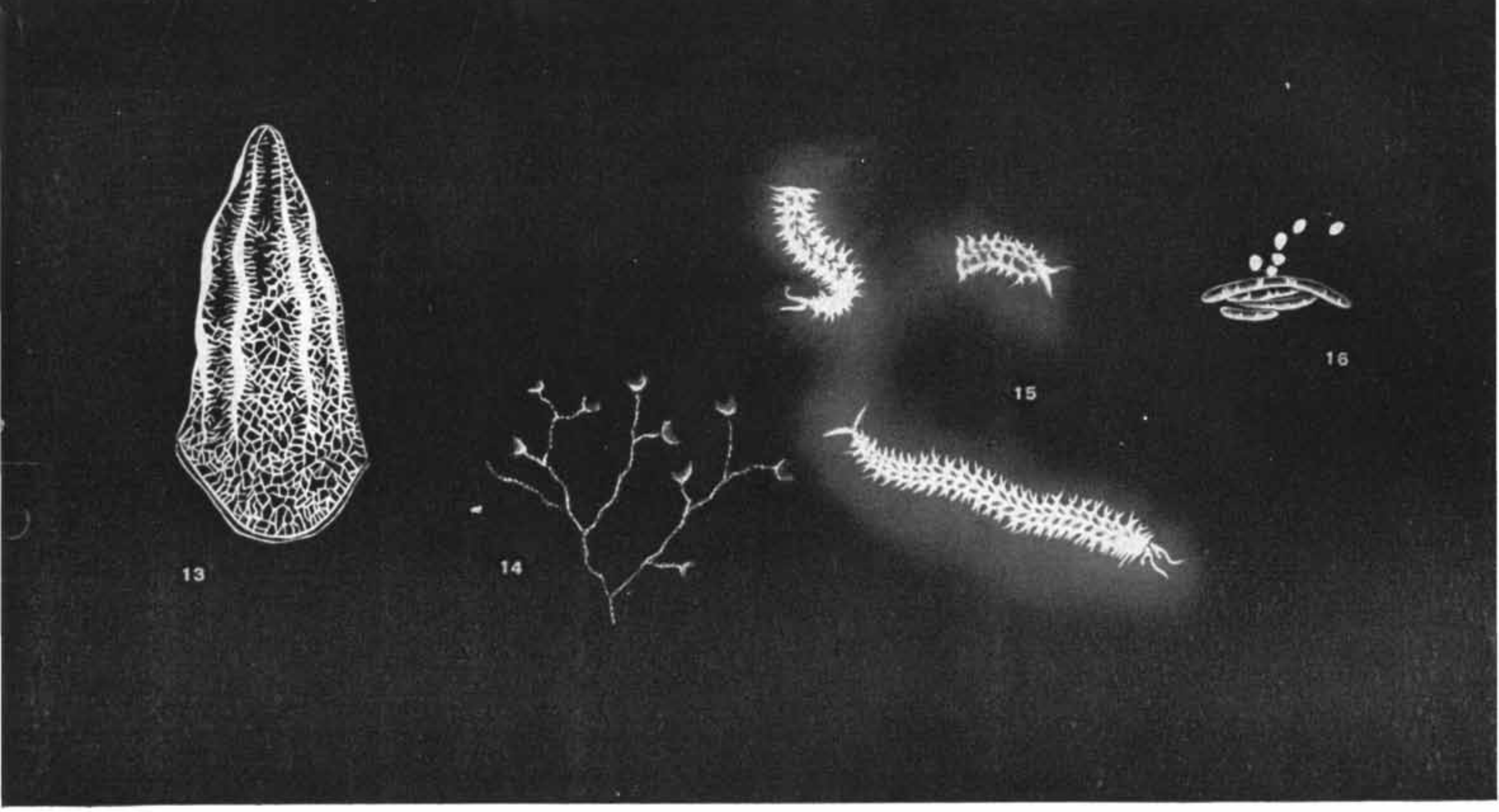
Another genus of Banda Island fish has a similar organ full of luminous bacteria, but with a different mechanism for controlling the light. In this case the organ is hinged, luminous on one side and dark on the other. The light is turned off by flipping the luminous surface against the body. The name of this fish is Anomalops (meaning peculiar eye). It is a strange sight indeed to see these Banda fish swimming through the water, flashing their large luminous organs in a series of winks.

Other luminous fish of the deep sea possess rows of photophores, or luminous spots. along the sides of the body. These look like portholes on a ship. Each species has a different arrangement of photophores and the guess has been that the sexes, living as they do in eternal darkness, recognize each other by the pattern of lights displayed.

Some animals eject a luminous fluid. For example, a deep-sea squid from the Mediterranean depths off Sicily surrounds itself with a brilliant luminous liquid when disturbed. Unlike the common squid, which ejects a black cloud of ink to conceal its position, this deep-sea cousin, living in perpetual darkness, shoots out a liquid fire. Here is one of the mysteries of evolution—one animal develops the blackest fluid known, while a close relative forms a clear, shining liquid. We can only conjecture what its purpose may be—perhaps to frighten enemies, perhaps to lure smaller animals on which it feeds, perhaps to attract the opposite sex.

A few animals have lights of two colors. The most famous is a grub-like South American beetle called the "railroad worm." It has a row of greenish-yellow lights along its sides and a red light at one end, like a train lit up at night. This lighting system is under the control of nerves which can turn on the red or yellow lights separately or together. When the red light alone shines, the animal looks like a glowing cigarette.

MOST luminous animals are small, but size is no barrier to chemical investigation, provided a sufficient number of specimens is available. As I have mentioned, the most valuable for chemical study is the tiny marine crustacean, Cypridina. Cypridina has a large lumi-



is almost entirely luminescent. Ctenophores, or comb jellies (13), glow with a tracery of luminescent body canals. Hydroids (14) luminesce like strange flowers. The polynoid worm (15), when it is attacked, has the faculty of leaving luminous fragments of its body behind while the less luminous head makes its escape. Bacilli of anthrax (16), like many other living things, luminesce only when they are excited by ultraviolet radiation.

nous gland that pours luciferin and luciferase into the sea water whenever the animal is disturbed. It surrounds itself with a luminous blue liquid. Cypridinae can be caught and, if dried quickly, will retain their ability to luminesce indefinitely whenever moistened. From the dried and powdered animals luciferin and luciferase can be extracted by various solvents for chemical analysis.

There is no doubt whatever that Cypridina has discovered how to make a chemiluminescent compound not known in chemical laboratories. According to present knowledge, it appears to consist only of carbon, hydrogen, oxygen and phosphorus with no nitrogen, sulphur or halogen in the molecules. The presence of phosphorus may be particularly significant. This is not, however, because the element phosphorus is luminous but because the high-energy phosphate bond has been found to play an increasingly important role in many biological processes.

The mechanism of bioluminescence is complex. The oxidation of luciferin undoubtedly takes place in a series of steps. During this process, one of the intermediate molecules retains some of the energy of oxidation. This energy-rich molecule is described as "excited." When it loses its energy, the energy appears as light.

Probably the luciferins from different animals are chemically distinct. The structural formula for Cypridina luciferin is as yet unknown, although suggestions have been made. One thing is certain: the molecular weight is relatively low. But when it comes to identifying the molecules, we have practically the whole of organic chemistry to choose from. A wide variety of organic compounds will emit light under proper conditions. Some of the better-known chemiluminescent substances are aminophthalic-hydrazid, which gives off a bright blue light; dimethyl-diacridylium nitrate, which emits light of a greenish-yellow hue, and metallic porphyrins, which produce a red light like that of the railroad worm. The spectra of these chemiluminescences are quite similar to those of animal luminescences—short bands with no lines or fine structure, with their maxima of emission in various regions of the visible, and with no ultraviolet or infrared wavelengths.

In spite of these similarities, it is quite certain that none of the organic chemiluminescent substances thus far synthesized is the same as the ones utilized in bioluminescence. We know this because none will emit light in the presence of the enzyme luciferase. This latter compound is of high molecular weight and, like other enzymes, has the chemical characteristics of a protein.

WILL it be possible to synthesize luciferin and luciferase? Chemists would undoubtedly answer an unequivocal yes, so far as luciferin is concerned; concerning luciferase, probably yes, in time. Synthesis of complex proteins is not possible now but may be accomplished in the future once their structure is known.

Will it be possible to use animal light for illumination? Calculation indicates that a room whose walls were covered with a bright culture of luminous bacteria would be light enough for reading. However, no chemiluminescence has yet been devised for general lighting. It would be overoptimistic to say that the use of living light is just around the corner. On the other hand only an unwise scientist would assert that it is impossible.

Inherent in all chemical reactions is the principle of reversibility, that is, the possibility of rebuilding a reacting substance from its products by reversing the reaction which destroys it. After a chemiluminescent substance has oxidized with production of light and formed reaction products, it could be re-formed by reversing the reaction. Thus it would be ready for a second light emission. Like the Phoenix of old, which arose from its funeral pyre in all the freshness of youth, luciferin might be regenerated for continual use as a light-giving substance.

Whether of practical utility or not, the study of animal light presents a fascinating field of investigation in pure science. Here the biologist, chemist, physicist and even the illumination engineer can meet on common ground of mutual interest.

E. Newton Harvey is Henry Fairfield Osborn Professor of Biology at Princeton University.

IN 1925 C. J. Davisson (*left*) and L. H. Germer set up their modest apparatus on a workbench in the Bell Telephone Laboratories. The apparatus, here concealed by shielding, is depicted on the cover.

DAVISSON AND GERMER

In 1927 they discovered that the electron is a wave as well as a particle, a seemingly paradoxical fact which is a part of the foundation of modern physics

by Karl K. Darrow

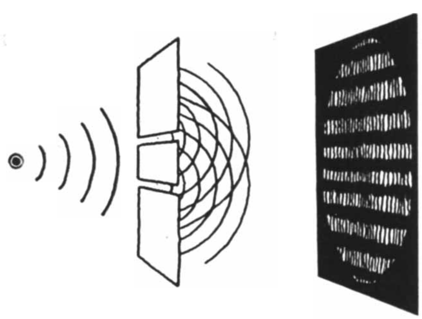
Editor's note: Modern physics is constructed of closely-fitted hypotheses and experimental observations. The historic observation of the wave nature of electrons by C. J. Davisson and L. H. Germer is a cornerstone of the theory of wave mechanics, upon which rests much of the physicist's present understanding of fundamental particles and the structure of atoms. This account of the experiment of Davisson and Germer by their colleague Karl Darrow is not only a description of how they made their discovery but also an essay in how the physicist approaches a problem of his exacting science.

FROM the latter part of the seventeenth century to the middle years of the nineteenth, physicists argued with passion a question which now appears pointless—the question whether light is of the nature of corpuscles or of the nature of waves. The argument was suspended about 1850 because of certain experiments which were supposed to prove that light definitely has the character of waves and definitely not that of corpuscles. It is now evident that the suppositious proof was not a proof, and indeed that no experiment will ever banish either view. The question on which our forefathers expended so much effort is a trick question, though the trick is one played by nature herself. It has no answer, but in hunting for the nonexistent answer we have found that the physical world is interfused with a complexity much greater and much harder to imagine than would have been the case had either of the apparently possible answers been valid by itself.

Halfway through the twentieth century, we have come to the conclusion that light is *both* of the nature of waves and of the nature of corpuscles. Various phrases have been contrived to describe this strange association of corpuscles and waves, but all of them are lame because the situation defies all ordinary language and all familiar processes of thought. The particular lame phrase that shall be used here is: *light is composed of corpuscles guided by waves.*

This article, however, is devoted to the similar law by which *electrons* are governed, and to the historic experiment by C. J. Davisson and L. H. Germer which demonstrated the law, thereby adding a new feature to atomic physics.

In considering electrons, we suffer at the start from a fault of language from which the case of light is free. The word "light" carries no connotation either of corpuscle or of wave, but the word "electron" is meant to imply a corpuscle, and it does imply a corpuscle. What we need is a word that shall specify negative electricity flowing across a vacuum or through a metal, without prejudging the ambiguous issue—for again it is an ambiguous issue—between corpuscles and waves. But we cannot use "negative electricity" safely, for negative electricity is usually taken as comprising negative ions of atomic mass in gases and conducting solutions. I have no intention of trying to increase the vocabulary of physics by introducing an invented word. Unless the reader wishes to invent a word of his own, he must use the word "electron" and do his best to regard it as a word that embraces both particles and waves in its difficult meaning.



DIFFRACTION of light waves is caused by passing them through slits. Pattern (*right*) is produced by interference of diffracted waves.

The rule that correlates the waves and corpuscles of light is very simple to express. *Corpuscles of momentum p* (momentum is the product of speed and mass) *are guided by waves of wavelength h/p.* Here *h* stands for one of the most famous of the great universal constants of nature, the constant of Max Planck, the pioneering German physicist who died, full of years and honors, in the autumn of 1947.

So expressed, the rule generalizes itself. If light may be so described, what is more natural than to infer that electrons of momentum *p* are guided by waves of wavelength *h/p*? Yet wisdom based on habit may be a greater obstacle to the emergence of a new idea than ignorance itself, and many a wise man overlooked this simple possibility before the proper combination of wisdom and originality brought the idea to birth in the mind of Louis de Broglie of Paris. Even de Broglie overlooked the simple consequence which is the theme of this article. Now I must make clear what I mean by saying "waves guide corpuscles."

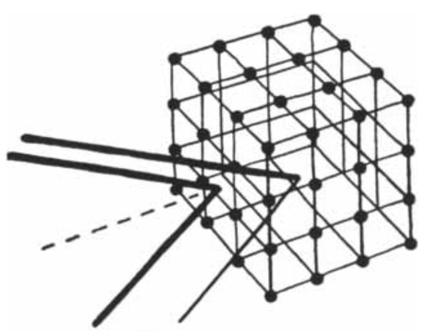
Think of the most primitive of all "diffraction gratings"—the fence of parallel wires, evenly spaced, which Joseph von Fraunhofer first made more than a hundred years ago. Think of a narrow pencil or beam of monochromatic light—the yellow light of sodium will serve as an example—projected against this fence of wires at right angles to their plane. Owing to the even spacing of the wires, the light will be divided into several beams: one will continue in the direction of the original beam, the others will diverge at distinctive and sharply marked angles.

This is the phenomenon of *diffraction*, and the diverging beams are called "diffraction beams." From their angles of divergence we may compute, by a simple trigonometric formula, the wavelength or crest-to-crest distance of the light waves. for this experiment furnishes both the prime evidence that light partakes of the nature of waves and the way of determining the wavelength. If the even spaces between the wires are widened, the angles of divergence shrink. If the spaces are narrowed, the angles of divergence broaden. If the even spacing of the wires is done away with by pushing them to and fro until the intervals between consecutive wires lose all their uniformity, the diffraction beams are missing.

Here indeed is the distinctive peculiarity of waves: they notice the presence or the absence of order. They respond to an orderly array of obstacles by disposing themselves into beams in an orderly fashion. Thus, light is of the nature of waves; and yet, we know also that light consists of energy packed into corpuscles! (Indeed, when a beam of light falls on a metal, the corpuscles pass over their energy individually to the individual electrons, each electron springing from the metal with the energy received from one sole corpuscle of light; if the energy were evenly spread over the waves, it would be so rarefied that no electron could ever gather up so much.) We try to conciliate these contradictory statements by saying that the diffraction grating forms the light waves into diffraction beams, and the waves guide the corpuscles along these beams. This is indeed a crude thing to say, and the more sophisticated a physicist is the more likely he is to decry this manner of speaking, but it will serve our purpose.

Shall we then place a grating of wires athwart a stream of electrons, and look for diffraction beams on its far side? No, this will not work, because of a difficulty of scale. The wavelength of electrons at any feasible speed is too small. Their momentum (speed times mass) is very high as compared with the momentum of visible light. The "rule of correlation" between waves and corpuscles—wavelength of waves is h divided by momentum of corpuscles—teaches us that for electrons of any convenient speed and a wire grating of any feasible spacing, the diffraction beams (if any) will be pinched into such small angles with reference to the main forward-faring beam that we shall be unable to distinguish them. Conceivably we might use electrons so very slow-moving that the wavelength would be large enough to yield a broadly diverging pattern of diffraction beams; but in so slow-moving a stream the repulsions between the electrons would spread out the beam until it became so vague that again the phenomenon we seek would be blotted out. We must take electrons of a convenient speed—the speed conferred on them by a potential difference of 100 volts is a convenient one—and seek for a grating of obstacles regularly spaced, with a spacing of the proper scale.

Now, a *crystal* is just such a grating because of the orderly arrangement of its atoms and the narrowness of the spacings between them. Accordingly, it was a crystal which in the hands of Davisson and Germer formed a stream of electrons into distinct and unmistakable diffraction beams, and thus proved that electrons are under the guidance of waves.



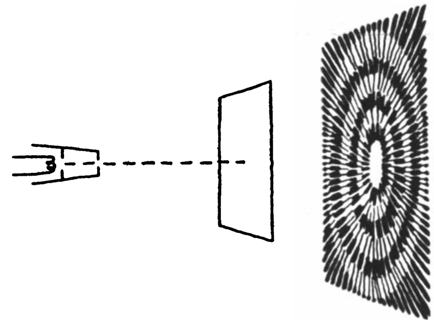
CRYSTAL'S atoms form a diffraction grating when electrons (*left*) are directed against them. Deeper atom layers also diffract electrons.

But let me interrupt the argument to introduce the major figures of this story and the scene of their researches. Davisson, a native of Illinois, a doctor of philosophy of Princeton University (where he worked on the emission of positive ions by incandescent metals) and a professor of physics in the Carnegie Institute of Technology, came to the Bell Telephone Laboratories in 1917 to participate in the research work of World War I. There he remained until he retired in 1946. He was in his early forties at the epoch when this story commences. Germer, a native of Chicago, just turning 30 at the time of these experiments, made his debut as a physicist at the Bell Telephone Laboratories. His measurement of the energies of electrons emitted from hot filaments, made at these Laboratories, had served as his doctoral thesis at Columbia University. Later he continued for years to develop the applications of electron diffraction. These, however, were not foreseen before the discovery, which confuted for all time (not that it still needed confutation) the erroneous idea that "pure" science cannot flourish except in academic institutions.

From this point on I might leave the reader under the impression, implied though not demanded by what has gone before, that Davisson and Germer set out to test a prediction made by Louis de Broglie. But science does not always advance in such a logical fashion, and in this case particularly it did not. De Broglie, as I have already said, apparently did not foresee that electrons might be diffracted by crystals. Though he did associate waves with electrons according to the rule of correlation which I gave above (and which often bears his name), he did it in order to make a theory of the hydrogen atom. As for Davisson, he was exploring the reflection of electrons by surfaces of metals, with no particular aim beyond the furtherance of knowledge.

Metals normally are aggregations of tiny crystals turned in every way. In this normal condition, they do not form a single diffraction grating. Therefore Davisson did not observe diffraction beams. But he did observe surprising preferences of the reflected electrons for certain directions over certain other directions of rebound. (The technical way of expressing this is that the distribution-in-angle of the reflected or "scattered" electrons showed a strange and striking dependence on angle.) This body of facts Davisson interpreted in terms of the structure of the metal atoms. He had not yet invoked either the significance of the crystalline arrangement of the atoms or the idea of waves.

At that critical juncture, an accident later recognized as happy brought about the transformation of a large part of the metallic reflector into a single crystal. Here I quote from Germer, who has graciously supplied his recollections for this article:



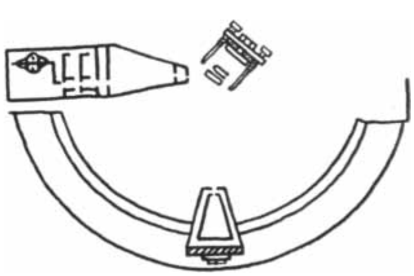
PATTERN of diffraction similar to that produced by light is created when electrons are beamed through a thin foil made up of metal crystals.

"In the spring of 1925 occurred an accident which led to the discovery that the crystalline arrangement of atoms did, after all, take part in determining directions of electron rebound. The accident happened while air was being exhausted from a glass bulb, somewhat like a glorified and very special radio tube, which contained a metal reflector upon which these experiments were to be continued. It consisted of a break in the apparatus which allowed air to rush in, and fortunately it happened at a time when the reflector was red-hot. The result was oxidation of the reflector. Here again good fortune intervened. The oxidized and blackened reflector might very well have been thrown away and a shiny new one substituted for it. The course of the experiment was otherwise. It was decided to clean the oxide from the surface by heating it for a long time in hydrogen. This was done, and at the end of this long annealing process the reflector consisted no longer of a great many tiny crystals, as metals usually do, but of a very few large ones. This change in number and size of crystals was not noticed at first, but when experimentation was begun again the phenomena were startingly changed. The distribution-in-angle of the electrons rebounding from the re-crystallized reflector was quite altered and much more complicated."

This observation proved that the structure of the metal atoms was not the only source of the singular scattering phenomena. Davisson conjectured that there might be "transparent directions" in the crystal, along which the electrons could travel without suffering reflection or disturbance. The key had not been found as yet, but the idea of diffraction emerged in the course of the months, and in the following year Davisson calculated where the diffraction beams should lie and set about to find them. On January 6, 1927, Davisson and Germer found a strong and sharp diffraction beam due to the arrangement of atoms in rows in the crystal surface, and it was at the proper inclination—that is to say, it was just the beam which should have been formed by waves of the wavelength given by the rule of correlation.

It will help now to look at the illustration in this column. At the upper left an "electron gun" shoots electrons in a steady stream toward the metal crystal to the right. The electrons come from an incandescent filament, and there are various voltages applied between the various slits and the casing of the gun. This design requires careful planning, but its details are immaterial to our present purpose.

The neatly defined beam of electrons, of a uniform and controllable speed, impinges on the crystal. The reflected or "scattered" electrons fly off in all directions from the surface of the crystal, and most of them depart from the plane of the drawing; but this also is immaterial, for it is possible so to orient the crystal that diffraction beams will appear in this plane of the drawing. In the same plane

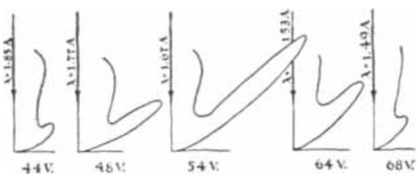


APPARATUS of experimenters fired electrons from gun (*left*) at crystal. Diffracted electrons were gathered in a movable collector at bottom.

swings an "electron collector" that is moved from point to point along the arc which also appears in the drawing, sojourning at each stopping point long enough to collect an appreciable number of electrons. All of this apparatus was enclosed, while the experiments were going on, in an evacuated tube of glass. The presence of air would have ruined the observations, for the air molecules would have dispersed the electrons and blotted out the beams.

Next we should consider a diagram of the diffraction beam. The curve in the center indicates a beam which is strong and sharp. The curves to the left and right indicate beams which are less marked. The difference springs from the fact that the middle curve depicts electrons of the speed corresponding to a voltage of 54; those on the left represent lesser speeds and those on the right, greater. Smaller speeds correspond to greater wavelengths, and vice versa; the wavelengths in Angstrom units (one Angstrom=1/100,000,000 cm) are written along the vertical axes. The inclination of the beam varies with the wavelength, but this is scarcely obvious in the pictures. Much more obvious are the differences in the strength of the beam.

But why should the diffraction beam be



CURVES plotting the voltage and wavelength of electrons diffracted in apparatus lent further support to the Davisson-Germer experiment.

favored by a certain particular electron speed, and impaired at other speeds? Nothing I have thus far said suggests anything of the sort, and indeed nothing of the sort would occur if this were diffraction by wires in a plane or by an optical diffraction grating. This complication arises from the fact that the atoms of the crystal form a *three-dimensional* grating. The atoms of the surface layer are indeed arranged in evenly spaced rows of evenly spaced atoms. If they alone were operative, a change in the electron speed would swing the diffraction beam to another angle without blunting or reducing it. But beneath the surface layer there is another layer of evenly spaced atoms and beneath these there are others and others. These collaborate in the diffraction, conspiring to magnify the beam for a certain optimal speed, which happens to correspond to 54 volts, conspiring to attenuate it more and more as the speed departs from this optimal value. This is not a very easy thing to grasp: what is simple in two dimensions is often complicated when a third dimension enters into the picture. Suffice it here to say that the favoritism shown the diffraction beam by this peculiar value of electron speed adds support to the theory.

Much has been done in this field in the years since these first experiments proved that electrons share with corpuscles of light the universal deference of particles to waves. "Universal" is not too strong a word: other experiments like those of Davisson and Germer have shown that atoms, nuclei and neutrons all submit to the guidance of waves, and always the wavelength of the guiding waves is h divided by the momentum of the guided particles. To identify these with electromagnetic waves, to identify them with acoustical waves, to invent an ether to sustain them—all such enterprises are worse than fruitless. Even the metaphor of "guidance" speedily loses its fitness when one attempts to penetrate further into the intricate association of particles and waves. We shall enter into it no further; but two things remain to be said to round out this article.

FIRST, to give credit where credit is due: the young German physicist Walter Elsasser was the first to publish, in a brief letter to a German journal, the idea that electrons may be diffracted by crystals. He adduced as evidence the singular phenomena which Davisson observed in 1925 and earlier, when the electrons were being scattered by polycrystalline masses of metal. It does not appear that these phenomena prove the idea, nor that Elsasser's letter affected the subsequent course of the experiments of Davisson and Germer, but it should not be forgotten that Elsasser bridged the gap which the theoretical physicists of the time had left open.

Second, I must not leave uncorrected the implication that a mass of small crystals is unable to testify to the diffraction of electrons. When a beam of electrons passes through a very thin sheet of metal composed of many tiny crystals, and a photographic plate parallel to the sheet awaits the electrons at a suitable distance beyond, the plate—after exposure and development—reveals a glorious spectacle of concentric rings. These are due to diffraction beams, and so they add their testimony to the doctrine that electrons are guided by waves. These rings were first produced by G. P. Thomson (now Sir George Thomson) of England, who shared the Nobel Prize with Davisson for the coincidental making of one of the most notable discoveries of modern times.

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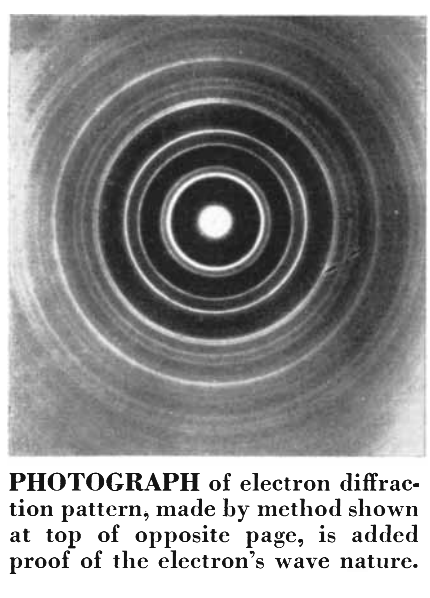


PHOTOGRAPH of electron diffraction pattern, made by method shown at top of opposite page, is added proof of the electron's wave nature.

SMELTING UNDER PRESSURE

The U.S., world's largest producer of iron and steel, must have more of both. One way to ease the shortage is to increase the pressure of blast in blast furnaces

by Leonard Engel

THE blast furnace, certainly one of the half-dozen fundamental machines of our industrial civilization, was invented by an unknown Central European iron-maker some time before 1340. It has remained essentially unchanged for more than 600 years. The modern blast furnace, for all its awesome size and accessories, differs little in principle from the original. Within the past year, however, a major innovation in blast furnace practice has made its appearance and passed its tests. It consists merely of raising the pressure of the seething atmosphere within the furnace. The comparative simplicity of this idea is a poor measure of its technological and economic importance.

At Cleveland and Youngstown, the Republic Steel Corporation has modified two of its blast furnaces so they may operate under pressure. By this single alteration, Republic has substantially raised the output of iron from each furnace and has cut coke consumption by 250 pounds per ton of iron. And, significantly, it has done so while using inferior ores.

The performance of Republic's two furnaces comes with dramatic timeliness. The U.S. and the world are critically short of iron and steel. American furnaces and mills, which already produce more than half the world's iron and steel, are working nearly at full capacity. To keep our economy functioning smoothly, an increase in their productive capacity is urgently needed.

If this is true, it might be asked why we do not expand our iron-and-steel-producing plant. The answer is that plant expansion is slow and expensive. And to complicate the problem, our supply of top-grade iron ore and coke is dwindling. This means that more finished products must be made from poorer raw materials, with the least possible construction of new plants. That is precisely what the new pressure method promises to accomplish. It is estimated that if pressure equipment were installed in all of the 234 blast furnaces in the U.S., without any new plants and in spite of the declining quality of ore and coke, American pig iron production would be increased from the present 58.5 million net tons to at least 75 million tons a year.

To understand how the pressure process works we must briefly consider the art of iron-making. Until the invention of the blast furnace, iron was available only as wrought iron. This form, in which many impurities of the ore remain in the metal, can be wrought (hammered) into some useful shapes, but cannot be cast or made into steel. Wrought iron was produced in small furnaces that did not melt the ore. Iron for steel requires a more elaborate process because of a peculiarity of the oxide ores of iron: iron oxides are reduced, *i.e.*, the oxygen is separated from the iron, at a temperature of about 1,100 degrees F. This is approximately 900 degrees below the melting point of cast iron. To run off the major impurities in the ore as slag and produce metal suitable for steel-making, the iron must be melted. But the melting must not take place in close proximity to the reduction process because reduction does not proceed efficiently at the temperature of molten iron. The problem is solved in the blast furnace by making the furnace very tall and carrying on reduction and melting in different parts of the furnace.

The blast furnace makes iron from ore, coke, flux (usually limestone or dolomite) and air. Air, which is the "blast" of the blast furnace, is reacted with coke at the bottom of the furnace to produce carbon monoxide and heat. The carbon monoxide reacts with ore in the upper part of the furnace to produce iron. The iron then falls through the burning coke, where it melts, permitting the impurities to separate and combine with the flux to form slag. The molten iron collects at the bottom of the furnace and the slag collects in another molten layer above the iron.

The product of the blast furnace, pig iron, actually contains a higher total of impurities than wrought iron. The major impurity, however, is four to five per cent of carbon. Fortunately this gives iron desirable casting qualities (a sharply defined melting point and the property of expanding on solidification so that molds are completely filled). Carbon is easily burned out, in any case, by steel-making Bessemer converters and open-hearth furnaces.

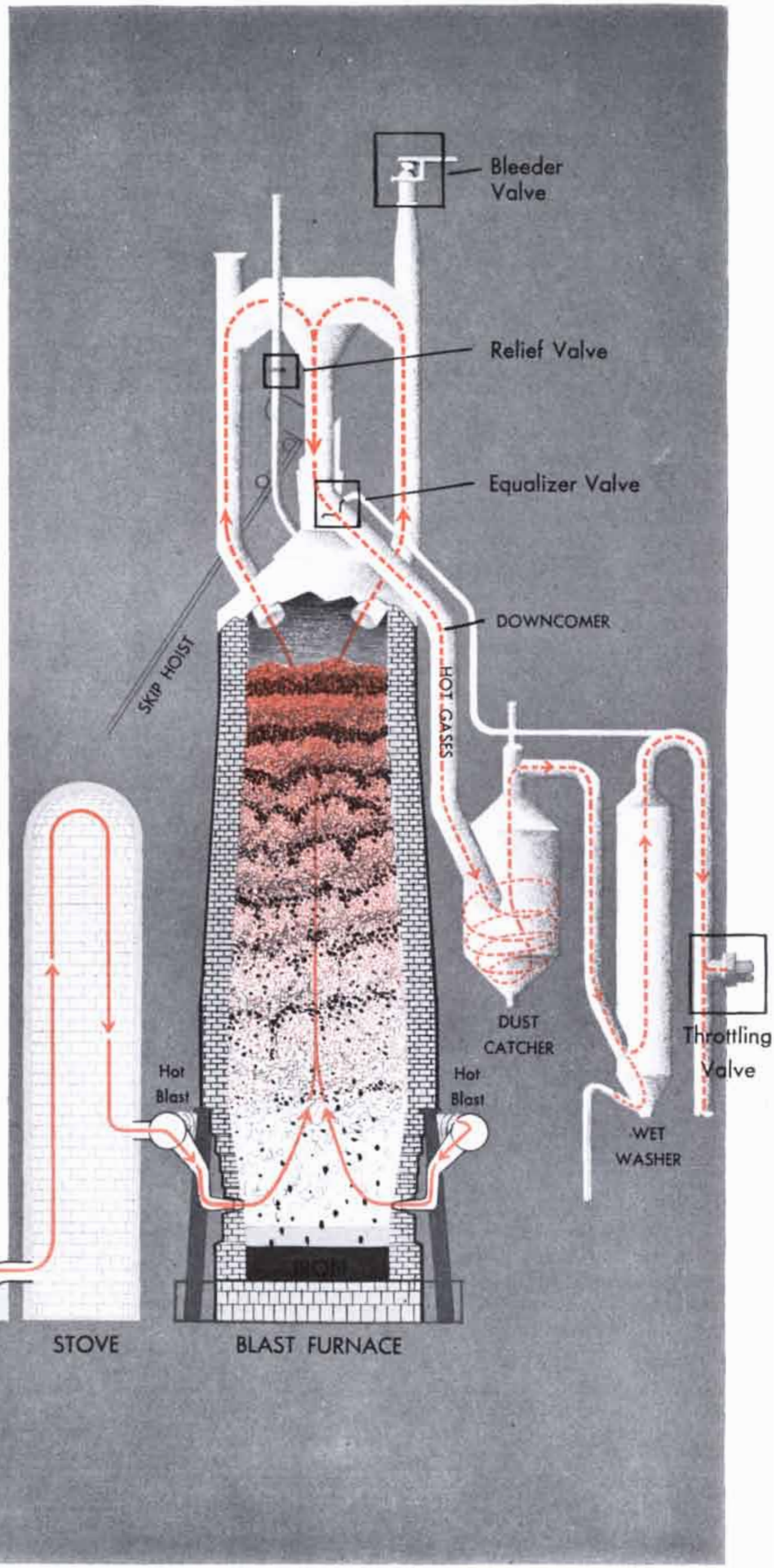
Like so many other phrases in the furnaceman's language, the term "pig iron" recalls the age before steel, when blast furnace iron was cast into 80-pound units in molds on the floor of a shed next to the furnace. In the furnaceman's imagination, the trench from the furnace taphole, together with the group of molds, resembled a sow and a litter of suckling pigs. Today, of course, the pig molds are gone from the shed. Molten pig now goes directly to the furnaces which make iron into steel or to the casting machines. But tapping the furnace is still "making a cast," the shed remains the "cast house" and the foreman of the tapping crew is the "keeper of the cast house."

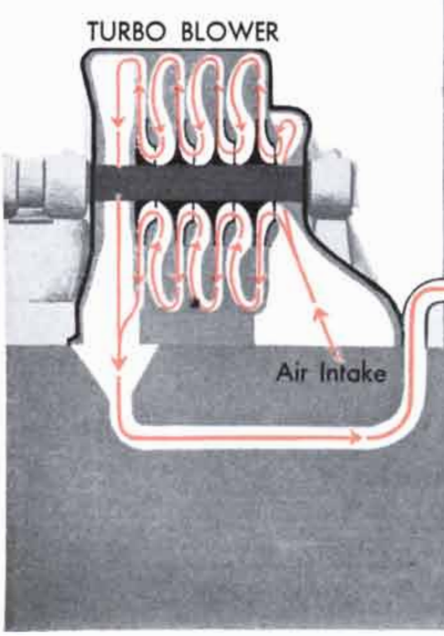
In early blast furnaces the fuel was not coke but charcoal. Coke was introduced in 1519 by iron-makers in England, where wood has been scarce since the Middle Ages. Three centuries later, in 1828, British iron-makers made another innovation, heating the blast before it went into the furnace. But from that time until the present development of pressure operation, there were no important changes in the blast furnace itself. Advances were confined to auxiliary features. such as the burning of furnace gases to produce power as a by-product, developed in several countries around 1880. This does not mean that there has been no increase during the past century in the output of furnaces; a modern blast furnace producing 1,250 tons of pig a day has more than 60 times the capacity of those which operated a century ago. But the increase has come about almost entirely through mechanizing the handling of raw materials and enlarging the blowers and furnaces to Bunyanesque size. A modern blast furnace is 30 feet in diameter and towers 110 feet above its dust-laden surroundings.

THE blast furnace has been slow to change partly because of the weight of tradition and partly because it is a peculiarly difficult object for research. Since it must be large enough to have two distinct temperature zones, the blast furnace cannot be reproduced on a laboratory scale. After six centuries, therefore, exact knowledge of events in the furnace interior is still limited—a fact which is reflected in the furnaceman's habit of referring to the furnace as "she." Iron-making, like love-making, remains largely an empirical art.

Until fairly recently the principal obstacle to raising the output of the blast furnace was the inadequacy of the blowers which supplied the volume of air needed to feed its iron-making reaction. It was impossible to pump in enough air to react as much ore, coke and flux as could be charged into the furnace. Within the past three decades, however, blower design has come so far that blowers with practically any desired capacity can now be built. But air supply is still the chief bottleneck in boosting furnace productivity, for there is a limit to the rate at which air can be blown into a furnace. If the "wind" is increased even slightly beyond a certain point—determined by the size of the furnace and the fineness of the ore—a large percentage of the ore, sometimes as much as a sixth, is blown completely out of the furnace as "flue dust."

In American furnaces this is a serious problem. Most American ores, particularly those from the fabulous Mesabi Range, are rather fine weathered earths.





RESPIRATORY SYSTEM of a blast furnace is traced by red arrow beginning at the lower left of this diagram. Unchecked, the air tends to blow fine material out of the furnace. But when the furnace is throttled with the comparatively minor modifications indicated by four small squares, pressure and furnace capacity can be increased while keeping the "charge" from blowing away.

As a result, the largest American furnaces are limited, under the best conditions, to a wind of 75,000 cubic feet per minute delivered at the tuyères (pronounced tweers), the nozzles through which air enters the furnace. This limits their iron output to 1,250 tons a day. Under average conditions, since an ever-larger percentage of the available ore is fine stuff, the limits are 65,000 cubic feet per minute of wind and 1,150 tons daily of iron. A partial solution of the problem, currently being adopted by some iron-makers, is the preliminary sintering of fine ores, *i.e.*, roasting them with coke to form clinkers. Pressure operation seems a more effective approach.

The basic feature of the pressure technique, which is known as "high top pressure blowing," is a valve or some other form of throttle to block the flow of air out of the furnace and build up pressure inside. Pressure does two things to a furnace. First, because the usual draft is blocked, it sharply reduces wind velocity through the furnace. Second, it distributes the gas more uniformly through the dense "stock" of iron-making materials which fill the furnace. When the gas velocity is reduced, more wind can be blown, more ore smelted, finer ores used and more iron can be made without generating excessive flue dust. Furthermore, with reduced gas velocity and improved gas distribution, the carbon monoxide in the furnace gas remains in longer and more uniform contact with the ore. Thus the carbon monoxide is utilized more efficiently and coke consumption is lowered.

IN its first two pressurized furnaces, Republic Steel has used comparatively low pressure—about 10 pounds per square inch above that in the conventional furnace. At this pressure 10 to 20 per cent more wind can be blown. The result is a rise of up to 15 per cent in the amount of iron produced from rather lean ore containing 48 to 50 per cent iron, with a 10 to 15 per cent saving of coke and a 30 to 70 per cent reduction of the flue-dust loss. Higher pressures will further enlarge these gains. Moreover, the pressure furnace can be manipulated to maximize any particular increase in production or economy that the current conditions demand.

In two of the five additional furnaces which it is pressurizing this year, Republic plans to raise the pressure to 20 pounds per square inch above normal. In one of these, a unit at Warren, Ohio, will be installed one of the largest blowers ever built, an Ingersoll-Rand unit capable of delivering over 105,000 cubic feet per minute through the tuyères under relatively high pressure. This combination of wind and pressure—according to figures prepared by engineers of Arthur D. Little, Inc., designers of the installation—will result in an increase in iron output of 40 per cent, from the use of an ore containing 50 per cent iron and good-sized particles. Or, if it is necessary to use leaner ores, the same wind and pressure formula will make it possible to maintain substantially normal production from ores as lean as 40 per cent iron, which now require preliminary concentration if they are to be used effectively in blast furnaces. In either case, the saving of coke would be some 200 pounds a ton and flue-dust losses would be cut in half. To illustrate the flexibility of pressurization just a little further, if 20-pound pressure were combined with the normal wind volume of 75,000 cubic feet per minute, iron production would go up less and might even decrease somewhat (depending on the ore). The saving of coke, however, would exceed 300 pounds a ton. If the wind volume were cut farther back, say to 60,000 cubic feet a minute, flue-dust losses would all but disappear and very large percentages of fine ores could be used without sintering and without any sacrifice of iron.

During the past two years furnacemen have also been experimenting with a second new method of boosting furnace output—enrichment of the blast with oxygen. Increasing the air's natural concentration of oxygen from 20 to 25 per cent raises iron production one-sixth. But oxygen enrichment does not permit any saving of coke. Since saving coke is currently almost as important as making more iron (coking coal quality is declining more rapidly than ore quality), pressure will probably be preferred to oxygen enrichment for most furnaces. Besides, the pressure installation is cheaper.

Most furnaces can be converted to pressure operation in less than a week for about $125,000—one per cent of the present $10 million cost of a new furnace. The changes required are essentially devices for throttling exhaust gases and for sealing the pressurized furnace. Since it has long been the practice to install extra blowing capacity in case a dying fire must be stimulated, the majority of furnaces already have adequate blowers. But even if new blowers must be installed, the total cost will go only a little beyond $1 million.

A number of imaginative furnacemen looking into the future see a combination of pressure and oxygen-enriched blast which would double furnace output. The use of pressure and oxygen together will bring another major innovation in furnace operation: a new system for handling raw material. A furnace smelting 2,000 tons of iron daily would require 6,400 tons of ore, coke and flux a day, or 3.2 tons of raw material for every ton of iron produced. This means that seven full railroad cars of these various ingredients would have to be fed into the furnace every hour. Such a spate of material is far beyond the capacity of the "skip hoist," the standard double-track cable railway which for a century has moved ore, coke and flux up the side of the furnace from storage bins to the charging hopper. In place of the skip hoist, a system of overhead bins fed by radial conveyor belts from separated unloading points has been proposed. This would meet the raw material requirements of any foreseeable combination of wonderful new iron-making techniques.

The inventor of blast furnace pressurization is Julian M. Avery, a New York chemical engineer. A dozen years ago Avery, now vice-president of the Hodges Research and Development Corporation, made one of the rare studies of blast furnace metabolism. Becoming convinced that pressure would raise furnace efficiency, he worked out and patented the details of pressure operation.

Avery put forward his conclusions in a paper at the 1938 meeting of the American Institute of Mining and Metallurgical Engineers. Most steelmen dissented sharply, and pressure did not receive a trial until 1944. Then the War Production Board, goaded by the shortage of pig iron and scrap, negotiated a license agreement with Arthur D. Little, Inc. (to whom Avery had assigned his patents) and awarded Republic a contract for a test installation. This was made on furnace No. 5 at Republic's Cleveland plant.

FURNACE IS TAPPED when molten iron has trickled from the charge

Because of mechanical difficulties, the wartime test was generally disappointing. But the results were good enough during the few weeks the pressurized furnace actually operated to decide Republic and Little on a further trial. After the war, Republic's furnace No. 5 at Cleveland and No. 3 at Youngstown were converted to pressure. They have been operating that way ever since.

The mechanical difficulty responsible for the drab outcome of the first trial was the failure of devices which sealed the furnace at the point where its charge was loaded. A successful system was worked out, however, by the pioneer Republic-Little engineering group, which was headed by B. S. Old of Little and the late J. H. Slater of Republic. Pressure has given no unusual trouble since. Although the smelting reactions proceed at an accelerated rate, pressure has no effect on furnace temperatures. Consequently it does not affect the chief item in furnace maintenance, the life of the lining. Both Cleveland No. 5 and Youngstown No. 3 are well on the way toward completing two million tons—the usual output between overhauls—with the same linings.

In the Cleveland furnace the exhaust gases are throttled and pressure built up by a set of valves. At Youngstown No. 3, some of the gases are throttled by being led through an experimental turbine, an arrangement which merits notice because it enables this pressurized furnace to produce not only more iron, but more power. In conventional furnaces recovery of the exhaust gases—which are rich in carbon monoxide and may be burned—yields enough fuel to preheat the blast, to drive the blowers, and, in the case of a large furnace, to generate some 8,000 kilowatts more for other purposes about a plant. Although the extra pressure of the Youngstown furnace is only 10 pounds per square inch, it has been calculated that a throttling turbine might recover 2,000 additional kilowatts—a clear profit in power since the turbine takes nothing from the fuel value of the gas. A large turbine-equipped furnace under pressure of 20 pounds per square inch would recover more than 6,000 kilowatts, according to these estimates.

POWER, of course, is a secondary consideration in blast furnace operation. Nonetheless the extra wattage yielded by the throttling turbine is important because it means greater economy in the making of iron and steel. In coming years, the United States will have an increasing need for these various advantages of pressure smelting. By making possible the production of more iron from poorer raw material, it may resolve the dilemma inherent in the shortage of iron and steel.

To an extent not generally appreciated, U.S. industrial strength is based on an accident of nature: the unique geographical combination of Minnesota and Michigan ore, Appalachian coking coal and the Great Lakes highway. On this triple gift of nature rests our towering steel industry. To it we owe three generations of the cheapest and most abundant iron and steel in the world—and, in the final analysis, our standard of living. But one part of the dowry is giving out. The high-grade, open-pit ore of Minnesota's Mesabi Range is largely used up; some observers say 10 years will see virtually all of it gone. To prevent the loss of Mesabi ore from reducing our standard of living, we are compelled to turn to new and more efficient ways of making iron and steel. Among those that have appeared thus far, pressure operation of the blast furnace is most promising.

Leonard Engel is a free-lance writer.

of ore, coke and flux. Here the iron is run into ladles at the Ford Motor Company's River Rouge plant, which operates its furnaces at conventional pressure. Base of the furnace and air-carrying tuyères are at upper right.

BOOKS

Geoffrey Gorer's "The American People": An anthropologist's critical view

by Ralph Linton

ONE phase of the American "need to be loved" which Geoffrey Gorer stresses so much in his book "The American People" (W. W. Norton & Co.), although it is a phase which he fails to mention, is our almost adolescent eagerness to know what other people think of us. Books about America and Americans written by foreigners always find a larger and more interested audience in this country than in their authors' homelands. I feel sure this book will be no exception, for it is clever and exceedingly well-written. The author's literary skill, spiced with a considerable admixture of sly malice, is sure to keep the reader interested from start to finish.

The book describes those aspects of modern American life and character which appear most striking to an Englishman, and attempts to account for these on the basis of modern psychoanalytic theory. Since the author has invoked the name of science to give his work greater authority, it seems justifiable to consider the techniques he has employed. These techniques certainly do not meet any of the requirements of science as they are ordinarily understood. Although the author speaks with great assurance about American behavior and attitudes, he gives no indication of the way in which the crude data were obtained. He pays frequent compliments to the Margaret Mead-Ruth Benedict school of anthropologists, but anyone familiar with their techniques knows that they vary from precise, careful and well-documented studies of child care and adult behavior to a free exercise of feminine intuition unhampered by either facts or frequencies. Gorer also fails to give any indication of the length of the series of observations on which his conclusions are based, or of the groups in this country from which his subjects were drawn. Instead he lists the parts of the United States in which he has traveled. No statistical methods were employed at any stage in the study.

In the absence of any precise information as to how the author got his data or arrived at his conclusions, one must deduce these from the evidence provided by the book itself. It appears that Gorer's American contacts have been almost exclusively with the members of two groups: middle-aged clubwomen, who are always eager to extend dinner invitations to presentable and amusing young Britishers, and the semi-Bohemian intelligentsia of New York and vicinity.

To his limited range of observations he has applied purely subjective methods of analysis. While the reviewer recognizes that in certain cases such methods are not only justified but may even be the only ones applicable, it would seem highly desirable to check the results by more objective techniques wherever possible. It would also seem desirable to supplement immediate observations by background information. Even slight attention to the known past of American culture. which is also generally accepted as a proper field for anthropological study, would have raised considerable doubts as to the validity of some of the author's conclusions.

Gorer employs an approach which is psychoanalytical without slavish adherence to the theoretical tenets of any one school. Modern American attitudes and institutions he explains as results of the individual's projective system. Infantile or childhood experience shapes all adult behavior. The future American citizen, says Gorer, raised on a formula and tormented by hunger because books say he should get only so much food at such and such hours, as an adult takes an almost psychopathic interest in feminine bosoms, manifests an abnormal craving for milk, and fears that aid to Europe will result in starvation for America. Oversolicitous mothers and schoolmarms urge him to the limits of his powers, impressing him with the importance of being popular and successful and filling him with an overwhelming fear of being a "sissy." At the same time, Gorer states, they provide him with a feminine type of conscience or superego quite at variance with the demands of business. The result is the American pattern of exaggerated competition in all spheres and puzzling differences between idealistic statements and anything but idealistic behavior.

While the author's description of this adult behavior is accurate enough—at least for the American groups he knows—it would be interesting to know the sources of his information on the overwhelming influence of mothers and schoolmarms. Outside the narrow confines of suburbia, most American families include fathers who are far from negligible quantities either as ultimate sources of reward and punishment or as models to be imitated by the growing boy.

THE author dwells at considerable length on the American child's rejection of paternal authority. (If this is true in the American hinterland, the son had better not let his father find it out.) Gorer assumes this rejection to be a revolt against the Old World ways of the immigrant parent. The son wishes above everything to become a full-fledged American, indistinguishable from other Americans, and despises his father for his foreignness. It is easy to see how such an idea could originate from discussions with urban intellectuals, many of whom do have such a background. However, there is a fine old tradition of American resistance to parental authority which can be traced as far back as Benjamin Franklin, Davy Crockett and Huckleberry Finn. Whatever it was that set these sons against their male parents, it certainly was not the latter's accents or fondness for un-American cooking. May not the truth of the matter be that in a rapidly changing society, such as our own has been throughout its history, few fathers could offer their sons rewards for submission which would equal those they could get by striking out for themselves?

According to the author, this rejection of authority carries over into all phases of our national life. Americans fear any sort of strong government because they subconsciously identify it with paternal authority. They are less disturbed by the scandals of a Harding administration, Gorer thinks, than by the implications of power in a fourth term for Roosevelt. With this attitude there goes a deep suspicion of anyone who enters politics for avowedly altruistic motives. The grafter can be understood and occupies the quasi-respectable position of the bootlegger under prohibition, but the man who serves honestly and at financial loss to himself must be trying to establish some sort of control over others and enjoying such control.

Gorer's typical American childhood situation. in which the love of the mother can be won only by success in competition with other children. also has its repercussions in adult behavior. In adolescent years this is reflected in the institution of "dating."

Dating, according to the author, is a typically and almost exclusively American custom. Of course, he admits, young people of opposite sex seek each other out in all countries. and "love laughs at locksmiths." However. in most societies these contacts are either a courting preliminary, the object being matrimony, or direct sexual expression. Many primitive cultures allow for a period of sexual license and experimentation among their adolescents. Gorer finds that the unique feature of American dating is that it is neither a sexual overture nor a courting technique but rather an elaborate game played largely for prestige purposes. This may be carried to fantastic lengths. In one midwestern coeducational institution, for example, the campus belles rarely spent an entire evening with one date. They portioned out their evenings, an hour to each boy. Such dates can scarcely have been amusing for either party. But for the girl it was a collection of scalps, for the boy a sign that he could get a date with the most popular girl on the campus. This description of Gorer's is certainly accurate for college communities and the upper class in general, but it would be interesting to know how far it is a general American pattern. Alfred C. Kinsey's recent work suggests that the adolescent behavior of a large sector of American society has more in common with that of the Trobriand Islanders than with that of The Four Hundred.

IN spite of our American competitiveness, Gorer believes, the desire to be loved is the mainspring of our national character. As a nation we yearn to have people love us and admire us. We are upset if shopkeepers, garage attendants and waitresses are not cordial and friendly. Whites even expect these responses from Negroes, who have little reason for friendliness toward members of the dominant group. The need to be loved even influences our foreign relations. We expect other nations to recognize our benevolence, our rightness and our friendliness and to meet us with love and gratitude. When they fail to do this, we feel that they have taken advantage of us. Although one must agree with the essential truth of these statements, one wonders whether it is necessary to invoke an infantile trauma to account for such attitudes. Annoyance with beggars who jeer at their benefactors after asking alms is not limited to citizens of the U.S.

The author does not underrate the generosity of Americans as a group. Whether his interpretation of the reasons for this generosity is correct or not is another matter. He says that we value money as a symbol of success, not as a value in itself. Once the money has been made, it will be rapidly disposed of either in charity or by transforming it into other prestige symbols. "A man is known by his wife's fur coat," while the wife prides herself on having a home decorated according to the latest suggestions of home-making magazines. "It is rare in American homes," says Gorer, "to come across that crowded absence of taste which distinguishes so many European interiors, and it is almost equally rare to come across a house with decorations distinctive enough to be remembered."

Gorer sees the Americans as a highly pragmatic people with what he calls an "atomistic" view of the world, referring not to atom bombs but to a curious ability for dealing with things and situations as so many unrelated items. This is responsible for the constant inconsistencies in our political and economic behavior and keeps us, for the most part, from realizing that there are inconsistencies. He finds this reflected even in our dual symbolism for our country. At one moment we represent America as the benevolent Goddess of Liberty and at the next as Uncle Sam, the shrewd Yankee horse-trader.

The American male, Gorer says, leaves the world of relations to women. He feels apologetic about any aesthetic interests he may have, but in the world of things he is supreme. No other people have so completely dominated their materials nor carried technology to such heights. But although we pride ourselves on our inventiveness, we have few basic inventions to our credit. We have taken the inventions of other nations, improved upon them and adapted them to mass production. Our slogan has been to get the most things to the most people. Gorer quotes as typical of American values an alleged remark of President Roosevelt: "If I wanted to point out to the Russians the superiority of the American way of life, I should try to get just one book into their hands, the Sears, Roebuck catalogue."

Curiously, Gorer does not seem to have discovered any feature of American child-rearing to account for this attachment to things and for skill in manipulating them. Neither does he seem to be conscious of the basic contradiction between that most American invention, the assembly-line, and the American resentment of authority. If the latter is as universal a characteristic as he assumes, it is difficult to see how the assembly-line technique of mass production could have been developed.

AN exceedingly interesting chapter of this book is devoted to the minority groups within our borders. "Attainment of complete Americanism is judged principally by the eye and only secondarily by the ear," he says. "The criteria for Americanism are in descending order of importance: appearance, clothes, food, housing, amenities, ideology and language." By these standards, the Negro is obviously the most discriminated against. By length of residence in America and desire to adopt American ways he should be ranked high. But, because he is different in appearance, he cannot compete on equal terms in a white world and must suffer under the capricious and illogical hostility of the dominant group.

Although this book can lay no claim to being a scientific study of American character, it presents a number of penetrating, intuitive observations on the modern American scene. Future historians will probably turn to it for information on present-day America, much as current historians turn to the accounts of earlier British visitors to the U.S. The non-technical reader will find in it much food for thought, but it is to be hoped that he will think rather than believe.

Ralph Linton is Sterling Professor of Anthropology at Yale University

THE AMATEUR

Conducted by Albert G. Ingalls

THIS department for amateur astronomers, thousands of whom have made their own telescopes and glass optical parts, was begun in SCIENTIFIC AMERICAN 20 years ago this month. Since then the amateur telescope making hobby has established a permanent place in American life. The ground covered in these columns has been and will be mainly the description of telescopes and other optical instruments built by its readers, plus improvements on the optical art.

Why has telescope making had so lasting an appeal? For a dual reason. First, it gives outlet to the mechanical instinct, expressed in the form of a telescope, an article greatly worth owning and worthy of some pride because it is not easy to make. Second, the telescope unlocks the way to astronomy, a majestic science that far transcends man's imaginative powers.

It is usual for the potential participant in the amateur astronomical hobby to regard telescope making as little more than preparation, but more often he discovers in it so much hidden fascination, largely in shaping curves on glass, that he makes telescope after telescope of different sizes and types, usually neglecting to use them.

Semerau and his six-inch

From an enthusiastic recruit to amateur telescope making, Walter J. Semerau of Box 64, Alloy, W. Va., comes this:

"Those who helped make the amateur telescope making books possible have caused me to live about two years of my life in complete contentment. I started grinding the mirror for my six-inch reflecting telescope in June and finished in December. I don't believe there is another telescope mirror maker who has derived as much hell and satisfaction from a six-inch hunk of Pyrex. After using up all the wrong methods I reached the right ones after a total of 700 hours' work and finished with a good figure and some small scratches. In doubt, I whipped up a temporary mounting to see whether the mirror would really perform. It performed much better than I had hoped, so I made the permanent mounting shown in the enclosed photograph. The two large setting circles and the saddle by which the tube is fitted to the declination axis were homemade from patterns and castings of duralumin, with the help of your second book *Amateur Telescope Making—Advanced*, which taught me all I needed to know about this accessory art."

Semerau's claim to utmost hell and 700 hours of work is not a record. While about 70 hours for making a first telescope is closer to the average, such an easy outcome robs the maker of much fun in fighting and whipping troubles. This department has on hand for publication descriptions of optically flat precision tools that cost their maker 3,000 hours of work, and of an ultra-fine refracting telescope that accounted for 17,000 hours of enjoyment. There is no limiting length to the enjoyment.

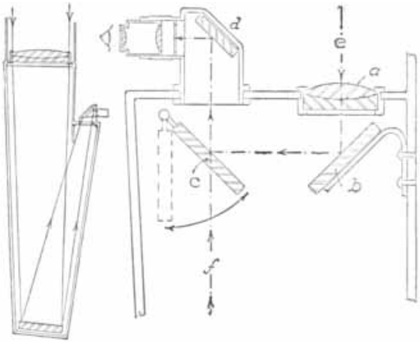
Semerau's telescope is typical amateur work at about the level of the second or third try. Its home-grown design centers on sound conventional ideas, but the details are the maker's own. The casting of the metals is not a "must" nor even the custom, since there are other and simpler approaches to the mounting problem. But it is a nice approach. The two setting circles which appear in the photograph are uncommon in first telescopes and the little finding telescope near the top of the tube is a luxury.

A feature of this telescope is the method of focusing the eyepiece by means of a rack and pinion and thumbscrew which move the entire eyepiece, visible in the illustration, and the small diagonal mirror or prism within the telescope tube. These move as a single unit in a lengthwise direction, guided by v-ways and retaining strips. This method is a little prettier than the more familiar alternative of sliding the eyepiece in and out of an adapting guide in a direction perpendicular to the telescope tube. It is also more pleasing mechanically and often less troublesome, as it is less inclined to bind and otherwise perform cantankerously.

IF you study the telescope shown in the second photograph you may discover its type but it will be easier to look for the key at the left-hand side of the third picture, drawn by Russell W. Porter. It

Dr. Paul and the euphonium refractor

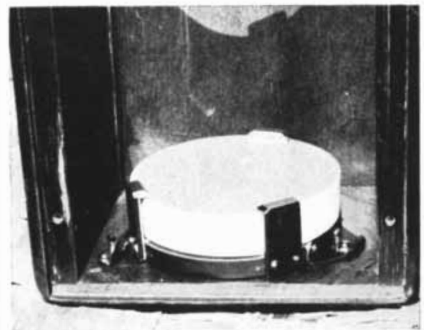
is a folded refractor made possible by a flat and a prism, and it was built by Dr. Henry Paul of 119 North Broad St., Norwich, N. Y., after a design first proposed by Captain M. A. Ainslie of London. Ainslie's design is embodied in an eight



Detail of the euphonium

and a half inch refractor of 120-inch focal length made by H. E. Dall of Luton, Bedfordshire and described by this department in October 1937 and September 1938. Ainslie called it the euphonium telescope, after the musical instrument of that name, which it resembles.

Unfolded, this would be a six-inch refractor, eight feet long. This is too long to be portable and is therefore not easy to use. The euphonium design brings the eyepiece near the telescope's center of gravity so the observer need move but little in viewing various parts of the sky. It affords normal astronomical inversion,


The flat that folds the refractor

since the stubby eyepiece can be swung through more than 180 degrees to accommodate any desired angle of view for orientation of image (also for comfort). In this respect Captain Ainslie has said it equals or surpasses reflectors, not omitting those with a rotating tube. Dr. Paul has found that his recent version of the euphonium, or jackknife, refractor is very successful.

"I had among my miscellaneous items a perfect six-inch achromat of 94 inches focal length," he writes, "and decided to make a *good* compact telescope. The design appeared in SCIENTIFIC AMERICAN some years ago and I should now like to renew interest in this type, as the problem of mounting a long refractor is sometimes a discouragement. The excellent six-inch achromat and four-inch flat were made by Patrick A. Driscoll of Lima, N. Y., author of several articles in *The Amateur Astronomer*, and I made the instrument in a few days, mainly from insulating Bakelite and aluminum angles.

"The flat (*see cut—Ed.*) is of fused quartz and is precise to a tenth of a wavelength. The eyepiece, which swings more than 180 degrees, should be placed in the corner for convenience to the owner's better, or leading, eye (important). The unoccupied corner may be used for a finder as sketched. In this drawing, *a* is the finder lens (two inches in diameter, 10 inches focal length); *b* is a fixed optical flat; *c* is a hinged, swinging optical flat; *d* is the eyepiece diagonal; *e* is a ray of light to the finder objective and *f* is a ray from the main objective by way of the flat at the bottom of the tube. A knob swings the mirror *c* as shown, instantly making the change from the wide (six-degree) field of the 10X finder to the two thirds of a degree field of the 90X telescope. But the finder alone, with the 10X, 20X and 30X magnification afforded by different eyepieces, is an interesting and useful instrument for open clusters, the Milky Way, and nebular observation.

"Advantages I find," Paul continues, "are: 1) Compactness: the whole telescope fits crosswise in a car, is easy to handle (note handle on side), and is fully portable. 2) The mounting need be no larger than for a six-inch reflector. 3) Ease of viewing because of widely swinging eyepiece. Disadvantages are: 1) Need of a flat two thirds the diameter of the objective. 2) Some light loss. 3) Heat from the observer's head if the eyepiece is too near the main objective lens; this is why it is placed as shown."

For the three and a half inch, very long focal ratio ($f/30$), special planetary observing type of refractor described with lens specifications by this department in April 1946 by Colonel Lewis of Little Rock, Ark., the euphonium seems to be one good answer.

ONE of the numerous ramifications of telescope making is sundial making, in the course of which the worker becomes familiar with the earth's motions in a way that makes them really sink in to stay. Russell Porter, patron saint of the amateur telescope makers, has found no cure for his sundial itch. His drawing here shows his nineteenth sundial or sun clock since he moved from Vermont to California 20 years ago. After each sundial binge he takes the pledge and promises faithfully to give up the habit, but it always gets out of control and he takes just one more. Like some of its predecessors, this sundial is in a bottle, a pretty large one at that. He writes:

"This is a sun timekeeper that requires no machining or gears, if one is willing to spend something under five dollars for the 11-liter flask (made by Corning).

"It is equatorially mounted, with a thrust bearing at *B* and two pads at *F*. *A* is a single lens that throws the sun's image on the analemma *C* when the flask is turned on its supports.

"The time scale is on a strip of paper *E* pasted on the outside of the sphere. The divisions are five-minute intervals and by interpolation the index at *D* easily permits estimating to single minutes.

"The base is of wood but any kind of base may be used to provide a three-point support. At *B* is a hole drilled through the flask. The stud through it acts as a thrust bearing.

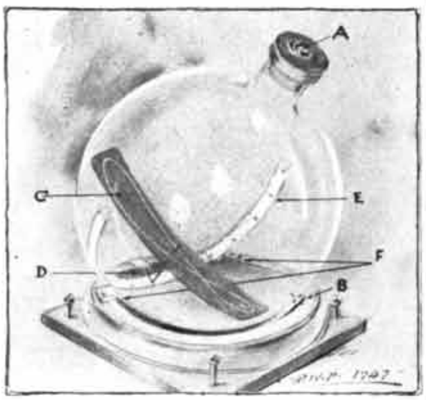
"Another hole is drilled through the flask just under the center of the analemma for a screw to draw down its metal band to a curvature with the lens at its center.

"The flask is remarkably spherical; calipers can detect no departure.

"Warning: Extreme care must be taken to locate accurately *B*, the analemma screw, the time scale and the plane of the central line of the analemma. Fortunately the throat of the flask neck was just large enough to allow insertion of the plate carrying the analemma.

"The sun clock makes an interesting garden ornament but, after playing with it a while, go to your telephone and ask, 'What time is it?'"

Fully to explain this sundial, if perchance the reader lacks a rudimentary education in astronomy, and how to design one for the maker's own unique latitude and longitude, would require several articles, after which the reader still would find himself resorting to the book *Sundials*, by Mayall and Mayall, to learn the fundamentals of all sundial types. If, however, he has made and used an equatorial telescope he is already down to first base in knowing the earth's motions for sundial design. He still may have to give an hour or so to looking into the fact that the earth does not move uniformly in its orbit and to studying the effect of the obliquity of the ecliptic. These are combined in the "equation of time," of which an analemma shaped like the figure eight is a graph. In Porter's sun clock the sun's image falling on that graph automatically allows for the equation of time. Incidentally, the graph can also be made a calendar.



Porter's nineteenth sundial

To make the holes in the flask calls only for a hand drill, an inch of small tubing in its chuck, a few dabs of wet abrasive grains and five minutes' elbow grease.

The underlying motivation behind sundialing isn't to tell the time, though the editor of this department has one at his summer cabin and really uses it, in the happy absence of a radio, to set his dollar watch. It brings visitors up with astonished surprise to be told the sundial time and to find that it agrees with their watches often to seconds. The main motivation in sundialing therefore is intellectual—call it scientific vanity. Your dial's correct functioning shows you that you know a little positional astronomy and gives you a feeling of superiority over people who own department-store sundials and don't know why they can't keep time.

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The next time you hear voices —LISTEN!

IT MAY BE your conscience speaking.

It may be saying: "Save some of that money, mister. Your future depends on it!"

Listen closely next time. Those are words of wisdom. Your future—and that of your family—*does* depend on the money you put aside in savings.

If you can hear that voice speaking clearly, do this:

Start *now* on the road to *automatic* saving by signing up on your company's Payroll Savings Plan for the purchase of U.S. Savings Bonds.

There's no better, no surer way to save money. Surer because it's automatic . . . better because it pays you back four dollars for every three you invest.

Do it *now*. If you can't join the Payroll Savings Plan, tell your banker to enroll you in the Bond-A-Month Plan that enables you to purchase a bond a month through your checking account.

Remember—better *save* than *sorry!*

Automatic saving is sure saving— U.S. Savings Bonds

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