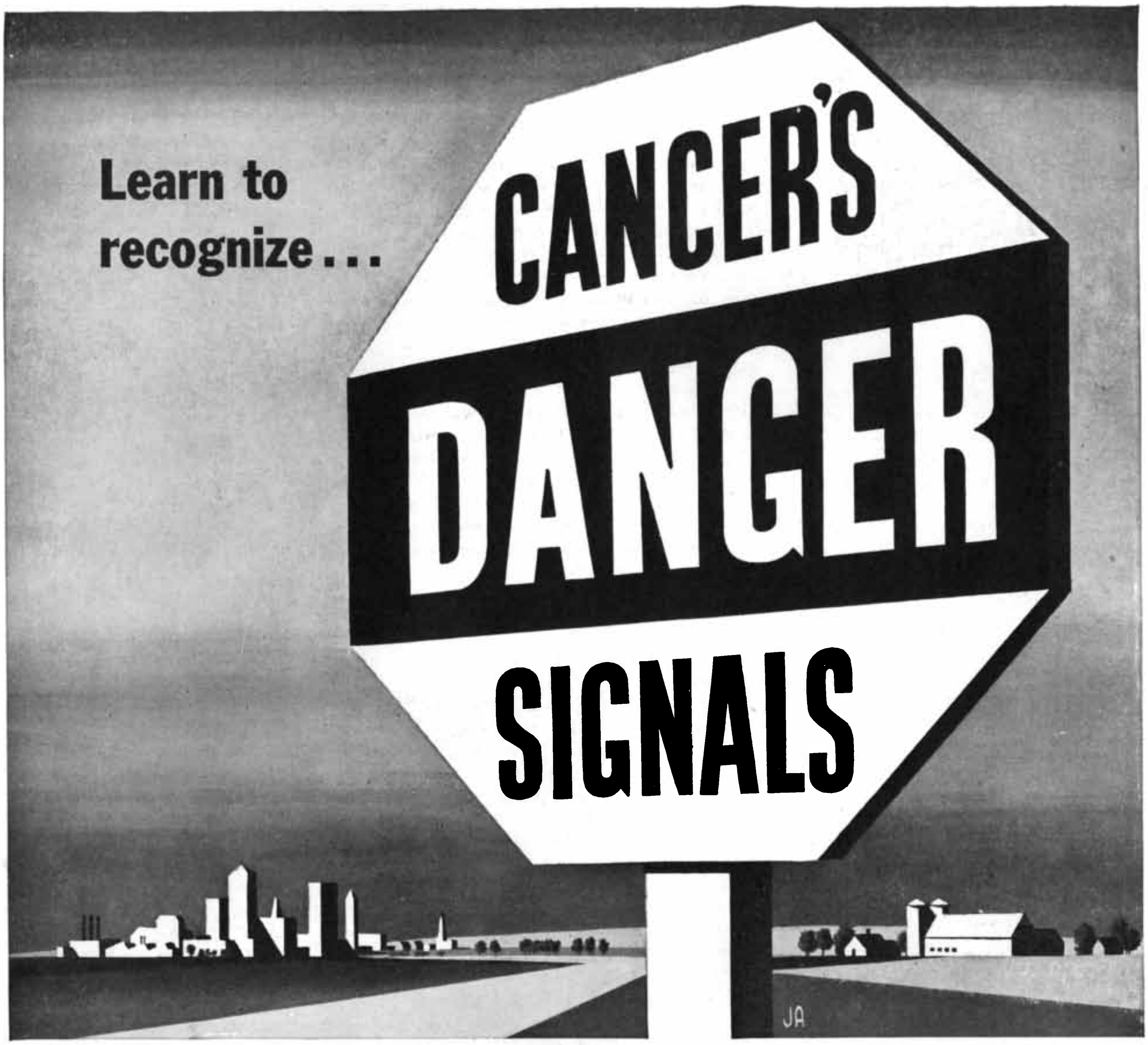
SCIENTIFIC AMERICAN

PHOTOSYNTHESIS (PAGE 24)

FIFTY CENTS

August 1948



If you detect any of the following symptoms, see your doctor at once. It may not mean cancer, but if it should, remember that most cases can be cured if treated in time.

1. Any sore that does not heal—particularly about the tongue, mouth or lips. Do not pass it off as "nothing at all." Go to the doctor.

2. A painless lump or thickening, especially in the breast, lip, or tongue. Do not wait "to see what happens." Go to the doctor.

3. Irregular bleeding or discharge from any natural body opening. Do not wait for pain. Go to the doctor.

4. Persistent indigestion. Do not wait for loss of weight. Go to the doctor.

5. Progressive change in the color or size of a wart, mole or birthmark. Don't try salves or ointments. Go to the doctor.

6. Persistent hoarseness, unexplained cough, or difficulty in swallowing. Do not assume that it is due to smoking or some other form of irritation which will clear up. Go to the doctor.

7. Any change in the normal bowel habits. Do not attempt to diagnose yourself. Go to the doctor.

SEND COUPON FOR FREE BOOKLET THAT TELLS THE FACTS ABOUT CANCER

AMERICAN CANCER SOCIETY
47 Beaver Street, New York 4, N. Y.

Send free booklet by medical authorities.

Name ....

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City .... State ....

LETTERS

Sirs:

The lack of interest displayed by many social scientists in the type of mathematical regularity which has built physical science is underlined by two letters in your July issue. Each letter advocates that social problems be approached exclusively in such anthropomorphic and purely verbal terms as "frustration," "misery," "aggression," and "minority groups." Your readers need not be reminded that millions of dollars are spent every month in support of research and instruction limited to such terms. It is significant of the primitive state of their science that your two correspondents evince emotional opposition to even a little investigation of a different sort.

Although with my article, "Concerning 'Social Physics,'" references were given directly and indirectly to a number of related scholarly papers, both letters seem to have been written without examination of them. Mr. Eaton "pointedly" suggests "that the editors of the *Scientific American*, when preparing future articles on social science topics, first secure the views of social scientists," but this is a formality which he himself ignores.

For example, the place which the principle of demographic gravitation now holds in investigations of marketing is shown by a comprehensive study of the United States: "Market Areas for Shopping Lines," published in 1947 by the Curtis Publishing Company. It was prepared by their Research Department with the aid of Professor P. D. Converse. Much thought and labor have been required to apply Newton's laws of mechanics to detailed problems of mechanical engineering. No doubt a variety of obstacles must be overcome before Reilly's law of retail gravitation is fully utilized in the field of marketing, but a good beginning has been made.

Mr. Eaton advocates that we "approach the data of social behavior at their own level and in the terms which they themselves suggest." With this prescription we all can be in complete agreement. The terms which suggest themselves to an investigator familiar with physics may well differ from the conventional ones, and the level he selects for initial treatment will be that of large groups of people rather than of individuals.

Professor Henry objects to population potential as "mysterious." Actually the concept sums up, in a single powerful abstraction, an extensive complex of human processes which when examined separately have nothing mysterious about them. Physicists have learned the usefulness of this sort of abstraction and "mystery." Generalities in natural science are tested by their agreement with the course of phenomena, rather than by prejudgments which spring from philosophical dogmas and whatnot.

Mr. Eaton's statement is devoted wholly to the expression of his own prejudgments. Professor Henry makes only one specific criticism which relates to observed phenomena: his point is well taken that in the formula population divided by distance, an average inhabitant of India or China exhibits a weight much less than that of an average inhabitant of the United States. He is not justified in dismissing the formula on that account. When enough social data are available the "molecular weights" can be determined from the observations.

Because of limitations of space my article had to be confined almost exclusively to conditions in the United States, although even here a refined study uncovers evidence which suggests that Negroes in the Deep South have lower weight than average while people in the eleven Rocky Mountain and West Coast states have higher weight. To find the reasons for these differences will be important.

Sociologists, even demographers, have not attempted to make a systematic study of distance, and number of people, as social factors. Professor Henry wants to dismiss these factors as "mechanistic," and he asserts that their study "distracts attention from the real problems of social living." He is quite right in (unconsciously) implying that much sociological discussion (of the problems he considers "real") treats human beings as disembodied spirits. He is right also in declaring that thinking which is purely mechanistic about human relations may associate itself with tyranny, and I had indicated as much in my own concluding paragraph. But the world has known tyrants for thousands of years; they have used to bolster their positions not exact mechanistic thinking but often irrational slogans purporting to possess spiritual connotations.

For the immediate future I can foresee no serious threat of tyranny in the proposition that economic, social, and cultural welfare are maximized when the total number of effective relations among all individuals is maximized, subject to the inescapable restrictions which space and time and number exert statistically on men. Industrial plant, utilizable natural resources, and monetary funds must be looked upon not as things which operate automatically of themselves, but as a continual re-creation out of human relations.

Detailed statistical support for this point of view is included in a longer paper in the journal *Sociometry* for May. It is hoped that continued study will serve to improve the definition of some such controlling concept as "the public interest" by bringing to bear upon it the principles of social physics. From the vigor of their communications it is evident that both Professor Henry and Mr. Eaton can make contributions of another nature to an improved definition, provided they realize that existing conclusions and methods of sociology—and of physics—are incapable of providing all the answers.

With respect to the first use of the name "social physics", this opportunity is taken to record a remark which the eminent historian of science, Professor George Sarton of Harvard, kindly made in a letter from Switzerland after he read the May issue: namely, that it was introduced before Comte by Quételet, who in 1835 wrote a book with that title.

JOHN Q. STEWART

Randolph, N. H.

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50 AND 100 YEARS AGO

AUGUST 1898. "This week the American Association for the Advancement of Science celebrates the fiftieth anniversary of its existence. In 1847 the American Association of Biologists and Naturalists, which had been formed in 1840 as the Association of American Biologists, met for its annual meeting in Boston. It was then determined to enlarge its scope and broaden its work. This year the Association turns to the place of its birth and meets again in the hospitable precincts of Boston."

"Within a week we have had the synthetic production of albumin demonstrated before a learned body, and within a month 'coronium', which has been supposed to exist only in the sun, has been detected in volcanic gases, and the Italian scientists gravely observe 'that there are probably other new elements in these gases.' In June last, Prof. Ramsay announced the discovery of 'krypton', a new gaseous element existing in the air, and close on its heels come two other elements, also obtained from the atmosphere, which have been named 'neon' and 'metargon.'"

"There is only one thing that can match the splendid heroism of our soldiers at Santiago, and that is the criminal incompetence of the Subsistence and Medical Departments to which the feeding and nursing of these brave fellows was intrusted. There are times when silence is a sin, and we feel that to remain quiet in the presence of a shameful and fatal maladministration that has added to the natural horrors of war others that might easily have been avoided, is to do a positive wrong to the heroes of Guantanamo, El Caney and San Juan."

"It is well known that the production of intoxication by the drinking of ether is a vice especially prevalent among the north and northwest portions of Ireland, that it obtains in some degree in the western counties of England, and also that it sometimes finds its way into the boudoirs of titled and aristocratic dames; but until recently it was held to be strictly confined to the United Kingdom. The medical officer of health for the district of Heydekrug in Lithuanian Prussia draws attention to the fact that ether tippling is excessively prevalent and constantly increasing. The startling, increased and general consumption of substitutes for alcoholic beverages raises again the pertinent question whether the restriction placed upon the sale of absolutely pure products does not work harm rather than good."

"The official report on the production of iron made by the American Iron and Steel Association shows conclusively our pre-eminence in this branch of industry. In the first half of 1898 our output was the largest known, either in the United States or any other country for the same period, and more than half a million tons greater than in any other half year of our existence. Production has increased so as to reach 984,950 tons a month, and the apparent consumption has risen even more, reaching 991,391 tons."

"Excessive loading of the central span of the Brooklyn Bridge, due to a blockage on the roadway, assisted possibly by extreme expansion due to the heat, caused, on the evening of July 29, a buckling of the bottom chords of the four inside stiffening trusses."

AUGUST 1848. "Dr. Robinson lately gave an interesting account, to the Royal Dublin Academy, of Lord Rosse's telescope. Unfavorable weather had prevented much being done with the telescope, but in one good night Dr. Robinson observed in the moon the large flat bottom of the crater covered with fragments, and became satisfied that one of the bright stripes so often discussed had no visible elevation above the general surface. The nebula of Orion, even with the imperfect mirror and in bad nights, was seen to be composed of stars in that part which presents the strange flocculent appearance described by Sir John Herschel. The most remarkable nebular arrangement which the instrument has revealed is that where the stars are grouped in spirals, one of which Lord Rosse described in 1845."

"On one of the southern spurs of the Rocky Mountains, there is a valley full of geological wonders and curiosities, and is at present surrounded with a romantic interest, as being the place where that strange people, the Mormons, have taken up their residence. A portion of them have settled in a valley of California, in which there is a lake of salt water, so salty that it is impossible for a man to sink himself in it above his arm-pits, and after bathing there awhile and drying himself he will be encrusted over. There are also hot springs, boiling hot continually, thus indicating subterranean fires which will one day banish the Mormon from that land by a far fiercer tempest than that enmity which drove them from our midst."

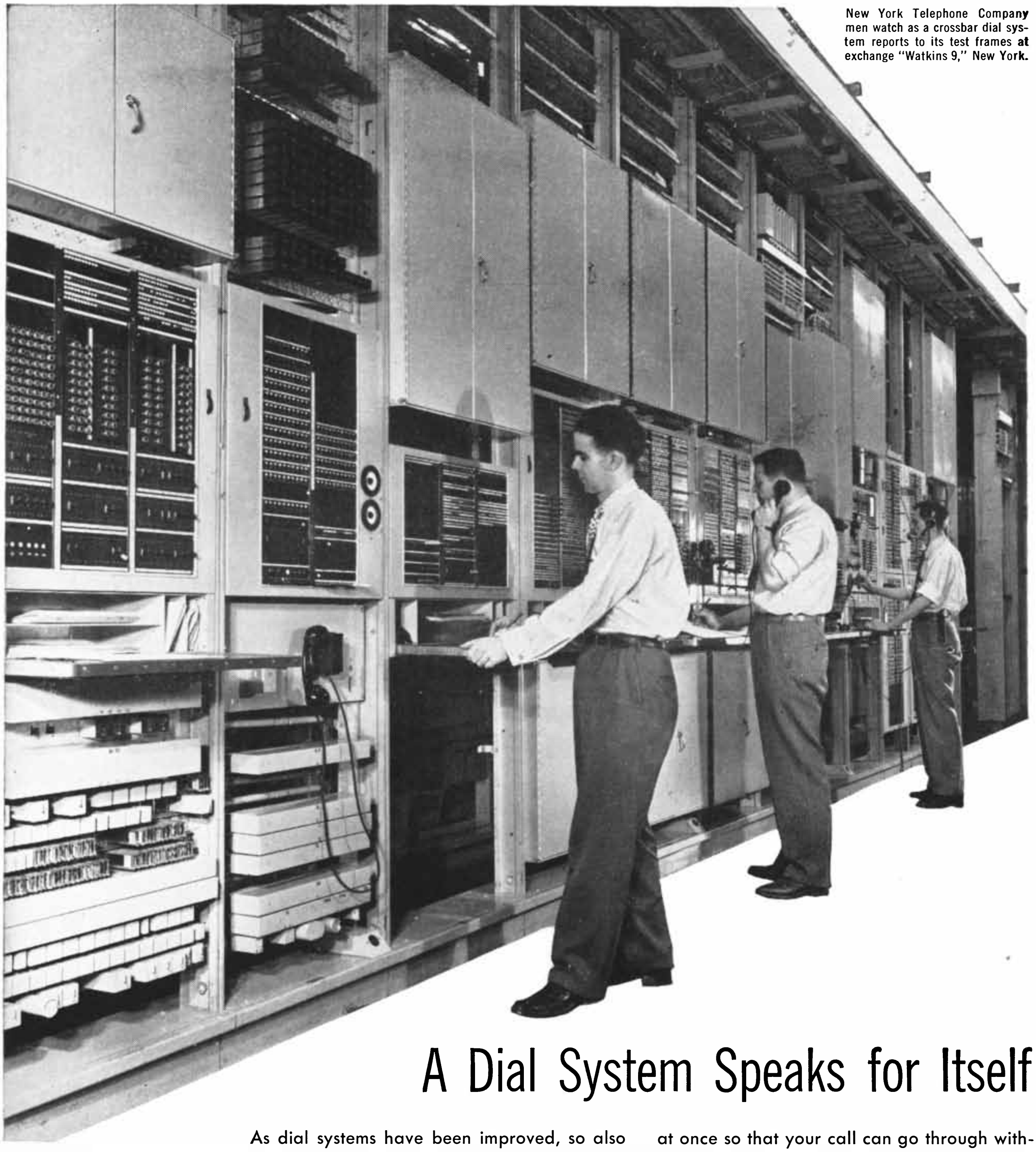
"The foot-way of the Suspension Bridge which spans the gulf of Niagara for a thousand feet, is now completed. Foot passengers now walk across from the dominions of Uncle Sam to the dominions of Aunt Victoria for 25 cents. This is a great work, not only physically but morally. It will promote intercourse and good will among the republicans and royalists. Difference of opinion regarding governments, should never make men enemies."

"Without oxygen animal life would cease to exist. It is the principal supporter of combustion and therefore without it we neither could light a candle nor kindle a fire. The gas is invisible and inodorous, and yet for all this, it is of the most importance and by its various uses, it fulfills the divine allusion to the simple laws of nature 'he has chosen the weak things of this world to confound the mighty.'"

"The celebrated Norwegian violinist Ole Bull is now working as a journeyman in the Manufactory of M. Vuillaume, a Parisian musical instrument maker, in the hope of being enabled to make a violin that shall equal the tones of those made by the celebrated Stradivarius, of Cremona; and for this purpose he has brought from Norway wood more than 200 years old."

"It is an established fact that a lightning conductor in order to fully accomplish the purpose for which it is designed, must have its lower extremity in perfect communication with the earth. The reason is that the electric fluid in passing from one body to another will select for its course that line which will afford it the most direct and perfect communication. Hence a lightning conductor to be effectual must give a free and uninterrupted passage of the fluid to the earth, which cannot in any manner be so well done as by having it terminate in water; that being also a good conductor."

"Professor Morse, the inventor of the electric telegraph, was married on the 10th inst. at Utica, N. Y. to Miss S. Griswold of New Orleans."



New York Telephone Company men watch as a crossbar dial system reports to its test frames at exchange "Watkins 9," New York.

A Dial System Speaks for Itself

As dial systems have been improved, so also have the means of keeping them at top efficiency. Even before trouble appears, test frames, developed in Bell Telephone Laboratories, are constantly at work sending trial calls along the telephone highways. Flashing lamps report anything that has gone wrong, and the fault is quickly located and cleared.

If trouble prevents one of the highways from completing your call, another is selected at once so that your call can go through without delay. Then on the test frames lights flash up telling which highway was defective and on what section of that highway the trouble occurred.

Whenever Bell Laboratories designs a new telephone system, plans are made for its maintenance, test equipment is designed, and key personnel trained. Thus foresight keeps your Bell telephone system in apple-pie order.

BELL TELEPHONE LABORATORIES *EXPLORING AND INVENTING, DEVISING AND PERFECTING FOR CONTINUED IMPROVEMENTS AND ECONOMIES IN TELEPHONE SERVICE*

THE COVER

The painting on the cover, showing a group of tropical plants, illustrates the lush biological product of photosynthesis (*page 24*). This process is constantly performed by green trees and microscopic diatoms, but it is imperfectly understood by man. In land plants the essential pigment is green chlorophyll. The brilliant red leaves at center and left are the familiar *Caladium*, or ace of hearts; the green at upper right is *Philodendron hastatum;* the small cluster of leaves at bottom center is *Episcia coccinea;* the sawtooth leaf to the right is *Neoregelia spectabilis* (fingernail plant); small leaves in lower right-hand corner are *Ficus repens* (creeping rubber plant).

THE ILLUSTRATIONS

Cover by Stanley Meltzoff

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10	Emil Lowenstein
11	Farm Home Administration, U.S. Department of Agriculture (*top*) Soil Conservation Service, U.S. Department of Agriculture (*bottom*)
12-13	Bob Landry—Pix (*top*), Russell W. Porter (*bottom*)
14	California Institute of Technology (*top*), Bob Landry—Pix (*bottom*)
15-17	Russell W. Porter
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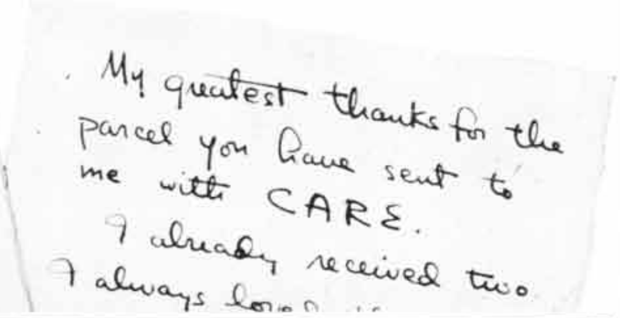
DEPARTMENTS



My greatest thanks for the parcel you have sent to me with CARE.
I already received two
I always long

yesterday we have received your recent "CARE" package. Once more the unpacking of these very useful foods has been a joy
Par cette lettre je vous remercie d'un nouveau colis que vous avez eu la bonté de m'envoyer
All the wonderful foods in your CARE package are still scarce here. It is impossible for you to imagine how des-
PAR AVION

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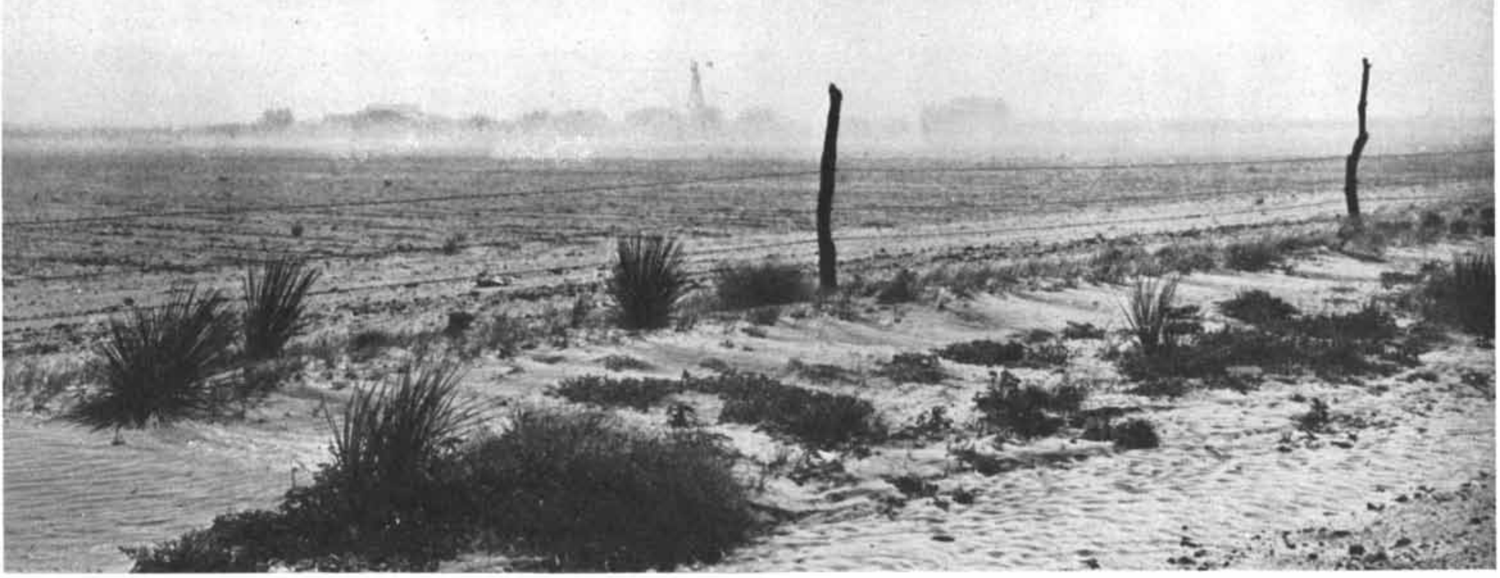


THE LAND BLOWS from the farm of Mrs. Addie Gregory near Causey, N. M. Drifted soil lies in a roadside ditch. Excessive farming of sandy soils, not lack of rain, is the primary cause of dust storms in this area.

THE DUST STORMS OF 1948

The drifting soil of marginal lands in New Mexico and west Texas is an ominous reminder of the 1930s

by H. H. Finnell

ON THE GRAY prairies of the Southwest, the dust is blowing again. Over wide stretches of New Mexico and west Texas the ominous signs are plainly written. Drifts of soil lie banked across the roads, and yellow clouds have begun to rise from the naked land. The specter of a new dust bowl haunts the Great Plains. It has developed rapidly, but not unexpectedly, within the past few months. Three years ago the black cycle of wind erosion that began in the 1930s was finally ended; in the whole plains country that year there was only one major dust storm. Last year three big dust storms sprang up in the cotton, sorghum and bean area of Texas and New Mexico. This year, in the blow season from January to May, there were 17. Of the 3.5 million acres of farming land darkened by the storms, more than a fifth was heavily damaged.

The reason for the new menace is as plain as are the signposts of coming trouble. The dust bowl is developing on the arid western plains, west of the land of the Okies. Its cause is not primarily drought, although below-average rainfall (as measured at Amarillo, Tex.) during the past three years may accelerate the disaster. The major cause is the great wartime plow-up of marginal soils. Much of the land that has now begun to blow has been broken out since 1941. Under wartime and postwar pressure for food and fiber, many hundreds of thousands of acres too thin or too sandy to stand up under cultivation have been forced to crop and are still being forced. Texas boosted its wheat crop, for instance, from 32 million bushels in 1940 to 124 million in 1947, and New Mexico from 2 million to over 9 million. While the bloom of the new land was wearing off, the marginal soils performed beautifully. But past experience has shown that farmers have rarely been able to stay on top of such soils very long. After two or three crops the soil begins to break down. This year's outbreak of dust storms along the Texas-New Mexico line was the harvest of the quick decline of stability in the sandy soils.

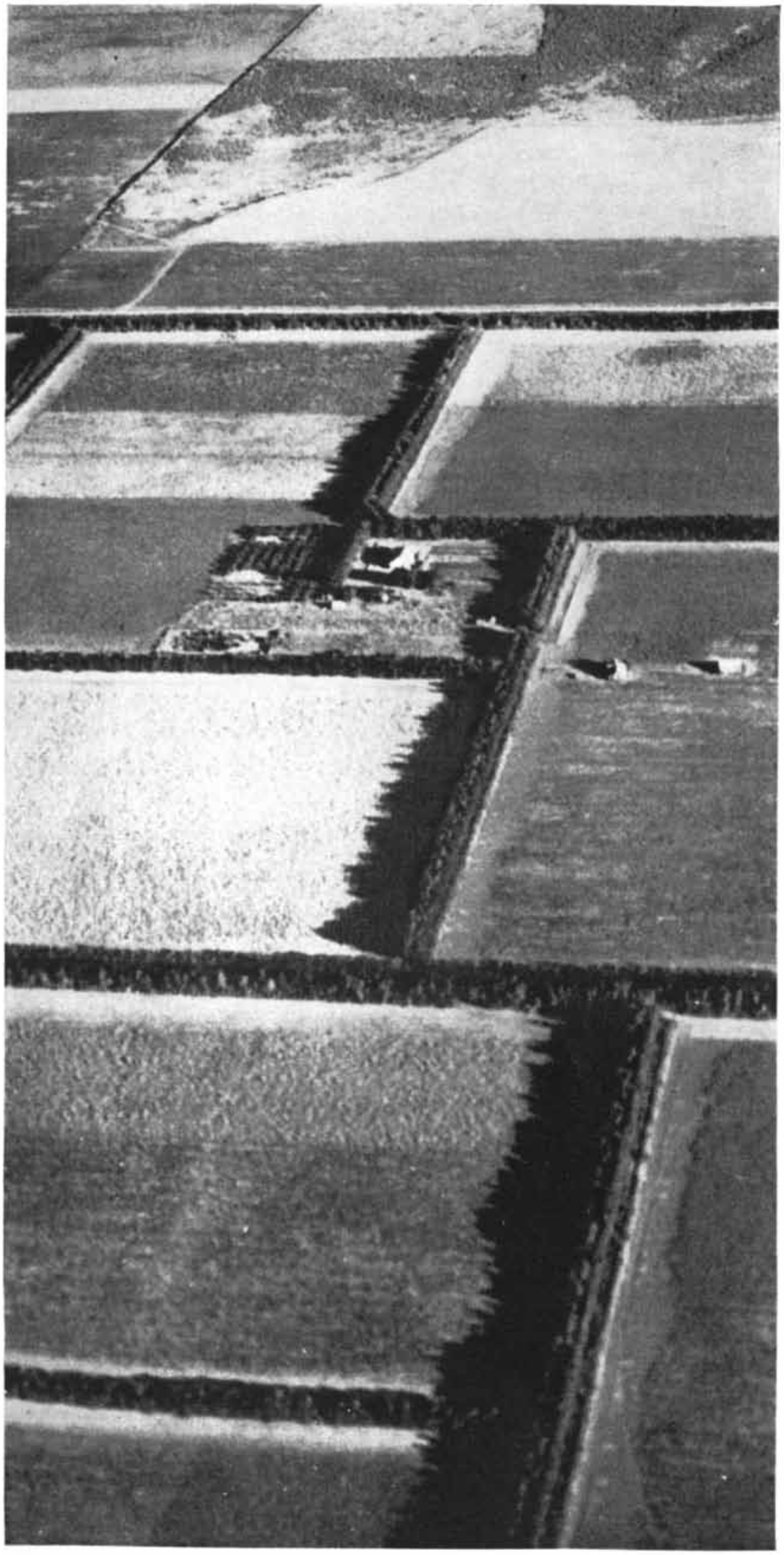
Will a new cycle of dust be permitted to blow itself out? It need not. We have learned from the dust storms of the past that with scientific controls they can be stopped. It took the lessons of the '30s to drive home the truth that dust storms are less an act of nature than a product of ruthless farming.

The devilish, nagging winds of the Great Plains are said to have made lonely pioneer women in dugouts go crazy. The same relentless, moisture-sucking winds more recently have seemed to make dry-land farming go crazy. Due to the resourcefulness of the plainsmen, agriculture did succeed on the plains, and marvelously—up to a certain point. It is this certain point that most concerns the farmers and ranchers of the wide open spaces, and the conservationists.

During the 1930s the dust storm area in the southern plains that was called the Dust Bowl grew to the size of a big midwestern state. It swelled and shrank and bobbed around on the map for a decade. Farmers groped through the dust for an explanation of the unprecedented scourge. The things that were blamed for it ranged all the way from plows to drought, from people to sun spots, from gas wells to sin. The suggested remedies were of an equally fantastic variety. They included such ideas as coating the soil surface with plaster of Paris, junking all one-way disk plows, depopulating the plains, damming a pond on every farm, mulching the land with crushed limestone, planting mulberry trees, irrigating all the cultivated land from wells!

The disaster mounted. There were 40 dust storms in 1935; 68 in 1936; 72 in 1937. The storms were fearful to behold. They gave casual observers the impression that the whole face of the earth was blowing away. Yet this was and still remains a popular misconception. Surveys by the Soil Conservation Service proved that those frightful black blizzards were built up out of dust arising from less than a twentieth of the total Dust Bowl area, and, more astonishing still, from only a seventh of the plowed acreage.

THE ANSWER to the blizzards of dust was eventually found in that vast acreage of farmed land that stayed put in spite of the winds. It was not strong winds alone that caused the storms, for even high velocity winds in the open plains cannot raise dust without soil exposure. Nor was it plowing alone. Experiment and field experience demonstrated that land could be kept safely in cultivation even in the high-hazard areas of wind erosion—provided only that a cover of vegetation was maintained continuously on the soil. The ideal way is to use the residues of productive crops, leaving a stubble mulch



WINDBREAKS OF TREES have been planted on the farm of J. H. MacDougal near the Texas-Oklahoma border. Trees were planted in 1939 under supervision of the Forest Service. Conservation of fields may be estimated by comparison with bleak expanse of unprotected land in background.

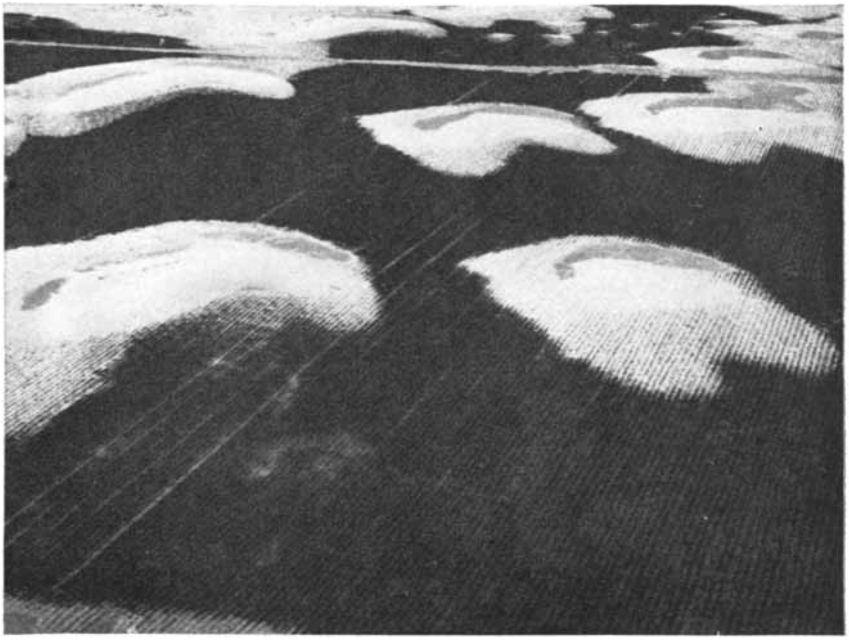
of stalks and straw to tide over the soil from one crop to another. It is surprising to observe how small a quantity of the right kind of litter it takes to protect the soil against a 60-mile-per-hour wind. And the straw from one good wheat crop will hold the soil through the blow season for two years, if it is well managed.

Few farmers on the southern plains had fully realized what a revolution in their soil management problems had been wrought by the advent of winter wheat. In the early days when corn, millet. oats, barley and sorghum were the only crops, wintering the land with stubble standing was the natural and easy thing to do. During the 1920s, when wheat-farming swept over the plains like a prairie fire. three new conditions were injected: 1) soil preparation for this new crop came at the end of the wet season instead of at the beginning; 2) wheat lent itself well to large-scale mechanized production and prompted a huge increase in cultivated acreage; 3) this in turn induced the plowing of considerable areas of low-grade soils. All this, combined with the lack of a stubble residue and with successive years of drought. set the stage for catastrophe. At their height the dust storms became not a local but a national calamity. Frantic emergency aid programs were undertaken to beat down the dust. Progressive farmers. state institutions and federal agencies began a long, slow fight to cover the soil.

THE stubble mulch, called "trashy" farming, proved to be the most universally practical method. The semi-arid climate of the southern plains is favorable to slow rotting of crop residues, and fields were stabilized by successive additions of trash in all stages of decay mixed into the topsoil. Farmers were persuaded to grow crops affording a good supply of durable stalks or straw as cover. Contour tillage was introduced to save water runoff, increase yields and overcome crop failures. Curved rows and stubble-mulched fields had never been considered entirely respectable before. They needed any encouragement that science could give. So tests were made of crop yields, and new implements were devised to till the soil in such ways as to leave the straw and stubble of crops on the surface for protection.

Although rainfall remained below average through 1940, the tide was turned against the dust in 1938. That year there were 61 major dust storms, 11 fewer than the year before; in 1939 they fell to 30; in 1940 to 17; and by 1945, with increased rains, the cycle dropped to the low point of a single dust-bearing storm.

In the end, a recapitulation of the damage to our soil resources told an eloquent story. All in all, 6.541.000 acres in the southern plains had been put out of cultivation by wind erosion. But 25,500,000 acres of good soils came through un-



RECLAMATION of Dallam County, Texas, field that has gone into dunes is begun by planting grasses which hold soil and trap dust. This field is classic example of evil of farming poor land. It was put into cultivation in 1931 and farmed for three years. It went into dunes when it was left idle.

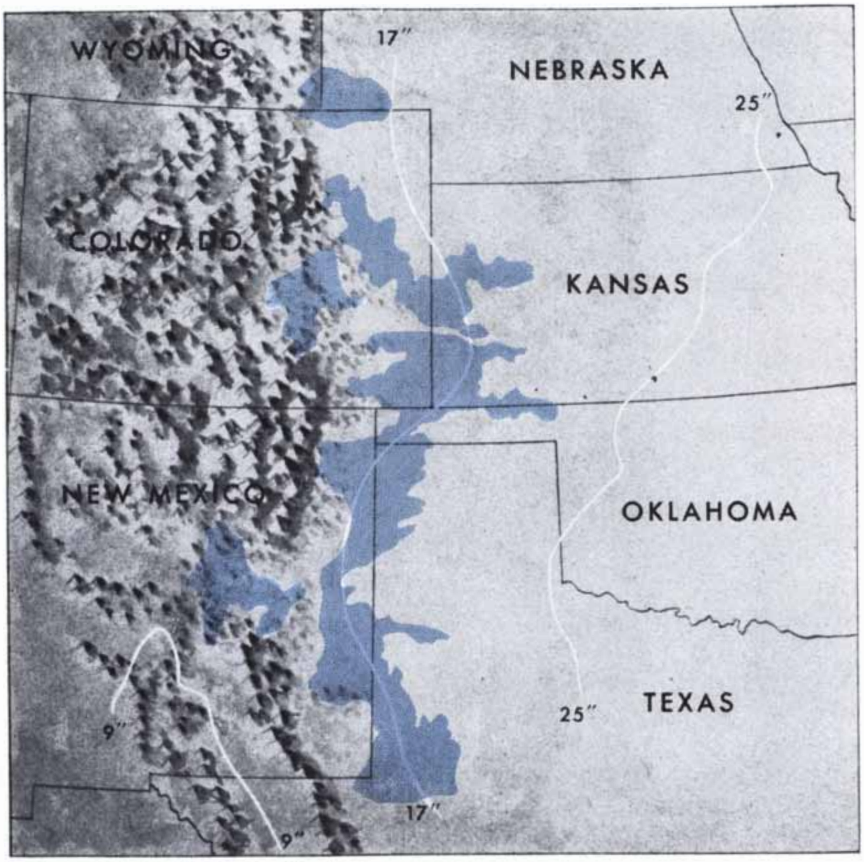
MODEL FARM in Grayson County, Texas, uses several methods to conserve water and prevent erosion. Fields are terraced and cultivated along the contours of the land. Different crops are also planted in long strips. Smaller field near the farmhouse is to provide vegetables for the home.

scathed. Of the top-grade wheat lands, only four fifths of one per cent was lost. On medium-grade soils, the loss was 26.5 per cent. Far and away the greatest damage was to the 3,890,000 acres of low-quality soils which had been in cultivation (and were just about played out anyway when the storms and low prices struck in twin fury). Of this poor land, 90 per cent was damaged beyond repair; it could never be restored for cultivation, and even as grazing land its capacity was permanently lowered.

Thus 59 per cent of the storm dust of the 1930s came from poor land, the kind which cannot long be maintained under cultivation. The moral is clear: we could avoid more than half of our dust trouble before it starts by recognizing the limitations of soils and refraining from overcultivation of poor land.

But the problem is not simple. The fact that farmers broke into inferior soils is a symptom of national and world-wide poverty of land resources. It means that good virgin soils have become very hard to find. And the desperate nature of this pinch will become more and more clearly apparent as the years go by. Ironically, the more urgent becomes the need to lighten the pressure on poor soils to prevent their complete destruction, the more difficult the problem will become, for the pressure to use these lands will increase.

The Great Plains, because its acreages and productive potential are vast, is the crucial area to us as a nation. The great weakness of our position in the plains is along the western fringe of dry farming—the area of less than 17 or 18 inches of annual rainfall. This marginal zone of major risk, scene of this year's dust storms, lies beyond the former Dust Bowl areas. The difference is symbolized in the altered color of the dust storms; the black dust of the '30s that arose from the richer loam of Okie territory was less ominous than the yellow storms now rising from the more vulnerable lands of Texas and New Mexico.



MARGINAL LANDS (*outlined in blue*) **adjoin the established dry farming or irrigated farming areas of seven western states. Three white contour lines indicate inches of average annual rainfall. Farmed during the war, these lands were less able to withstand wind erosion than established areas.**

This is where semi-arid climate breaks off into arid climate, where the deep soils of the high plains give way to the medium-depth soils and the shallow, where the sandy loams merge into shifty, loose sands. The better lands in this area can be handled safely by stubble-mulch farming, but most of the land should be kept in grass. On the low-capability soils, once taken out of sod, wind-erosion control is a physical impossibility.

It is on this critical soil that the current battle with dust is being fought. Under war's pressure, cotton and feed-crop cultivation in Texas expanded westward, too far beyond that certain point of safety. Farther north, wheat-growing has spread over the shallow clay and silty soils of Colorado, Oklahoma and Kansas—soils that may last a little longer than the sands but that are destined for inevitable breakdown and abandonment. This is the territory of the big land companies and the "suitcase farmer," who leases a tract for a short period, mines it to exhaustion, and moves on.

At the south end of the plains, we are already facing the unpleasant consequences of submarginal cultivation and failure to protect the soil. At the start of the present planting season, 2.8 million acres were not sufficiently protected by cover crops or residues. To date, plantings have failed on about one third of this unprotected area. To head off continued soil-blowing which is in prospect for next year would require a miracle of favorable fall crop conditions. To insure against a long period of trouble we need prompt and drastic action: the immediate converting of the recently plowed poor lands to pasture, which may take several years to accomplish. If events run true to form, however, the operators of these marginal soils will hang on to the bitter end, resisting pleas to save the soil before its final breakdown.

THE PERMANENT residents left behind who will have to contend with the dust, the encroachment of creeping drifts of soil and the long and tedious task of stabilizing blown-out fields, are for the most part members of the Soil Conservation Districts. These districts are legal subdivisions of the states under enabling legislation. Organized and controlled by the member farmers and ranchers, they receive technical assistance from the U.S. Department of Agriculture. Nearly 400 Soil Conservation Districts have been organized in the Great Plains area and new ones are formed from time to time. They have authority to deal with serious erosion emergencies in several ways. One that was widely used in the late 1930s was to accept free leases from distressed or absentee land owners for the purpose of planting cover crops.

But standing by to pick up the pieces is not enough. The land cannot endure one emergency after another. Real and thorough precautions to prevent emergencies from developing are what we need. Maintaining suitable control measures on legitimate crop land is a vital part of that program. Beyond that, we cannot escape the conclusion that it is equally important to keep crops out of arid territory and off the thin and sandy soils of border areas.

H. H. Finnell is research specialist for the Soil Conservation Service of the U.S. Department of Agriculture.

DRIFTS OF SOIL rippled among the buildings of the Karnstrum farm in the 1930s (*above*). Abandoned during the drought and dust storms, the farm was later rehabilitated by planting it with Sudan grass, a tough species which requires little water. In the picture below the surface of the barnyard has been stabilized by a heavy growth of grass. In the fields of the farm, the grass has yielded a crop of 8 to 10 tons to the acre.

PRIME FOCUS of 200-inch telescope *(see diagram on opposite page)* is in a cylinder suspended at upper end of the tube. Here camera looks down toward the mirror. About prime focus cylinder is a plywood screen which is perforated for special mirror tests. The man in the cylinder has his left hand on the prime focus photographic plate-holder. In his right hand are buttons for limited control of the telescope from the prime focus station.

ACTUAL CURVATURE of the mighty 200-inch mirror is less than the common conception but more than any other mirror of comparable size. The 200-inch mirror is *f* 3.3, bringing the light it collects to a focus at a point 3.3 times the mirror's diameter away from its surface. This required that the spherical surface be ground down 3¾ inches at the center. Making the sphere parabolic called for grinding the center .05 inch deeper.

A Night on Palomar

Now that the mirror has been through the early tests, where do we go from here? An account of present problems and future astronomical plans

by Albert G. Ingalls

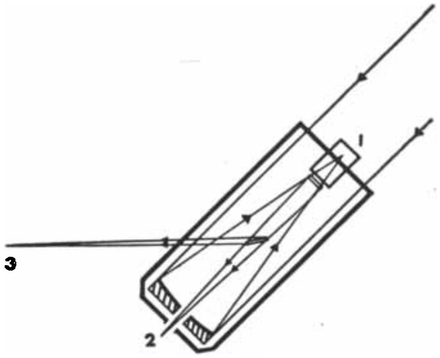
"WOULD YOU be interested," Russell Porter inquired, "in an afternoon, an evening and a morning at Palomar Observatory with the run of the 200-inch telescope and perhaps a squint or two through it, as a guest of the Hundred-to-One-Shot Club?"

The Hundred-to-One-Shot Club is a group of ten middle-aged amateur astronomers, mainly physicists, who during a dozen years have met for camping trips in the desert and mountains. There they relax and have discussions about the philosophy of science, in which the chance of reaching a conclusion runs about a hundred to one.

From Pasadena—where the official owner of the 200-inch telescope, the California Institute of Technology, is located—to Palomar Mountain (not Mount Palomar) is 130 miles by road. Thus Palomar is not "just outside Los Angeles." The final 11 miles of the three-hour drive to Palomar includes a seven-mile ascent of the mountain over a fine road that winds in continuous curves up to a broad, rolling plateau. Four miles back on the plateau the silvery silhouette of the 137-foot observatory dome leaps into view. Its observation floor is 5,598 feet above the Pacific.

Arranged around the great dome at thousand-foot distances are the domes of the 18-inch and 48-inch Schmidt cameras. Tucked in a quiet cove under oak trees is the "Monastery," where the astronomers live while actually on the mountain using the telescope. Between times they return to Pasadena to work up their data. The Monastery is an unpretentious modified dwelling run by a steward and stewardess. In it are eight daylight sleeping cells, small soundproof rooms off quiet corridors with special window shutters tight enough to exclude the California sun so the nocturnal astronomer can sleep.

A quarter of a mile from the big dome is the observatory's private picnic ground. Here, while it was still light, we arranged our blankets on the dry ground deep in tall ferns to fend off night breezes. Someone called for an ax and came back dangling a beheaded rattlesnake. Someone else mentioned casually that hundreds of rattlers had been killed there, so theoretically they were "mostly" gone. The anticipation of seeing the 200-inch pushed such thoughts into the background. The members of the Hundred-to-One-Shot Club sat down before dark under mistletoe-mottled oaks to eat steaks almost a foot square. Soon it was dim enough to use the telescope.



THREE FOCI of the big mirror give it flexibility for differing problems. They are the prime focus (1), Cassegrainian (2) and the coudé (3).

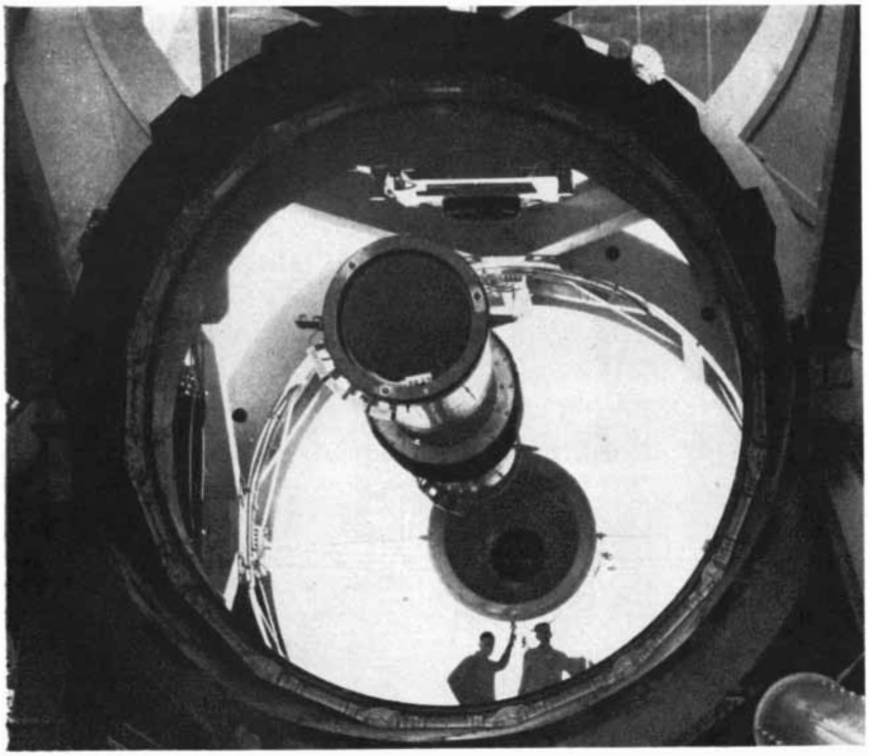
INSIDE the dome of the 200-inch the night assistant perches before a control desk having a satisfying array of dials, indicators and buttons. Here he executes orders given him through a talk box by the astronomers in any of three working positions on the telescope: the prime focus atop the tube, where most of the star photography will be done; the longer Cassegrain focus just under the tube, where the photography of stars or of spectra will sometimes be carried on; and the coudé focus a little below main floor level where stellar spectra will be photographed in a constant-temperature room.

Bruce Rule, engineer in charge of the telescope's vast complex of electrical equipment, much of which he designed, ran the control board. The million-pound mounting obeys the command of a finger. If you wish to point the tube at a given star you look up its declination (celestial latitude) in the astronomer's Ephemeris, turn a little hand crank to that declination, press an "exec" button and the tube swings north or south within its supporting yoke. Then you wind another little crank to the star's right ascension (celestial longitude), press an "exec" button and a three-horsepower "slewing" motor swings the yoke and tube across the skies at 45 degrees a minute. A one-twelfth horsepower driving motor then takes hold and keeps the star in the field as the earth turns. The actual power needed is theoretically only 1/165,000 horsepower.

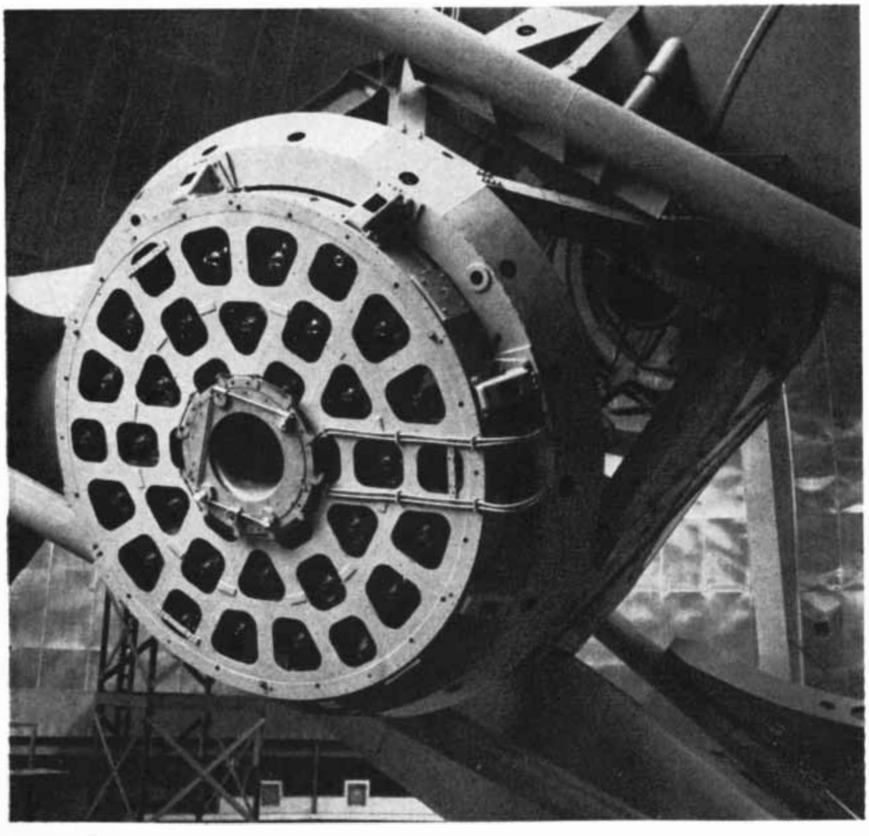
Officially, there is no way to use the 200-inch telescope as a visual instrument. It is a huge camera. However, a crude eyepiece in the form of an eight-power hand telescope had been attached temporarily near the coudé focus at the observatory floor level. This, in combination with the 200-inch, gave a magnification of 800 diameters.

With a prolonged carpet-sweeper whine from the slewing motor and worm gears, Rule swung the tube down nearly to horizontal and brought the image of the planet Saturn into the eyepiece. Alas, Saturn was so indistinct that not even Cassini's division between two of the rings could be seen. Otherwise the image was large (one inch apparent diameter) and was brilliantly illuminated by the light collected in the 200-inch mirror. Each person had a look at Saturn, and then Rule swung the tube to Mars. Of all the Martian markings the polar cap alone could be distinguished and that only vaguely.

The members of the Hundred-to-One-Shot Club made little comment about these poor images because they understood the



ALUMINIZED SURFACE of the main mirror, photographed from the upper end of the tube, confuses the anatomy of the telescope. The surface of the mirror is near the flange about the 40-inch tube in the center. Behind the flange are reflections of the tube, the prime focus cage and photographers.



SUPPORTING CELL of the mirror is revealed in a view of the lower end of the telescope tube. Through the perforations in the cell are visible the 36 lever mechanisms *(see opposite page)* that support mirror in all positions. Friction in these supports is a temporarily unsolved problem.

reasons for them. Light from objects too near the horizon passes through many added miles of atmosphere whose varying density causes irregular refraction. In any case, all understood that the visual use of the 200-inch was no more than a stunt. They knew also that a six-inch telescope might at times provide a better show, except for the brilliant images made possible by the big mirror. They knew, too, that they had been privileged to play with the 200-inch only because it was not yet ready for serious work.

Now the telescope was tried on Messier 13, a globular cluster of 50,000 stars 36,000 light-years distant. It easily resolved the cluster. We could look through it and out into the blackness of space beyond. The secret of the suddenly improved seeing was that M 13 was near the zenith and the rays from it had passed through a minimum of atmosphere.

Dr. John Anderson, who with his superintendent Marcus Brown made the mirrors of the 200-inch, exclaimed, "This image is wonderful. It could be photographed." Later at Pasadena he handed me the only six plates thus far made with the telescope and a magnifier for examining their images. They looked excellent. These six plates, however, had been taken only to locate the optical axis of the mirror.

To have supposed that the telescope would be ready to start working as soon as the 200-inch mirror was added to the waiting mounting would have been naïve. You can set up a Sears, Roebuck windmill with the wrench in the bottom of the box and use it at once, but a 200-inch telescope is not a windmill and many fine adjustments must be made.

We left the rigged-up eyepiece and wandered for hours among electrical mazes in the rooms beneath the observation floor. Much of the electrical equipment consists of interlocking controls to prevent absent-minded observers from using in damaging sequence the 60 control motors that operate parts of the telescope. We saw the vibrating-string time standards that are accurate within less than a tenth of a second a day, the pumps that force oil at 210 to 385 pounds per square inch under the bearings of the mounting so that the whole million-pound telescope floats on a film of oil. We poked our heads into the kitchen where the astronomer may get a refill after a chill night aloft, and into the lounge where he may study, read or loaf between jobs.

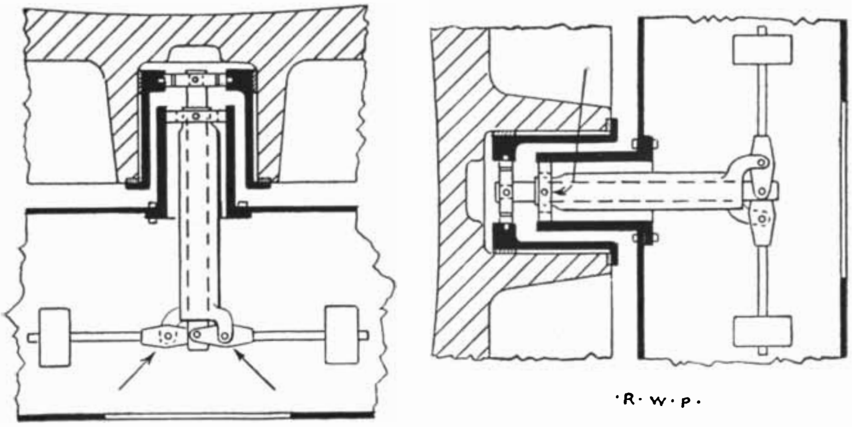
The optical essence of the two-million-pound telescope weighs less than a quarter ounce. Light from the stars reaches a paraboloidally curved aluminum mirror 200 inches in diameter and 1/200,000-inch thick—an amount of metal approximately the bulk of a nickel—which reflects it to a light-sensitized sheet of photographic emulsion a thousandth of an inch thick. The remainder of the telescope consists of accessories: the glass plate that supports the emulsion; the glass disk, commonly called the mirror, that supports the aluminum; the 36 levers with counterweights that support the glass disk and the platform or cell that supports both; the tube that carries the cell; the yoke that carries the tube; the base frame that carries the yoke and the big steel balls that carry the base frame and rest on plates set in Palomar's gray granite. The function of all these accessories is to support the mirror and emulsion in correct geometrical relation and to move them precisely and controllably.

Of all these mighty bones and vital organs only one, the lever support system beneath the main mirror, still keeps the 200-inch telescope a little under the doctor's care.

If the mirror disk were made of solid glass two feet thick, two specific effects would be so pronounced as to forbid its use in a telescope as large as 200 inches in diameter. The first is that when the mirror was tipped up at an angle it would slump appreciably of its own weight. The second is that because of changing air temperatures around the disk it would never cease bending. It is true that in a constant-temperature room it would reach one temperature throughout after about two days and thereafter its outer and inner layers would cease to contract and expand unequally. But in a telescope, even within a dome that is insulated against daytime heat by aluminum foil equal in value to 24 inches of cork, the night-time changes of temperature would chase one another continually through its mass. And so poor is glass as a conductor of heat that the optical surface would never cease flexing from the unequal expansion.

To defeat this bogey the Corning Glass Works suggested a cellular disk consisting of a face four inches thick and, cast as part of it, rear ribs four inches thick. In such a disk, no part of the glass would be more than two inches from the air. By this one trick the temperature-equalization time was reduced from the inadmissible 48 hours to a very workable 80 minutes.

The ribbed structure also afforded two other gains: 1) the weight was reduced from 25 to 14½ tons; 2) the ribs permitted the installation of a balancing mechanism. At their intersections, 36 deep round pockets were cored out and into these pockets lever mechanisms were inserted to support the mirror over its entire area. These levers balance the weight of each of the 36 local areas surrounding them, and pass the weight to a steel cell beneath the mirror. They are effective in all positions of the mirror between horizontal and vertical because they combine two lever principles. These are worth studying in the accompanying drawings. In both cases shown, horizontal and vertical, the fulcrum is indicated by arrows. In all positions between the two extremes the same lever automatically and at one time acts on both principles in proportion to the tilt of the mirror. So fine are these supports that even if the mirror were as thin as paper it would theoretically still be supported in all positions without flexure. Actually—and here comes a headache—the adjustment of the balancing weights each along its lever is an endless game because change of one support effects areas of the disk beyond its allotted territory.



SUPPORTING MECHANISM of the mirror is made up of 36 relatively simple arrangements of weights. When the mirror is horizontal *(left)*, each pair of weights pushes upward against its surface. When the mirror is vertical *(right)* the supports operate against ribs on back of the mirror.

The supports have recently been the optical sore thumb of the telescope. Refined as they are, each with 1,100 parts (the drawing is greatly simplified), there has remained within them residual friction amounting to about 1.3 per cent of the weight supported. This caused enough lag in response as the mirror took new angles of tilt to prevent it from remaining within the required 1/200,000 inch of a true paraboloid.

Just how important the "trifling" amounts involved can become in a large mirror is heavily underlined in the following data supplied by Anderson. If no local support system were provided under the 60-inch mirror at Mount Wilson—if it were supported only at the edge—the sag in wavelengths of light (each approximately 1/50,000 inch) would be 4; in the 100-inch mirror it would be 12; in the 200-inch mirror it would be 125. The amount of sag that can be tolerated is only one-fourth wavelength. The 200-inch would therefore sag to the extent of 500 times the allowable amount!

Newly designed supports are expected to reduce the friction lag from 1.3 per cent to only 0.05 per cent. If they are successful, and they probably will be, they will be installed and adjusted in September. After their first adjustment the mirror probably will perform satisfactorily at once. If it does not, a long series of adjustments may be necessary. These would not be so simple as adjusting a nut with a monkey wrench. The procedure would be to make trial adjustments and to observe the effect on the mirror. The observation would consist of making a Hartmann test photographically. For each such test a week would waste away.

During this period wild rumors may spread by grapevine. Those responsible for the success of the telescope are entitled to a generous period of time for making their adjustments. Cautious readers should judge rumors with reservation. Three decades ago it took a year and a half to adjust the 100-inch telescope and even then the support system contained a heavy friction lag for the first 10 years, until ball-bearing supports were installed. The supports of the 200-inch are also ball-bearing.

THREE DECADES of technical advances have been utilized to the utmost in the 200-inch. This is most notably true of its many remote-control mechanisms. Push buttons and small motors accomplish what formerly was done more slowly by hand. There are 60 small motors and 68 Selsyn units in the installation. An example of the value of remote controls which permit the telescope to be used to its greatest advantage was given me by Dr. Edwin Hubble.

The astronomer is working at the prime focus at the top of the tube but the air is unsteady and tremulous and he cannot get high resolution. Suddenly it settles down. He wants to get large-scale spectra of the components of a certain double star, so he pushes buttons that start motors that move auxiliary mirrors into place, and descends quickly to the coudé focus to carry on with his program. Elapsed time: 15 minutes.

Again, the astronomer is at work with a photocell at the prime focus. Along come intermittent clouds that destroy his brightness measurements. Leaving his photocell, he puts on the coudé focus and spectrograph—time 15 minutes—and works there. The only effect of passing clouds here is to delay the progress by lengthening the exposure. Later the clouds pass over and he easily changes back to his brightness measurements at the prime focus.

With the 100-inch at Mount Wilson there has been no such flexibility. The best the astronomer could do was to have two or three different programs at hand and choose the one best suited to the night. But, once started on it, he couldn't well change to another, since the change from prime to Cassegrain or coudé focus took more than an hour. Even then conditions might shift while he was changing over.

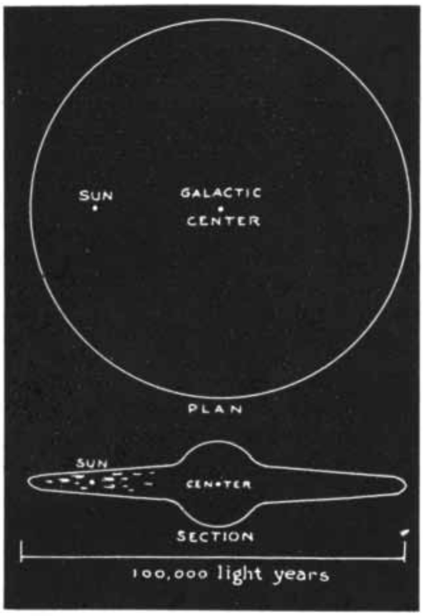
The 200-inch has been named the Hale Telescope in honor of George Ellery Hale (1868-1938) whose vision and leadership made it a reality. Hale, the founder of the Yerkes and Mount Wilson Observatories, obtained $6,550,000 from the Rockefeller Foundation General Education Board for the California Institute of Technology to build the telescope, which Caltech owns. Now that it is built, the astrophysical staffs of Mount Wilson and Caltech have been merged under the direction of Dr. Ira S. Bowen, formerly of Mount Wilson.

At the offices of Mount Wilson Observatory, which are in Pasadena and not on the mountain (10 air, 25 highway miles away), I asked several astronomers to name typical research problems—not necessarily their own—to be carried out by the 200-inch.

The problems stated by Dr. Paul W. Merrill, spectroscopist: 1) Astronomical check on the spectroscopic theory of the iron atom. 2) Analysis of stellar atmospheres to determine motions and accelerations in them. 3) Spectroscopic analysis, as detailed as the new telescope can make it, of the atmospheres of variable stars. 4) Study of long-period variable stars that have been too faint at their minima for further work with the 100-inch. The most interesting problems arise, in fact, when these stars are at their minima.

The problems enumerated by Dr. Walter Baade, cosmologist: 1) Use of the 200-inch to double our sampling of individual stars in the local galaxies. The basis upon which we have begun to explore the universe has been the detailed study of the "local group" or cluster of 14 galaxies within a million light-years. In these we have found Cepheid variable stars which make possible the determination of galactic distances. With the 200-inch we may find Cepheids in more distant galaxies. 2) Study of Type II stars in elliptical nebulae of the local group such as the two companions of the Andromeda Nebula. 3) Extension of our photometric (magnitude) scale to the limit of the 200-inch, to stars of magnitude 22.5. The limit with the 100-inch is about magnitude 21. 4) In the Andromeda Nebula, which is so good a model of our own galaxy that it serves as an excellent guide for its investigation, there are globular clusters similar to the 100 to 200 globular clusters in ours. Photographed by the 100-inch these show only as little round patches not resolved into individual stars. The 200-inch should resolve them and prove that their tentative identification as globular clusters is correct.

EDWIN HUBBLE lists these problems: 1) Determining the relative abundance of the chemical elements in different kinds of stars. These data will have direct bearing on the source of stellar energy and the origin of chemical elements. 2) General problems of cosmology—the structure and behavior of the universe as a whole. Is the region of space observable with the 100-inch, the contents of which are found to be quite similar throughout, a fair sample of the universe? The 200-inch, by penetrating twice as far into space as the 100-inch, will multiply our sample by 2^3, or 8. Again, is the universe actually expanding or is the red shift evidence of some new law of nature? 3) Hubble describes the question of the canals of Mars as an opportunity for the 200-inch, since for the first time it may be possible to photograph by snapshot with that great light-gatherer all that the eye can see with a telescope of moderate size.



STRUCTURE of our galaxy limits the view of the 200-inch, as it does that of any other earth-bound telescope. Solar system's view of outer space is obscured by dark clouds toward edge and center of galaxy.

Many astronomers react as unfavorably to the mention of Mars as they do to the common use of the word "lens" for mirror and "big eye" for the 200-inch mirror (it isn't an eye but a camera). Thoughtful laymen agree with them that cosmology vastly outranks nearby Mars in significance. But even thoughtful people sometimes take interest in what the next-door neighbors are doing.

Hubble divides Martian observers into two categories: those who claim to see the hairlike canals (adjacent to major markings that have been photographed) and those who don't. If you have seen them, as I have, you will swear they are as real as your hand, but one can feel the same way about optical illusions.

If, however, we could photograph the Martian canals, the dispute would be settled. Mars isn't bright enough for a snapshot with the 100-inch and during the necessary time exposure (a second or so) the fine detail of the supposed canals is smeared over the plate by our atmosphere's evil behavior. (The eye, however, can hold an image, as after a flash of lightning. This is largely how we see the canals and explains why, for once, the eye excels the plate.)

The 200-inch collects just enough light to allow snapshots of Mars. These may be made by having movie film ready to run off during a few minutes of "good seeing" afforded by the atmosphere when Mars is closest to the earth. A few lucky exposures may thus result. The canals of Mars almost never look like the neat maps published in books, which often embody the integrated momentary visions of months or years. Mars will be relatively close to the earth in March, 1950, and May, 1952. Astronomers may then find time to expose movie films.

The 200-inch, the astronomers say, is the last big telescope, "absolutely the final limit in size." Not technological but meteorological obstacles are what set this limit. Just as the 100-inch has been squeezed to its limit so the 200-inch will be. Some future type of instrument, possibly using microwaves, may, however, carry out explorations into new realms of space.

Of equal importance with the 200-inch, or even greater importance during the next few years, will be the 48-inch Schmidt camera at Palomar; yet so religiously do we worship magnitude that the 200-inch has stolen the show thus far. The Schmidt, though its bright dome is conspicuous from the entrance porch of the 200-inch, has not yet caught the public eye.

This big Schmidt camera is firmly wedded to the 200-inch. The importance of the Schmidt is due to the fact that it will photograph the whole sky. Has the sky not been photographed? Not as the Schmidt will do it, not so distantly into space and at the same time so thoroughly.

Ordinary telescopes reach great distances, grasp faint detail, but only in tiny areas. They bore deep but narrow shafts into space. The whole visible hemisphere of the heavens contains about 20,000 square degrees. To cover a single square degree would require about 25 photographs with the 200-inch. It would require an impossible half million photographs by the 200-inch to photograph the entire hemisphere.

The impression is widespread that because the 100-inch has been pushed to the limit it has photographed everything in the sky out to 500 million light-years. On the desk of the cosmologist Hubble is a chart of the heavens, dog-eared and dingy from years of handling, that shows the area photographed by the 100-inch over three decades. The unphotographed areas exceed the photographed areas by more than a hundred to one. What has been done can be considered no more than sample, though it is a sample that has been systematically distributed.

By about next June the 48-inch Schmidt will begin a program of systematically photographing the whole sky on 1,000 pairs of 14-by-14-inch plates, one red-sensitive, one blue-sensitive. Each will picture an area seven degrees square, with the light-gathering power (distance) of a 60-inch telescope of more orthodox design. Each plate will cover 1,225 times the area of good star images covered by a single plate taken at the prime focus of the 200-inch. And each plate will reveal stars only two magnitudes brighter than the dimmest picked up by the 200-inch (20th magnitude as against 22nd or 22.5).

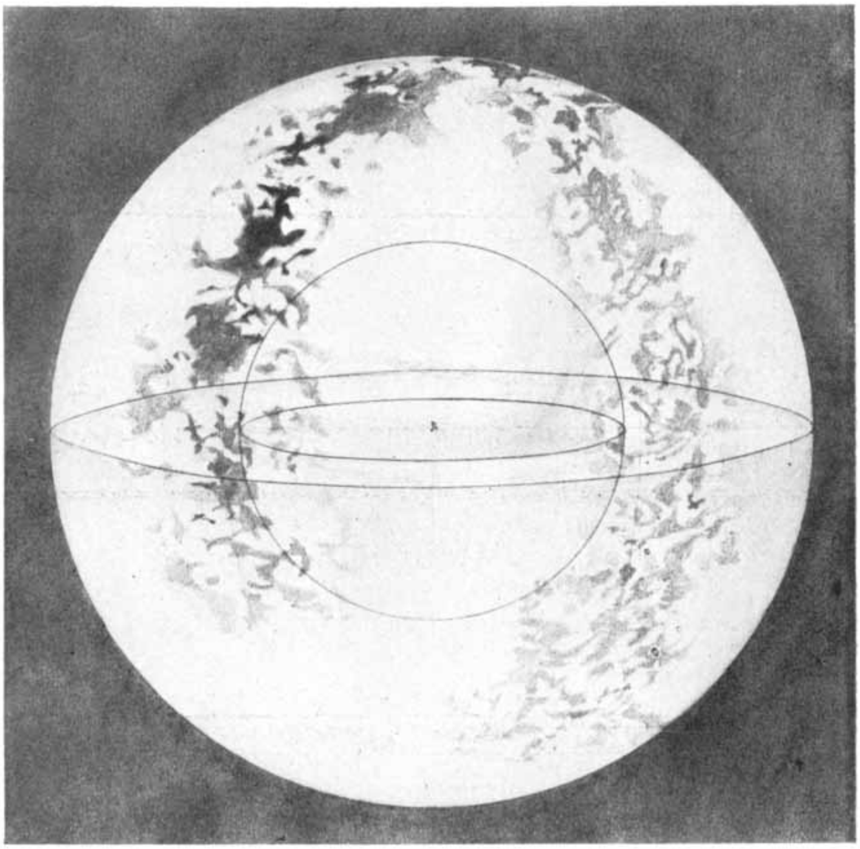
Thus the 48-inch Schmidt will reconnoiter for the deep penetrations of the 200-inch. With it astronomers can seek out likely spots to hunt for significant objects, on which the 200-inch will then be trained. Without the Schmidt the 200-inch, handicapped by its tunnel vision, would be virtually blind.

After a disappointing night without rattlesnake bedfellows, the antivenin provided thus being wasted, the members of the Hundred-to-One-Shot Club washed their faces, omitted to shave, and went to look at the Schmidt. Its optical parts were found in boxes ready for installation.

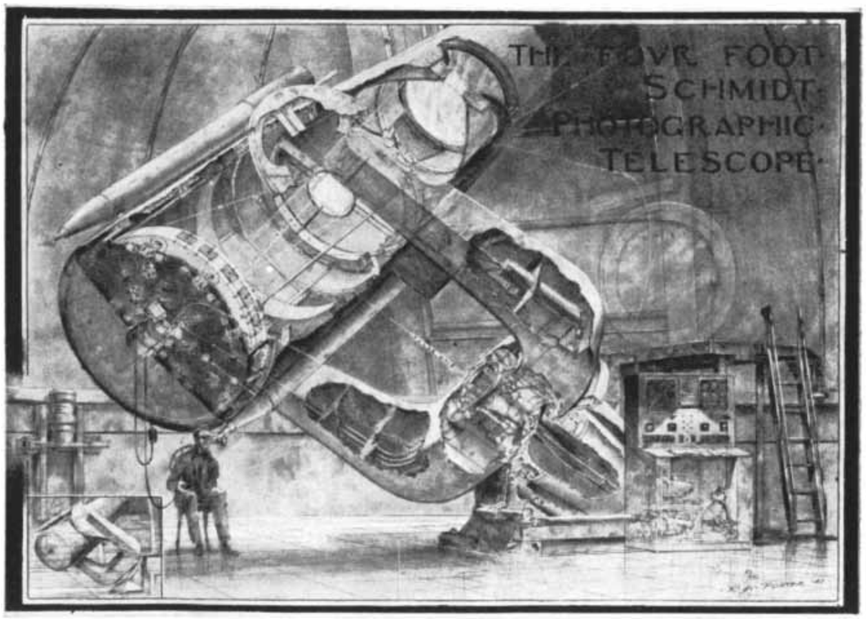
Porter's cutaway drawing shows more of this 20-foot "mortar" than could be seen at the site. The primary mirror, 72 inches in diameter, has a focal ratio of 2.5. The correcting plate has 49-inch clear aperture. The two identical 10-inch guiding telescopes permit control in any position of the tube.

THE 48-INCH Schmidt, like the 200-inch, is a push-button telescope. Dial the coordinates of the desired area, push the buttons and the tube turns to it and stops, ready for work. To insert a plate or remove one, push another button. The camera dutifully nods to horizontal position, facilitating the change. The plate-handling and developing rooms below the observation floor would turn an amateur photographer green.

The Schmidt is off bounds to visitors and so is everything at Palomar except the public parking area, the small museum of Porter drawings and astronomical transparencies, and the glassed-in visitors' gallery on the floor almost beneath the 200-inch. This affords an excellent view. Visitors may here enter freely any day before five and look their fill. With 100,000 of them already arriving annually, the observatory authorities must have some ground rules for visiting if the telescope is to accomplish its work.



VIEW of the 200-inch is a sphere two billion light-years in diameter set in the depths of space. Projected on the surface of the sphere in this drawing by Russell W. Porter are the actual areas obscured by dark clouds within our galaxy. The gap in the lower part of this projection is the area that never rises above the horizon at Palomar Mountain. Within the large sphere is a smaller one representing space penetrated by the 100-inch telescope.



THE BIG SCHMIDT camera will be the handmaiden of the 200-inch in its exploration of space. The precious observing time of the 200-inch cannot be wasted in searching the heavens with its tiny field of view. The wide-field Schmidt, however, can explore freely, revealing areas for the 200-inch to probe. Principle of the Schmidt is that primary mirror at the bottom of the tube is optically corrected by a thin, delicately curved plate at the top.

SWARM OF BEES, going forth to establish a new colony, is covered with a teeming layer of workers. Bees sometimes perform their dance on the surface of a branch, but here communication is less certain than in the hive.

THE

I PROPOSE in this article to describe the amazing experiments of Karl von Frisch on the ways in which bees convey information to their fellows, but first I should like to tell a little about the man himself. Von Frisch is an Austrian who for many years held a zoology professorship at Munich. He was in danger of being thrown out by the Nazis, but his work with the bees was considered so important by the food supply ministry that his dismissal was "postponed" until after the war. During the war the zoological laboratory where von Frisch worked was severely damaged by bombing and his private house, with the library he had moved there for safety, was completely destroyed. He is now working at the Austrian city of Graz. Most of his investigation of bees is carried on in a small private laboratory at Brunnwinkl in the Austrian Alps.

The studies to be described here were almost all made after the war. Most of them are as yet unpublished; some I know from a manuscript submitted to me before publication and the latest from correspondence between von Frisch and myself.

Von Frisch began his work about 40 years ago by showing that bees are not totally color-blind, as was then believed by many on very inadequate evidence. By means of experiments which he originated, he proved that bees have a very definite color sense and can easily be trained to seek food on the background of a specific color which they distinguish from other colors. They are, however, blind to the red end of the spectrum. From this beginning, von Frisch went on to a lifelong study of the other senses of bees and of many lower animals, especially fishes.

His early experiments showed that bees must possess some means of communication, because when a rich source of food (he used concentrated sugar solution) is found by one bee, the food is soon visited by numerous other bees from the same hive. To find out how they communicated with one another, von Frisch constructed special hives containing only one honeycomb, which could be exposed to view through a glass plate. Watching through the glass, he discovered that bees returning from a rich source of food perform special movements, which he called dancing, on the vertical surface of the honeycomb. Von Frisch early distinguished between two types of dance: the circling dance (*Rundtanz*) and the wagging dance (*Schwänzeltanz*). In the latter a bee runs a certain distance in a straight line, wagging its abdomen very swiftly from side to side, and then makes a turn. Von Frisch concluded from his early experiments that the circling dance meant nectar and the wagging dance pollen, but this turned out

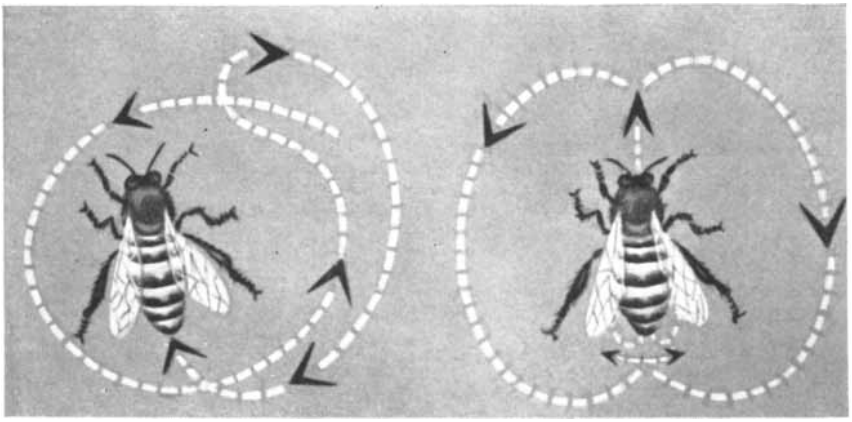
LANGUAGE OF THE BEES

A lone Austrian researcher has deciphered the ritual used by the industrious insect to direct its fellows to pollen and nectar

by August Krogh

to be an erroneous translation, as will presently appear.

In any case, the dance excites the bees. Some of them follow the dancer closely, imitating the movements, and then go out in search of the food indicated. They know what kind of food to seek from the odor of the nectar or pollen, some of which sticks to the body of the bee. By means of some ingenious experiments, von Frisch determined that the odor of the nectar collected by bees, as well as that adhering to their bodies, is important. He designed an arrangement for feeding bees odoriferous nectar so that their body surfaces were kept from contact with it. This kind of feeding was perfectly adequate to guide the other bees. In another experiment, nectar having the odor of phlox was fed to bees as they sat on cyclamen flowers. When the bees had only a short distance to fly back to the hive, some of their fellows would go for cyclamen, but in a long flight the cyclamen odor usually was lost completely, and the bees were guided only by the phlox odor. The odor gives very precise information about the flowers for which to search. In one experiment in a botanic garden, flowers of the perennial *Helichrysum*, which produces no nectar, were soaked in the sugar solution fed to the bees, and in a very short time their fellows sought out the tiny plot of Helichrysum among 700 species of flowering plants.



RUNDTANZ AND SCHWANZELTANZ (circling dance and wagging dance) are bee's principal means of communication. In Rundtanz (*left*) bee circles. In Schwanzeltanz (*right*) it moves forward, wagging its abdomen, and turns.

THE VIGOR of the dance which guides the bees is determined by the ease with which the nectar is obtained. When the supply of nectar in a certain kind of flower begins to give out, the bees visiting it slow down or stop their dance. The result of this precisely regulated system of communication is that the bees form groups just large enough to keep up with the supply of food furnished by a given kind of flower. Von Frisch proved this by marking with a colored stain a group of bees frequenting a certain feeding place. The group was fed a sugar solution impregnated with a specific odor. When the supply of food at this place gave out, the members of the group sat idle in the hive. At intervals one of them investigated the feeding place, and if a fresh supply was provided, it would fill itself, dance on returning and rouse the group. Continued energetic dancing roused other bees sitting idle and associated them to the group.

But what was the meaning of the circling and wagging dances? Von Frisch eventually conceived the idea that the type of dance did not signify the kind of food, as he had first thought, but had something to do with the distance of the feeding place. This hypothesis led to the following crucial experiment. He trained two groups of bees from the same hive to feed at separate places. One group, marked with a blue stain, was taught to visit a feeding place only a few meters from the hive; the other, marked red, was fed at a distance of 300 meters. To the experimenter's delight, it developed that all the blue bees made circling dances; the red, wagging dances. Then, in a series of steps, von Frisch moved the nearer feeding place farther and farther from the hive. At a distance between 50 and 100 meters away, the blue bees switched from a circling dance to wagging. Conversely, the red bees, when brought gradually closer to the hive, changed from wagging to circling in the 50-to-100-meter interval.

Thus it was clear that the dance at least told the bees whether the distance exceeded a certain value. It appeared unlikely, however, that the information conveyed was actually quite so vague, for bees often feed at distances up to two miles and presumably need more precise guidance. The wagging dance was therefore studied more closely. The rate of wagging is probably significant, but it is too rapid to follow. It was found, however, that the frequency of turns would give a fairly good indication of the distance. When the feeding place was 100 meters away, the bee made about 10 short turns in 15 seconds. To indicate a distance of 3.000 meters, it made only three long ones in the same time. A curve plotted from the average of performances by a number of bees shows that the number of turns varies regularly with the distance, although the correspondence is not very precise in individual cases.

How accurately do the bees respond to what is told them? This general problem can be studied by putting out, at various distances and directions from the hive, plates which are similar to the one carrying food but are charged only with the corresponding odor. An observer watches each plate and notes the number of bees visiting it during a suitable period. Von Frisch found in a typical experiment of this sort that the plates in the same general direction as the feeding place and at a considerable distance were visited by a large number of bees. One placed close to the hive was visited by very few and those in the opposite direction by practically none at all. It was evident that the dance must give information not only about distance, but also about direction. This was made abundantly clear by another experiment. The feeding table was placed in a certain direction and at four different distances in four trials of the experiment. Plates with the same odor were also laid out in the three other directions and in each case at nearly the same distance as the feeding place. At short distances (about 10 meters) the bees searched almost equally in all directions. But beginning at about 25 meters they evidently had some indication of the right direction, for the plate with food was visited by much larger numbers than the plates at the other points of the compass.

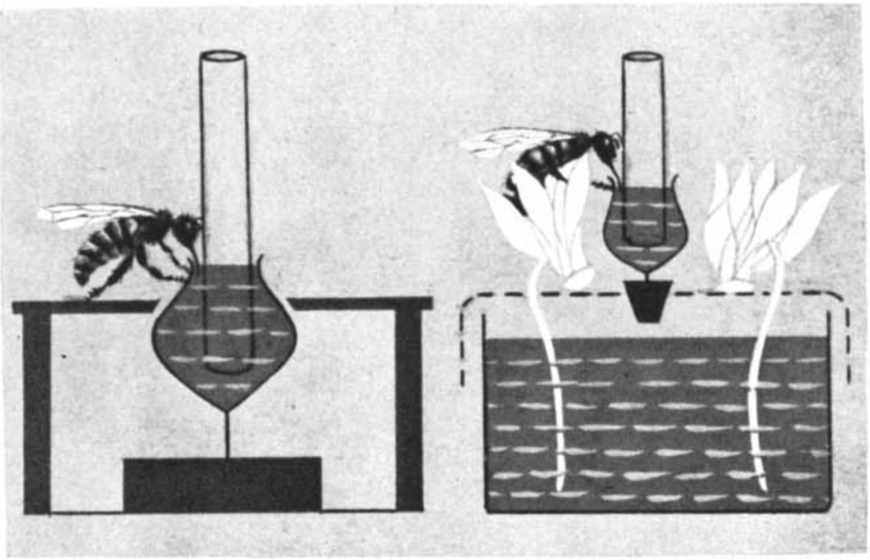
The indication of direction is often several (at least up to 10) degrees wrong, and the uncertainty regarding the distance also is appreciable. The searching bees are helped to find the right place by the odoriferous glands of their successful fellows, who send out into the air at the feeding place the odor which may be specific for each hive. (This odor may also serve as a kind of passport for the bees returning home. All bees having a foreign odor are attacked by the bees on watch at the entrance.)

How did the returning bees indicate to the other bees in the hive the direction of the feeding place? A key to the answer was given by the known fact that bees use the sun for orientation during flight. A bee caught far from the hive and liberated after a few minutes will fly straight back. But if it is kept in a dark box for a period, say an hour, it will go astray, because it continues to fly at the same angle to the sun's direction as when it was caught. Von Frisch deduced that the bee dance must signal direction in relation to the position of the sun. Obviously it is impossible to indicate a horizontal direction on a vertical surface like that of a honeycomb. By watching the dance, von Frisch discovered that the bees make a transposition to a gravity system and adopt the vertical as representing the horizontal direction toward the sun. When the sun, as seen from the beehive, is just above the feeding place, the straight part of the dance is vertical with the head up. When the feeding place is in the opposite direction, the straight part again is vertical, but with the head down. And when the food is not in line with the sun, the bee shows the horizontal angle between the sun and the feeding place by pointing at the same angle from the vertical on the honeycomb.

This indication of direction changes continuously throughout the day with the changing position of the sun, which is always represented on the vertical. The dance is normally performed in complete darkness within the hive, yet the bees, roused by, following and imitating the dancer, correctly interpret the signals to an accuracy within a few degrees. It can be observed without disturbing the bees in photographic red light, which is invisible to them.

In the special hive by which von Frisch first made these observations, curious deviations from the right direction were often shown by all the bees simultaneously. Recently von Frisch has found it possible to analyze these and attribute them to perturbations caused by light from the sky.

It is a very curious fact, for which no explanation has been found so far, that the position of the sun in the heavens is correctly used by the bees even when it is hidden behind an unbroken layer of clouds, and when in addition the hive is placed in surroundings totally unknown to the bees. This precaution is necessary because in territory that the bees know well they are experts in using landmarks. It appears possible that infrared rays from the sun, penetrating the clouds, may guide the bees. Experiments have shown that bees are not stimulated by heat rays as such, but the possibility cannot be excluded that the eyes of bees could be sensitive to near infrared although insensitive to visible red. This point has not so far been investigated for lack of a suitable light filter.



BEE FED NECTAR **without bodily contact (*left*) directs fellows to same scent, proving body surface is not only bearer of odors. Bee fed phlox nectar while sitting on cyclamen flowers (*right*) loses cyclamen odor on long flight.**

VON FRISCH has also undertaken some experiments to determine how the bees would cope with the problem of a mountain ridge or tall building which forced them to make a detour. He found that they would indicate the air-line direction from the hive to the feeding place, but would give the distance that they actually had to fly. One of the experiments of this type is interesting because the bees reacted in an unexpected way. The bees were carefully led by stages around a ridge about three hours' climb from von Frisch's house. The bees, however, soon found that they could save some distance (50 meters) by flying over the ridge instead of around it.

Von Frisch tells me that he himself considered some of these results so fantastic that he had to make sure that ordinary bees which had not been experimentally trained could also do the tricks. They could, and moreover he could see them work on honeycombs removed from the hive. In one such experiment he became curious to see what would happen if the honeycomb was put in a horizontal position instead of the vertical. To his surprise the bees responded by indicating the direction straight to the feeding place, and they kept on doing this even when the honeycomb was slowly rotated like a turntable. It looked as if the bees had a magnet in them and responded like a compass needle, but experiments showed them to be not the least affected by magnetic force. This method of pointing also takes place under natural conditions, the bees often performing horizontal dances in front of the entrance to the hive. It is known that bees in a swarm gathered in a clump on a branch sometimes perform dances on the surface, but it is not known whether this performance is intended to guide them to a suitable new residence.

On the other hand, experiments showed that on the underside of a horizontal surface the bees were unable to indicate any direction, and it turned out that their signals could also be easily disturbed in the shade. Von Frisch therefore decided to test directly their power of indicating direction on a horizontal surface in the dark. A movable chamber was built to enclose the observer and the observation hive. By photographic red light or even by diffuse white light in a tent, the bees proved unable to indicate any direction on a horizontal surface (although they can work with precision in the dark on a vertical one). They continually changed the direction indicated, but they were not restrained from dancing, and the stimulated bees, thoroughly confused, searched for food equally in all directions. The sun can be replaced in these experiments by any artificial light source of sufficient strength. But only if such a light is placed in the right direction, corresponding to that of the sun at the time, are the bees led toward the feeding place. Placed in any other position, the light will lead them astray.

Since the bees had proved able to give a correct indication of direction in several cases when the sun was not directly visible, the experiment was made of removing the north wall of the observation chamber, which allowed the bees to see only the sunless sky. In clear weather this proved sufficient to give them the correct orientation. Indeed, it was eventually found that when light from a blue sky came into the chamber through a tube 40 centimeters long and only 15 centimeters in diameter, this bare glimpse of the sky sufficed to orient the bees toward the sun's position. Light from a cloud, however, was without effect when seen through the tube, and sky light reflected by a mirror was misleading. The most probable explanation is that the bees are able to observe the direction of the polarized light from the sky and thereby infer the sun's position. This hypothesis has not so far been put to the test, as polarizing sheets were not available in Austria.

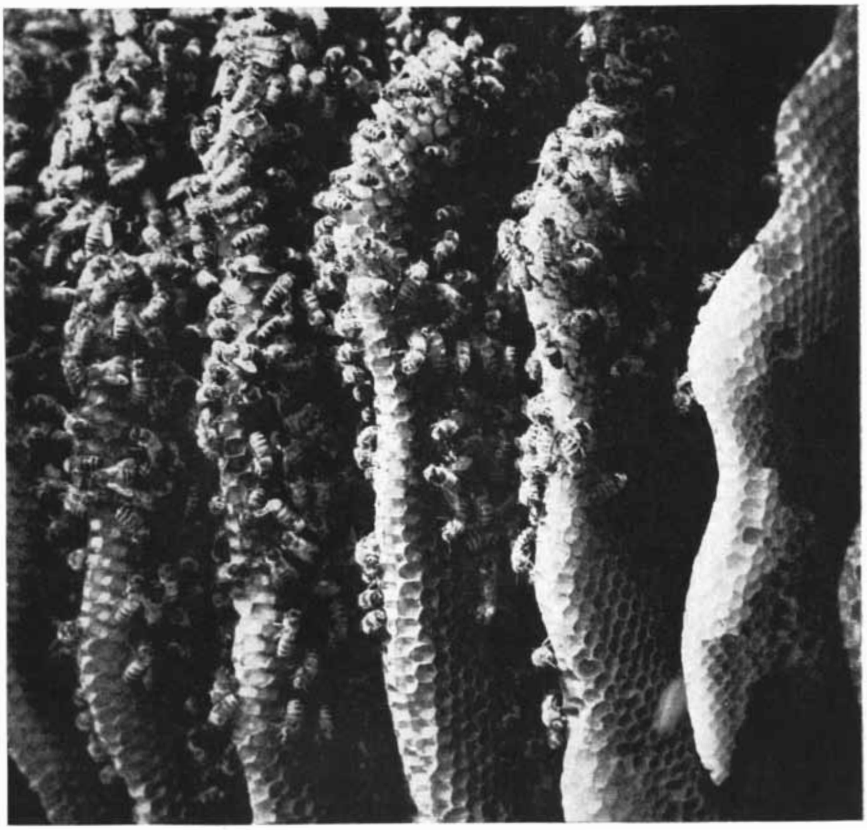
A SERIES of experiments made on inclined honeycombs showed a combined action of direct light and gravity, the result of which was, of course, a deviation from the true direction. Analysis of earlier experiments, in which light from the sky complicated the gravity reactions of bees on a vertical honeycomb, showed that the perturbations could all be quantitatively explained on the same basis.

I have tried to give a very condensed account of the principal results which von Frisch has so far obtained. This series of experiments constitutes a most beautiful example of what the human mind can accomplish by tireless effort on a very high level of intelligence. But I would ask you to give some thought also to the mind of the bees. I have no doubt that some will attempt to "explain" the performances of the bees as the result of reflexes and instincts. Such attempts will certainly contribute to our understanding, but for my part I find it difficult to assume that such perfection and flexibility in behavior can be reached without some kind of mental processes going on in the small heads of the bees.

Such processes may be, and probably are, very different from those taking place in the human brain. I would not venture to proclaim them as "thoughts" in the sense in which we use the word, but I do think that something is going on in the brain of the bee as well as in my own which cannot be reduced to the terms of matter and movement.

August Krogh, winner of the Nobel Prize for Physiology and Medicine in 1920, is professor emeritus of zoophysiology at the University of Copenhagen.

LONE BEE ALIGHTS on a rose to gather pollen and nectar to take back to the hive. Bees sometimes forage as much as two miles away from the hive, yet they are still able to direct other bees accurately to the same flowers.



BEES CLUSTER on the vertical comb surfaces of the hive. It is here that they perform their dance. The movements which convey the direction of pollen and nectar are transposed from the horizontal to a vertical system.

A.A.A.S. Centennial

ON September 13, some 7,000 scientists will gather in Washington for a four-day meeting to observe the centennial of the No. 1 American scientific organization, the American Association for the Advancement of Science. At its first meeting in 1848, officers reported that the A.A.A.S. had 461 members; now it has 50,000 and is growing at the rate of several thousand a year.

The "Triple-A.S." will mark its 100th birthday with an unusual kind of meeting. Ordinarily scientific gatherings are built around the presentation of papers reporting individual researches. As the number of participating scientists and the volume of research have grown, meetings have become more and more unwieldy; the A.A.A.S. assembly in Chicago last Christmas was a grueling marathon of hundreds of papers. For its centennial, the association is inaugurating what it hopes will become a new pattern for scientific meetings. Instead of technical reports, its members will hear outstanding scientists from different fields bring their specialties to bear on common scientific problems in carefully planned symposia and prepared addresses. The 15 symposia and 12 prepared addresses scheduled for its birthday party will, it is hoped, start the A.A.A.S. into its second century with a well-balanced report from key outposts on the endless frontier of science.

Selective Service

SCIENTISTS, advanced science students and doctors are practically exempt from military service under the new peacetime draft law. Although Selective Service headquarters, at the time of going to press, had not yet spelled out how the relevant provisions are to be applied, deferment is clearly indicated for most of the advanced science students and professional researchers who fall within the draft ages (19 to 25). Moreover, a section which would have permitted the drafting of doctors up to the age of 45 was dropped from the bill as it made its final trip through Congress.

In addition to a strong statement in the preamble on the importance of research to the national safety and welfare, the draft law contains this provision: "The President is authorized, under such rules and regulations as he may prescribe, to provide for the deferment from training and service . . . in the armed forces of the United States of any or all categories of persons . . . whose activity in study, research, or medical, scientific, or other endeavor is found to be necessary to the maintenance of the national health, safety, or interest; provided, that no person within any such category shall be deferred except upon the basis of his individual status." In another section, advanced science students are exempt from the provision permitting deferment of college and university students only to the end of the academic year.

When the new Selective Service measure was first introduced into Congress, doctors up to 45 years of age were included at the request of the Army. The Army has been short of medical personnel since demobilization and feared that it would not be able to meet the medical needs of the larger army to be recruited through Selective Service. The rejection of the medical draft will compel the Army to step up its appeal for doctor-volunteers and to recall more of the young doctors who were trained at Army expense during the war and who, in return, were required to accept reserve commissions.

AEC Compromise

AS the result of a last-minute Congressional compromise, the present members of the Atomic Energy Commission will continue in office until June 30, 1950. Early this spring, President Truman nominated AEC Chairman David Lilienthal and his colleagues, whose terms were to expire August 1, to new terms varying in length from one to five years, as specified in the Atomic Energy Act of 1946. The resolutions confirming the appointments were buried by the Senate. Instead, in the last hours before adjournment Congress passed a compromise resolution extending the old terms of the AEC's members for two years. On July 3 President Truman signed the resolution because the present commissioners would otherwise have had only temporary status after August 1 and "because the nation's vital interest in atomic energy requires even the limited continuity of leadership which this measure will allow."

In the case of another amendment to the Atomic Energy Act, the President was successful in registering his objection. During its final weeks, Congress passed and sent to the White House a resolution permitting Senate members of the Joint Congressional Atomic Energy Committee to obtain FBI reports on nominees to the Commission. The President claimed that the resolution was unconstitutional and vetoed it. His veto was sustained.

Owing to a budget cut initiated by the House, the AEC will have some $10 to $20 million less than was anticipated for basic research during the current fiscal year. In his original budget message, the President had asked for $550 million for the Commission, including $90 million for research and development. This was reduced to $512 million by Congress. About $10 to $20 million of the reduction, by Congressional recommendation, is to be taken from research and development, but not from research on weapons, or on biology and medicine. Thus the cut will fall largely on basic research projects.

WHO

THE World Health Organization, which has just wound up a five-week World Health Assembly in Geneva, has provided a rare gesture of Soviet deference to the U.S.

In ratifying the charter of the WHO, Congress made several reservations, one of which—the right to withdraw on a year's notice—raised a question as to American eligibility for WHO membership. Nonetheless, the U.S. was unanimously voted in last month by the Assembly on a motion by the chief Soviet delegate, Dr. N. A. Vinogradov.

Both the U.S. and the U.S.S.R. were elected by the Assembly to the 18-nation WHO executive board. As WHO president, the Assembly unanimously chose Dr. Andrija Stampar of Yugoslavia, rector and professor of public health and social medicine at the University of Zagreb, who had served as head of the Interim Commission that paved the way for the new international health agency.

WHO's permanent headquarters will be in Geneva. Regional offices will be established in five areas particularly in need of international health assistance—the eastern Mediterranean, western Pacific, southeast Asia, and Africa. Latin America will be integrated into the WHO regional organization by affiliation of the Pan American Sanitary Bureau.

Graded Hospitals

IN order to provide modern specialized hospital services to residents of smaller cities and rural areas—one of the most urgent of the world's current medical problems—the hospitals of Sweden 15 years ago were organized into a graded system around metropolitan medical centers. The State of Maine four years later instituted a similar plan. The system has been so successful in both Sweden and Maine that it has now been adopted by New York State. This fall New York begins construction of facilities for 54,000 new hospital beds under a five-year, $750 million program to be financed by Federal. state, local and private funds. As they are finished, the new facilities will band together with existing public and private hospitals capable of meeting modern medical standards in seven regional groups. The base of each group will be a score or more of 50-bed community hospitals—at least one within 15 miles of any resident of the state—able to give certain types of care; over the community hospitals will be more completely equipped 100-bed district hospitals; and over them, metropolitan medical centers equipped for the most elaborate diagnostic procedures and care, and also able to serve as teaching hospitals. The plan, which was drawn up by the state's Joint Hospital Survey and Planning Commission, has the backing of every branch of medicine in the state.

Underground Gasification

LATE this fall. the U. S. Bureau of Mines and the Alabama Power Company will conduct another experiment in the underground gasification of coal. a process that holds the alluring promise of producing power from coal without mining it.

Three generations ago, Sir William Siemens suggested that coal need not be mined to produce power. Siemens thought that the combustion processes whereby illuminating gas is made could be carried out underground. Nothing came of Siemens' proposal until the 1930s, when several underground gasification units were built in Russia. Similar experiments have also just been started in England and Belgium.

The first American underground gasification test was conducted last year by the Bureau of Mines and the Alabama Power Company in a small, isolated seam of coal near Gorgas, Ala. The test was generally successful, though the use of too small a seam held down the heating value of the product gas. This year, a larger, deeper seam is to be employed, with the hope of producing a "synthesis gas" suitable for synthetic gasoline manufacture, as well as a heating gas that compares favorably with industrial fuel gas.

Commercial exploitation of underground gasification is still some years away. Effective development of the process. however, might ultimately have a revolutionary effect on the world economy. Besides lowering the cost of synthesis and industrial fuel gases, it might make possible the use of coal deposits too poor to be worked by conventional methods and, most important, free several million men from the hard, dangerous task of digging coal.

Foreign Students

MORE than 20.000 foreign students, a record number, attended U.S. colleges and universities during the 1947-48 academic year. An even larger number is expected to register when the fall semester begins next month.

The rise in foreign attendance at American schools has come about despite the shortage of dollars abroad and despite the fact that only one of the three U.S. Government programs for assisting foreign students is actually in operation. Since 1943, Congress has enacted: 1) a law providing for exchanges with Latin America; 2) the Fulbright Act, under which exchanges are to be financed by the sale of American war surplus abroad; 3) the Smith-Mundt Act, which authorizes exchanges as part of the "Voice of America" program for promoting the U.S. abroad. So far. only the Latin American program, which is limited to a few hundred students a year. has made a real start. The Fulbright program has been delayed by the necessity for complex preliminary international negotiations and the Smith-Mundt program by Congress' failure to appropriate funds.

As a result virtually all foreign students now here are being financed with foreign-owned dollars. Since the latter are scarce, their studies represent a genuine sacrifice on the part of their nations—and a tribute to American education, particularly in the sciences and professions, which, it is hardly necessary to point out, are the visitors' main concern. The largest number of students, over 5,000, come from Asia. Latin Americans are in second place.

Meetings in September

AMERICAN Chemical Society, 114th National Meeting. Eastern session, Washington, D.C., August 30-September 3; Midwest session, St. Louis, Mo., September 6-10; Western session, Portland, Ore., September 13-17.

American Institute of Biological Sciences (the new federation embracing the American Society of Zoologists and other biological societies). National meeting. Washington, D.C., September 10-13.

American Association for the Advancement of Science. Centennial meeting (*see above*). Washington, D.C., September 13-17.

PHOTOSYNTHESIS

Life's essential process, performed by stately trees and microscopic algae, is imperfectly understood. But the problem is slowly yielding to a concerted attack

by Eugene I. Rabinowitch

MAN is monarch of the animal kingdom, in aggregate bulk outweighing all other animals except fishes, yet even man is less self-sufficient than the poorest weed in the field. Physiologically speaking, all the animals on land and in the sea, including man, are but a small brood of parasites living off the great body of the plant kingdom. If plants could express themselves, they would probably have the same low opinion of animals as we have of fleas and tapeworms—organisms that must lazily depend on others for survival.

We cannot conceive of life existing on the earth or any other planet without plants; our main reason for suspecting that there is life on Mars is the alleged green coloration of certain parts of that planet. So far as we know, green plants alone are able to produce the stuff of life—proteins, sugars, fats—from stable inorganic materials with no other help but the abundantly flowing light of the sun. This is the process called photosynthesis. Scientists have not been able to imitate it in the laboratory, even on a microscopic scale. But stately green trees and microscopic diatoms alike achieve it every day on a gigantic scale. Each year the plants of the earth combine about 150 billion tons of carbon with 25 billion tons of hydrogen, and set free 400 billion tons of oxygen. Few are aware, incidentally, that perhaps as much as 90 per cent of this giant chemical industry is carried on under the surface of the ocean by microscopic algae. Only 10 per cent of it is conducted on land by our familiar green plants.

A tiny fraction of the organic material synthesized by plants is later utilized as food by animals. A much larger amount is used in the respiration and other life activities of the plants themselves. The greatest part, however, is decomposed into water, carbon dioxide and mineral salts by the decay of leaves and dead plants on land and in the sea. Under certain geologic or climatic conditions the decay is halted. Huge masses of half-decayed plant material then accumulate for millions of years under a protective layer of rock or silt, eventually to become peat or coal.

CHLORELLA, the common green alga, is a favorite study of photosynthesis researchers. Here it is grown in flasks at University of Illinois.

In endlessly repeated cycles the atoms of carbon, oxygen, and hydrogen come from the atmosphere and the hydrosphere (the world sea) into the biosphere (the thin layer of living things on the earth surface and in the upper part of the ocean). After a tour of duty which may last seconds or millions of years in the unstable organic world, they return to the stable equilibrium of inorganic nature.

The organizations of atoms in the biosphere are distinguished from those of the inorganic world by two characteristics: chemical complexity and high energy content. In the inorganic state they are simple molecules of carbon dioxide (CO_2), water (H_2O), carbonic acid (H_2CO_3), carbonate and bicarbonate ions (CO_3^{--} and HCO_3^-). In striking contrast is the complexity of even the simplest organic compounds, such as glucose ($C_6H_{12}O_6$)—not to speak of the enormous and intricate structures which are the molecules of proteins. It is this complexity that permits the almost infinite variability of organic matter. One thing, however, all the multifarious organic molecules have in common: they are all combustible, *i.e.*, they have an affinity for oxygen. When oxidized, they release an average of about 100 kilocalories of heat for each 10 grams of carbon they contain. Thus all organic matter contains a considerable amount of "free" energy, available for conversion into mechanical motion, heat, electricity or light by gradual or sudden combination with oxygen. Such oxidations are the mainspring of life; without them, no heart could beat, no plant could grow upward defying gravity, no amoeba could swim, no sensation could speed along a nerve, no thought could flash in the human brain. Certain lower organisms can exist using sources of chemical energy not involving free oxygen, such as fermentation, but these are "exceptions that prove the rule."

Photosynthesis by plants is the process by which matter is brought up from the simplicity and inertness of the inorganic world to the complexity and reactivity that are the essence of life. The process is not only a marvel of synthetic chemical skill, but also a *tour de force* of power engineering. When plant physiologists and organic chemists study photosynthesis, they are struck most of all by the feat of manufacturing sugar from carbon dioxide and water. When physicists or photochemists contemplate the same phenomenon, they are awed and intrigued by the conversion of stable, chemically inert matter into unstable, energy-rich forms by means of visible light.

Not only are scientists unable to duplicate photosynthesis outside the living plant cell; they do not know of any halfway efficient method of converting light energy into chemical energy. If we knew the chemical secret of photosynthesis, we could perhaps by-pass plants as food producers and make sugar directly from carbonates and water. If we knew its physical secret, we could perhaps by-pass the "storage-battery" function of plants and produce chemical or electrical energy directly from sunlight. We might decompose water, for example, into an explosive mixture of hydrogen and oxygen that could be used as a source of heat or power.

Historical Beginnings

The story of the little we know about photosynthesis begins with Joseph Priestley, who announced in 1772:

"I have been so happy as by accident to hit upon a method of restoring air which has been injured by the burning of candles and to have discovered at least one of the restoratives which Nature employs for this purpose. It is vegetation. One might have imagined that since common air is necessary to vegetable as well as to animal life, both plants and animals had affected it in the same manner; and I own that I had that expectation when I first put a sprig of mint into a glass jar standing inverted in a vessel of water; but when it had continued growing there for some months, I found that the air would neither extinguish a candle, nor was it at all inconvenient to a mouse which I put into it."

In these words Priestley, religious re-

ENDLESS CYCLE of the element carbon in photosynthesis is really two meshed cycles. Perhaps 90 per cent of all photosynthesis is carried out in the sea by algae, which utilize atmospheric carbon dioxide (CO_2) dissolved in water as carbonate ions (HCO_3^-). Algae return carbon dioxide to the atmosphere by respiration and decay. In respiration, plants reverse photosynthesis, absorbing oxygen and releasing carbon dioxide. All fishes live basically on algae. Some fishes are eaten by man, who returns their carbon to the atmosphere by exhaling carbon dioxide. Land plants take in carbon dioxide and release it largely in decay and respiration. Animals, eating plants and other animals, also return plant carbon to the atmosphere. Industrial combustion releases carbon dioxide by burning coal and oil, which contain plant or animal carbon that has been stored in the earth from geologic past.

former, philosopher and spare-time naturalist of the Age of Enlightenment, described one of the most momentous observations in the history of experimental biology: the discovery of the capacity of plants to produce free oxygen.

Seven years later Jan Ingen-Housz, Dutch physician to the Austrian Empress Maria Theresa, noticed another aspect of the same phenomenon. Ingen-Housz wrote in 1779:

"*I observed that plants not only have a faculty to correct bad air in six or ten days by growing in it, as the experiments of Dr. Priestley indicate, but that they perform this important office in a complete manner in a few hours; that this wonderful operation is by no means owing to the vegetation of the plant, but to the influence of the light of the sun upon the plant. . . . I found that this operation of the plants is more or less brisk in proportion to the clearness of the day and the exposition of the plants; diminishes towards the close of the day, and ceases entirely at sunset; that this office is not performed by the whole plant, but only by the leaves and the green stalks. . . .*"

Thus was discovered the necessity to photosynthesis of light and of the green pigment chlorophyll. In 1782 a Geneva pastor named Jean Senebier added another important requirement: "fixed air" (carbon dioxide). Only three cubic centimeters of carbon dioxide is present in 10 liters of air, but take this small amount away and all oxygen production in light will stop.

The old and persistent theory of "humus nutrition" of plants (even now many still believe that "good, black earth" provides plants with organic nutrients, though in truth it supplies only inorganic minerals) had been shaken a hundred years earlier when the Flemish physician and chemist Jan van Helmont grew a large tree in a bucket of earth. The weight of the earth was not lessened by an ounce. The theory was now ripe for a final overturn. The discoveries of Priestley, Ingen-Housz and Senebier, interpreted in the new chemical language of Antoine Lavoisier, indicated that green plants exposed to light absorbed carbon dioxide and liberated oxygen. An inevitable question arose: what did they do with the other constituent of carbon dioxide—carbon? In 1796 Ingen-Housz supplied the correct answer: the carbon, he said, is the basis of plant nutrition; in other words, photosynthesis is not merely "epuration of air" for the benefit of animals and man, but first of all carbon assimilation for the benefit of the plants themselves.

An important ingredient in the chemistry of photosynthesis was still missing; the omission was corrected in 1804 by another citizen of the learned city of Geneva, Nicolas Theodore de Saussure. He found that in addition to carbon dioxide, water also enters into the photosynthetic production of organic matter:

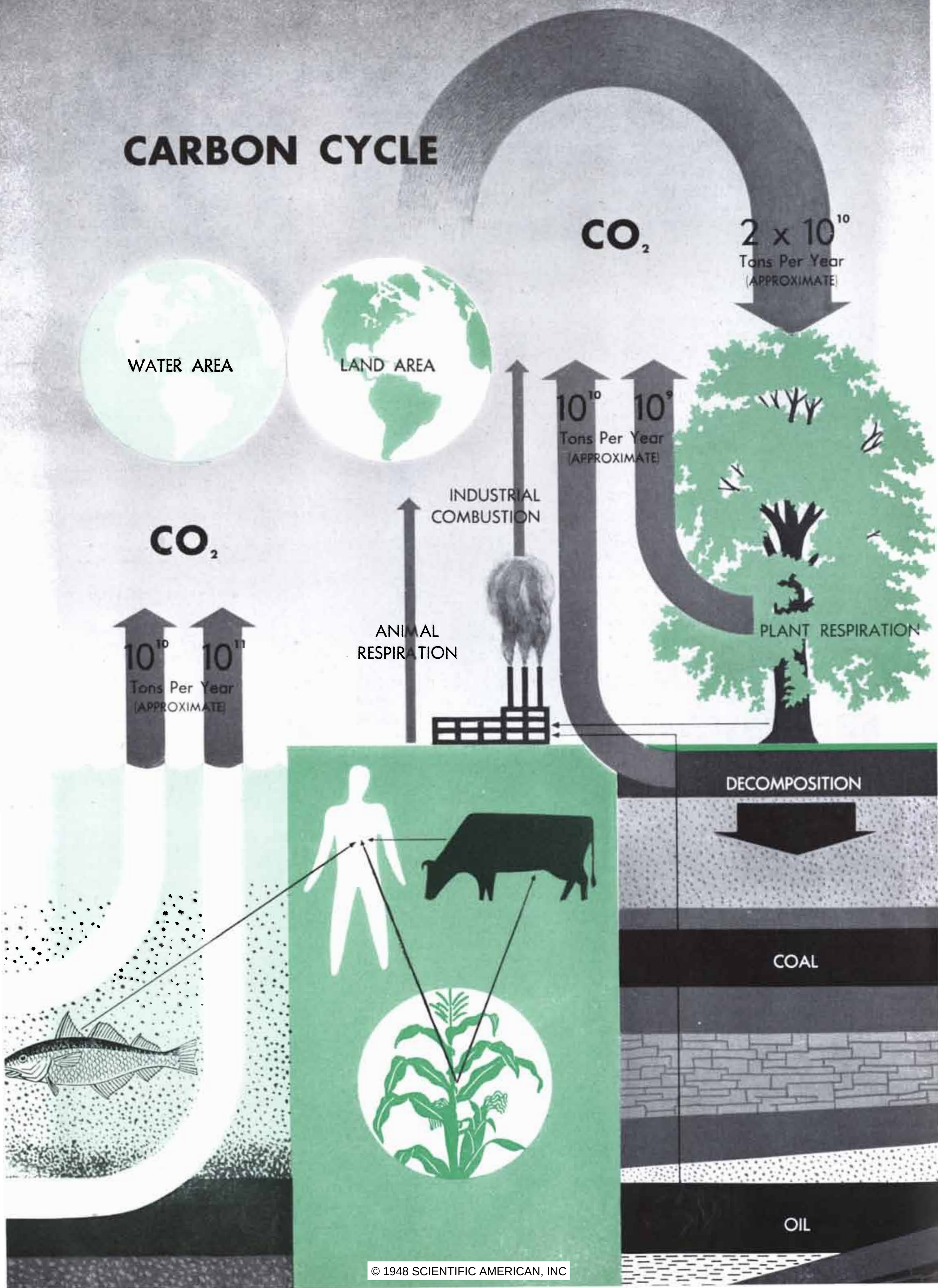
$$\text{Carbon dioxide} + \text{water} \xrightarrow[\text{light}]{\text{green plants}} \text{organic matter} + \text{oxygen.}$$

In the absence of light, or in parts of the plant that are not green, the process is reversed: respiration of the plant produces water and carbon dioxide from organic matter and oxygen.

Thus by about 1800 a general chemical definition of photosynthesis was established except for one detail—the recognition that the organic matter manufactured in photosynthesis is a carbohydrate. This class of compounds is made up of carbon combined with hydrogen and oxygen in the same ratio as in water. In the chemist's shorthand, carbohydrates may be written $C_m(H_2O)_n$. All sugars, as well as starch and cellulose, are carbohydrates. The conclusion that a compound of this type must be the first product of photosynthesis was reached by plant physiologists in about 1850, on the basis of quantitative determinations of the amounts of carbon dioxide and oxygen exchanged in photosynthesis and of qualitative observations of the formation of starch in illuminated leaves.

It was Julius Robert von Mayer, the German discoverer of the principle of conservation of energy, who first remarked the fundamental physical function of photosynthesis—the conversion of light energy into chemical energy. He wrote in 1845:

"*Nature set herself the task to catch in flight the light streaming towards the earth, and to store this, the most evasive of all forces, by converting it into an immobile form. To achieve this, she has covered the earth's crust with organisms, which while living take up the sunlight and use its force to add continuously to a sum of chemical difference.*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(APPROXIMATE)
WATER AREA
LAND AREA
10^{10} 10^{9}
Tons Per Year
(APPROXIMATE)
INDUSTRIAL
COMBUSTION
CO_2
ANIMAL
RESPIRATION
PLANT RESPIRATION
10^{10} 10^{11}
Tons Per Year
(APPROXIMATE)
DECOMPOSITION
COAL
OIL

"These organisms are the plants: the plant world forms a reservoir in which the volatile sun rays are fixed and ingeniously laid down for later use; a providential economic measure, to which the very physical existence of the human race is inexorably bound."

With this perception it became clear that photosynthesis by green plants, in addition to being the only ultimate source of food on earth, also is the only source of animal energy. And indirectly, through the use of wood, coal and peat, photosynthesis is the source of most of our industrial power, heat and light; indeed of all the energy requirements of modern civilization except those met by water power and nuclear disintegrations.

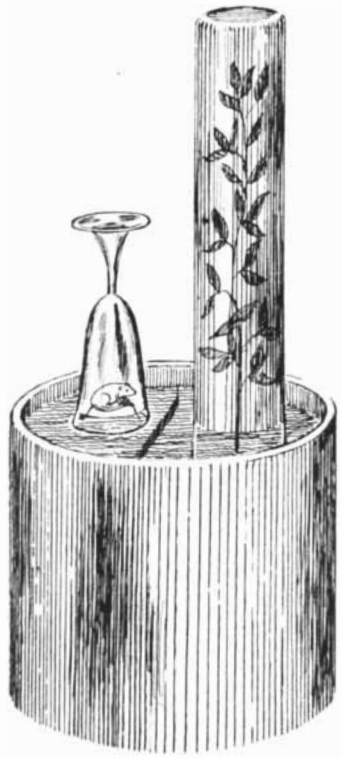
The Challenge Today

Since the discoveries of Priestley, Ingen-Housz, Senebier and Mayer, hundreds of botanists, chemists and physicists have studied photosynthesis. Thousands of papers have been published on its different aspects. And yet we still do not understand photosynthesis as it occurs in the plant—a vexing situation and a continuing challenge.

The biochemist feels that he "understands" a chemical process in the living cell if he knows its successive stages, the intermediate compounds that are formed and the enzymes (biological catalysts) that make the individual stages possible. This knowledge he achieves by taking the biochemical apparatus apart and putting it together again. His ultimate aim is to imitate a biochemical process, such as respiration or conversion of carbohydrates to fats, in the laboratory and to describe each step in detail by chemical equations. Our knowledge of metabolic reactions is rarely so complete, but often we know at least the main stages and can repeat them outside the living cell. We know, for example, the first steps in the breakdown of glucose by animal respiration. They are the formation of a molecule of glucose diphosphate which is then split into two molecules of a triose monophosphate; we know the enzymes involved and can repeat these reactions outside the living cell. It is true that we do not really understand the mechanism by which enzymes produce their characteristic effects, but this is a more advanced problem, the study of which comes after the elucidation of the reaction steps and identification of their enzymes.

In the case of photosynthesis, we know very little about the individual reaction steps and even less about the catalysts which make them possible. We can prepare extracts from plant cells containing chlorophyll or other pigments that are present wherever photosynthesis goes on. But not only are these extracts incapable of photosynthesis (here simply utilizing carbon dioxide and producing oxygen in light), but also we cannot find in them any catalytic or photochemical properties clearly related to the probable steps in photosynthesis. We may then decide that chemical methods of fractionating the plant-cell contents are too drastic, and attempt to take the cell apart mechanically. We take a giant green cell, such as that of some algae, and prick it with a needle in an attempt to reach its interior. Immediately photosynthesis ceases. The cell still respires, it is alive, but oxygen liberation and carbon dioxide absorption have stopped.

Thus we find ourselves in the position of being asked to find out how an automobile motor operates without being permitted to lift the hood. We see that the engine consumes carbon dioxide and water and produces an exhaust gas and chemical energy. We can look at the instrument board and note how the rate of the motor's revolution depends on the supply of fuel, the temperature of the coolant and other external factors, but there is not much hope that we shall ever find out from such circumstantial evidence how the motor is constructed and what chemical reactions take place in the cylinders.



PRIESTLEY grew mint in a tube and piped air from tube to a mouse. When mouse lived, he had proved plants have power to "restore" air.

This was the situation in the study of photosynthesis until quite recently. There was no known possibility of dismantling the biochemical apparatus and studying its parts separately. It was an "all or nothing" situation: at one moment we had a living cell engaged in complete photosynthesis; at the next it was an agglomeration of broken parts or isolated chemical components, with no indications of what role, if any, they had played in photosynthesis while the cell was whole and alive.

Within the last few years the situation has changed. The problem looks less forbidding. Some progress has come from an improved general understanding of the mechanism of chemical, in particular photochemical, reactions. Some has come from the improvement of old experimental methods and the development of new ones: exact analysis by electrochemical and pressure-measuring devices, the use of radioactive tracers, quantitative spectrophotometry. None of these methods, not even the glamorous radioactive tracers, provides an immediate solution to the secrets of photosynthesis, but all of them together promise progress toward the understanding of photosynthesis *in vivo* and its imitation *in vitro*. Beyond these two achievements there beckon grandiose technological goals: synthetic production of organic materials and the unlimited supply of useful energy from sunlight without the help of plants.

Light and Dark Reactions

From measurements of the rate of photosynthesis under different conditions, the English plant physiologist F. F. Blackman concluded as early as 1905 that photosynthesis is not a single photochemical reaction, but must include at least one "dark" reaction (one which is not affected by light). As the intensity of illumination is increased, the rate of photosynthesis (as measured, for example, by the volume of oxygen produced each minute) does not increase indefinitely but approaches a saturation state in which a further increase of light intensity has no effect. This suggests a two-stage process in which only one stage can be accelerated by light. The reasoning may be illustrated by the following analogy. If a million men are to be transported overseas in two stages—first by train to the harbor and then by ship to their destination—the provision of more and faster trains will accelerate the transportation only up to the point where all available ships are used to capacity. Thereafter the further improvement of rail transportation merely jams up the harbor. Conversely, it will serve no useful purpose to provide more ships than can be filled by the arriving trainloads. In photosynthesis there is a stage or stages accelerated by light (corresponding to the railroad journey), and another stage or stages independent of light (the ship voyage). The rate of the latter may depend on how many enzyme molecules—equivalent to ships—are available in the plant cell. It is useless to accelerate the light reaction beyond the capacity of dark reactions to transform the products of the light reaction.

The division of photosynthesis into a photochemical stage and a dark one is brought out clearly by experiments with flashing light. After a plant is exposed to a brief light flash lasting, say, for .0001 second. the liberation of oxygen continues in the dark for about .02 second; more exactly. a dark interval of about .02 second is necessary to obtain the maximum oxygen production per flash. The experiment measures directly the time required for the completion of the slowest dark reaction in photosynthesis. It is equivalent to the time our ships need to complete the ocean crossing and return to the harbor. It has also been found that there is a limit to the amount of photosynthesis that can be brought about by a single light flash: the maximum yield is about one molecule of oxygen for 2.000 molecules of chlorophyll present in the cell. This is surprising. One would expect that during a short flash each chlorophyll molecule would have a chance to perform its function once, producing one molecule of an intermediate product. Consequently the maximum production would be one molecule of oxygen for each chlorophyll molecule. or for a small number of them. James Franck of the University of Chicago suggested an explanation of the paradox: the maximum yield per flash depends not on the number of chlorophyll molecules but on the number of molecules of the enzyme involved in the second stage (*i.e.*. on the number of ship berths, rather than train berths). In other words, the flash can produce as many intermediate molecules as there are chlorophyll molecules, but comparatively few of them will succeed in completing the subsequent dark stage to produce oxygen.

But why cannot the intermediates wait at the harbor while ships (the catalytic enzymes) ferry some to the other shore and return for a second. third or fourth load? Franck's explanation is that the intermediate photoproducts are unstable. Unless they are immediately processed by a "finishing" catalyst. they disappear by "back reactions" before the catalyst is ready for a second load (as if the soldiers. unwilling to wait. all went AWOL and drifted back to their home towns).

Thus we have the following outline of photosynthesis. It consists of a light stage and a dark stage. The light stage produces unstable intermediates; the dark stage stabilizes them by conversion into the final products, oxygen and carbohydrate. The rate of photosynthesis is limited by the bottleneck of a dark reaction which can process only one molecule. or at most a small number of molecules. of intermediates per 2.000 molecules of chlorophyll each .02 second.

The Use of Light Energy

From our general knowledge of the nature of chemical reactions, particularly those involved in metabolic processes. we can make a guess as to the probable nature of the light stage in photosynthesis. Plant respiration, the reverse of photosynthesis, involves two types of reactions: those which break the carbon chains in the large organic molecules, and those which remove hydrogen atoms from association with carbon and, with the catalytic help of enzymes, transfer them to oxygen, thus forming water. In photosynthesis the same two types of processes must be involved, but running in the opposite direction—the transfer of hydrogen from water to carbon dioxide, and the building of carbon chains. Of these two types of reactions, the transfer of hydrogen is the one that *liberates* energy in respiration, hence this must be the one that *stores* energy in photosynthesis. The energy that is stored comes from light. Consequently the light reaction in photosynthesis in all probability is a hydrogen transfer from oxygen to carbon "against the gradient of chemical potential," meaning from a more stable to a less stable form. To use a mechanical picture, in respiration the hydrogen atoms run downhill; in photosynthesis, the impact of light quanta (discrete "atoms" of light), absorbed by chlorophyll, sends them uphill.

VAN HELMONT, by growing a tree in a bucket, showed that plants take little of their substance from earth. Weight of the earth was unchanged.

Let us illustrate this reversible process by mixing a solution of the dyestuff thionine with a solution of ferrous sulfate. In intense light, the color of the dye disappears in a second or less; in the dark, the color immediately returns. This is an example of how an oxidation-reduction reaction can run in one direction in the dark and in the opposite direction in light. In light, ferrous iron reduces the dye to a colorless form and is itself oxidized to ferric iron; in the dark, ferric iron oxidizes the dye back to the colored form and is reduced to ferrous iron. A reaction of this type must be involved as the primary light reaction in photosynthesis, the fundamental difference being that the plant is provided with an enzymatic mechanism which efficiently prevents any back reaction in the dark—as long as the unstable light products are not supplied too fast.

The energy content of the final products of photosynthesis—sugar and oxygen—is well known; it is represented by the amount of heat produced when sugar is burned to carbon dioxide and water. The energy is 112 kilocalories per gram atom (one gram multiplied by an element's atomic weight) of carbon. This, then, is the minimum energy that has to be supplied by light in photosynthesis. To reduce (hydrogenate) a molecule of carbon dioxide to the "reduction level" of sugar, four hydrogen atoms must be transferred to the molecule:

$$CO_2 + 4H \longrightarrow C(H_2O)_2$$

To move these hydrogen atoms "uphill" from water to carbon dioxide. each of the four atoms must receive a push equivalent to at least one fourth of 112 kilocalories. or 27 kilocalories per gram atom of hydrogen. These pushes must be supplied by light.

Niels Bohr and Albert Einstein showed in 1913 that light is absorbed by atoms or molecules in the form of quanta of definite energy content. which is proportional to the wavelength of the light. Red light, which is strongly absorbed by chlorophyll, has quanta with an energy content such that it provides about 40 kilocalories per gram atom of the absorbing atoms. Obviously one such quantum is not enough to transfer four hydrogen atoms (requiring 112 kilocalories). Could it be done with four quanta—one quantum for each hydrogen atom? Even this would be a marvelous achievement: the plants would have absorbed 160 kilocalories of light energy and stored 112 kilocalories as chemical energy—an efficiency of 70 per cent.

IN 1923 Otto Warburg, the German cell biologist, first attempted to measure the "quantum yield" of photosynthesis—the number of quanta required to reduce one molecule of carbon dioxide. This implied measuring exactly the light energy absorbed and the volume of oxygen produced. In order to obtain the maximum possible yield, it was advisable to work in very weak light to avoid saturation effects. The measurements therefore were very delicate. The results were striking: Warburg found an absorption of four quanta per molecule of oxygen! This corresponded with the minimum value theoretically plausible, and implied an extraordinary efficiency of plants as energy converters.

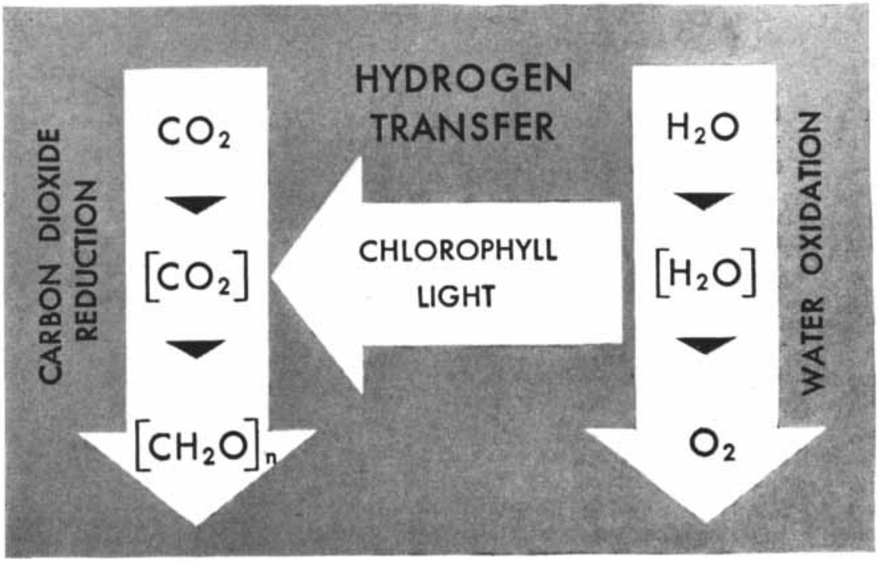
Warburg's result, however, did not remain unchallenged. Other groups of researchers were unable to confirm Warburg's observations. Instead they found yields of about 10 quanta per oxygen molecule; some values were as low as eight, but none was lower. The question is still unsettled; the weight of evidence favors the higher value: eight or more quanta per molecule of oxygen. Even at this value, however, the 35 per cent yield in energy conversion by plants is very respectable—considering that we do not know of any reaction produced by visible light *outside* the plant cell which would convert as much as 10 per cent of absorbed light into chemical energy. If some economical means could be found to capture and convert even 10 per cent of light energy, the discovery conceivably could produce a greater revoluton in our power economy than can be expected at present from the much-publicized discovery of atomic energy.

One plausible picture of how chlorophyll may use eight light quanta to move four hydrogen atoms from water to carbon dioxide is this: A chlorophyll molecule absorbs a quantum and is raised to an "excited," energy-rich state. It is then able to pull a hydrogen atom away from water (or from a product derived from water by a dark, enzymatic reaction). In this reduced form, chlorophyll takes up another light quantum and uses its energy to force the same hydrogen atom on a reluctant "acceptor," such as carbon dioxide or a compound derived from carbon dioxide by a dark reaction. It is as if a workman, suspended halfway on the face of a building, fortified himself with a drink, hauled a construction piece up from the ground, and then, fortified with a second drink, threw this piece up to the roof.

Chlorophyll and Other Pigments

It has long been assumed that chlorophyll is the only agent that can perform this trick. It has been well known that all green plants also contain yellow or orange pigments (carotenoids, identical or similar to the pigments of carrots and egg yolk), and that many algae contain red or purple pigments. But all plants capable of photosynthesis were found to contain chlorophyll, and chlorophyll alone among the plant pigments absorbs red light. Since photosynthesis proceeds satisfactorily in pure red light, light absorption by chlorophyll must be *sufficient* to bring about photosynthesis, and from that experimental fact there is only a short step to the assumption that it is the *necessary* prerequisite.

Recently, however, the position of chlorophyll has been challenged. First, indications were found that the light energy absorbed by the yellow pigments also is utilized in photosynthesis. Then at the meeting of the American Association for the Advancement of Science in Chicago last December, L. R. Blinks of Stanford University presented evidence that in some red algae the light absorbed by red pigments is more effective in photosynthesis than the light absorbed by chlorophyll. If this is confirmed, the red pigments must be assumed to participate in photosynthesis directly, and not merely as handmaidens of chlorophyll. To appreciate the importance of this observation, you must remember it is estimated that 90 per cent of photosynthesis on earth is carried out, not by green land plants, but by the multicolored sea algae.



PHOTOSYNTHESIS IS OUTLINED in diagram shaped like the letter H. On vertical leg at right, water gives up hydrogen, releasing oxygen. Hydrogen is then transferred to carbon dioxide by agency of light and chlorophyll. Reduction (hydrogenation) of carbon dioxide produces carbohydrate (*bottom of left leg*). Intermediate steps and compounds (*bracketed*) are unresolved.

by its dehydrogenation in light, and then the enzymatic conversion of the residue into free oxygen, perhaps through the intermediate formation of a peroxide, similar to but apparently not identical with hydrogen peroxide.

The Uses of Isotopes

Some of these reactions are now being studied with the help of isotopic tracers. We are concerned with the fate of three kinds of atoms—hydrogen, carbon, oxygen. The heavy non-radioactive hydrogen, deuterium, (H^2), has been available since before the war; the weakly radioactive tritium (H^3) is not yet generally available. Three isotopes of carbon are usable: the short-lived C^{11}; the long-lived C^{14}; and the stable, non-radioactive C^{13}. C^{14}, which the atomic pile at Oak Ridge has made widely available, is by far the most useful. To our great sorrow no radioactive isotope of oxygen is known; the stable isotope O^{18} offers the only means of studying the fate of this important element. Tracer carbon is an appropriate tool to study the reduction of carbon dioxide to carbohydrate. Tracer oxygen could be equally useful for the study of the oxidation of water to oxygen. Tracer hydrogen could help to trace the processes in the bridge between these sequences, including the primary photochemical process.

So we are beginning to get a somewhat clearer idea of the events in the light stages of photosynthesis, and recently we have also gained a little information about the dark stages. The total process, as we have noted, proceeds in two separate sequences: 1) the oxidation of water, which releases free oxygen, while hydrogen becomes attached to some intermediate "acceptor"; 2) the hydrogenation of carbon dioxide to produce carbohydrates. Each sequence of reactions apparently has a separate catalytic system. The two sequences and their relation to each other are pictured in an accompanying diagram, which shows the separate sequences as two legs, with chlorophyll as the bridge between them. One sequence (the left leg) begins with molecules of gaseous carbon dioxide. These are first bound or fixed in a form suitable for reduction, perhaps by enzymatic formation of an organic acid. The bound carbon dioxide is then reduced by hydrogen atoms supplied in light by chlorophyll, which has recovered the hydrogen from water in the other sequence. The reduction, in turn, is followed by other enzymatic transformations which lead to a carbohydrate molecule.

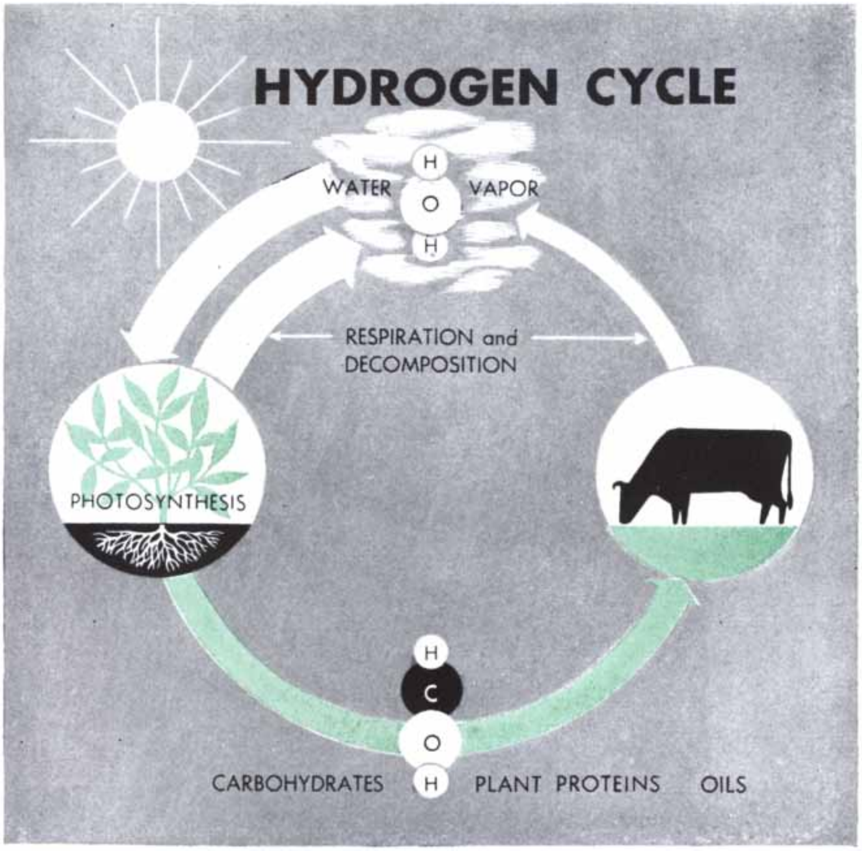
In the right leg we first have a similar binding of the water molecule, followed

Let us consider first the reduction of carbon dioxide. The process consists of a preparatory dark fixation stage, then a direct or indirect photochemical reduction, and finally the finishing enzymatic transformation, possibly taking place in a series of steps. The two phases where radioactive carbon might be used are obvious: it can be applied in the dark, with the intention of identifying the product of preliminary dark fixation, or in light, with the intention of identifying the intermediate products formed in light. Depending on the duration of exposure to light, we can expect to find the radioactive carbon distributed variously among the different intermediates and the final products of photosynthesis—sugar, starch, proteins, etc.

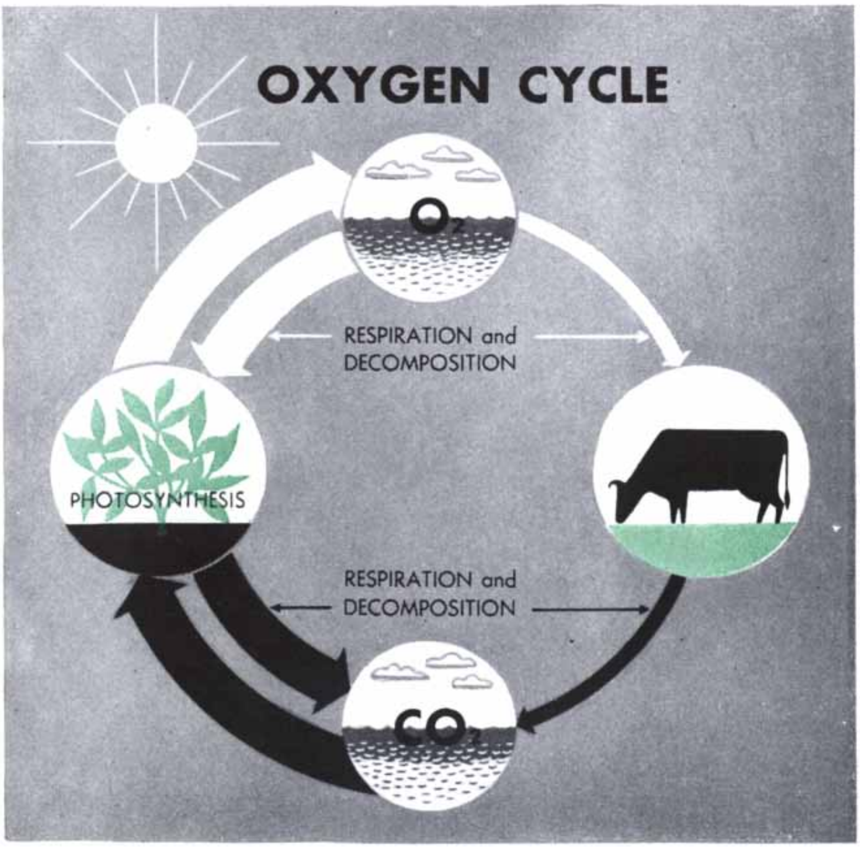
The first study seemed to be simpler and to provide a natural entering wedge for the tracer analysis of photosynthesis. Two groups of researchers connected with the Radiation Laboratory at the University of California have attempted it. Samuel Ruben (who died in a research accident during the war) and his co-workers used the short-lived C^{11}; more recently, Melvin Calvin and co-workers used the long-lived C^{14}. The results appeared promising. It was found that radioactive CO_2 was taken up by plants in the dark. At first it seemed as if this uptake consisted in the addition of carbon dioxide without reduction to a large organic molecule, leading to the formation of an organic acid, as was suggested above. In more recent experiments, however, radioactive carbon has been found in many different fractions, including partly or completely reduced ones, such as proteins or sugars. Since the amount taken up was much greater when the plants were illuminated before being exposed to radioactive carbon dioxide in the dark, Calvin suggested that the whole reduction sequence is a dark reaction; in other words, that in light chlorophyll forms some powerful, unknown reducing agent, which then reduces carbon dioxide all the way to carbohydrate without the help of light.

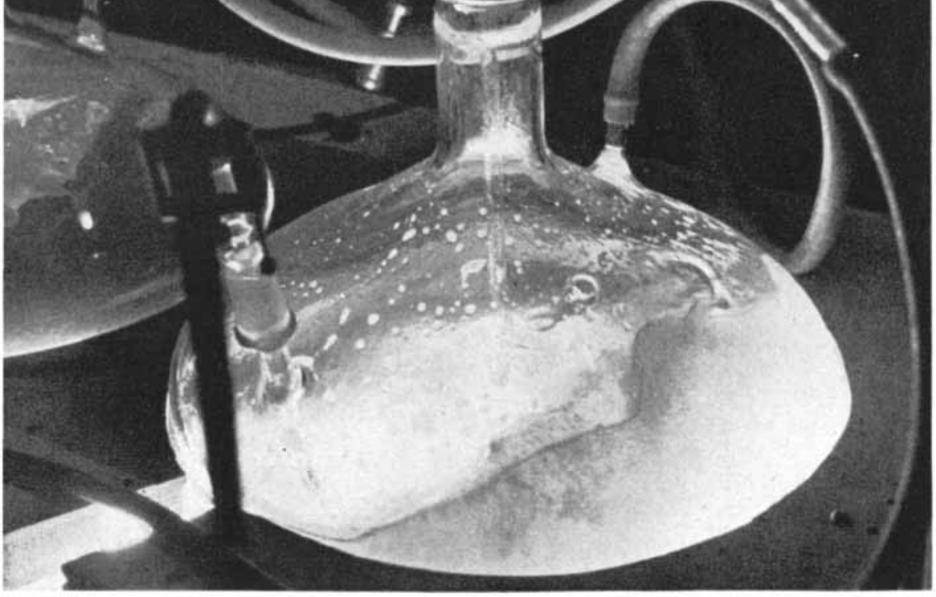
This hypothesis conflicts with some well-established facts. It has been observed, for example, that manometric (pressure) measurements can detect no significant carbon dioxide uptake or oxygen liberation by plants after they are deprived of light. Moreover, another possible explanation of Calvin's results has developed recently: it has been discovered that many metabolic processes in animal tissues as well as in plants involve absorption of carbon dioxide. At the December A.A.A.S. meeting in Chicago, many critics of the Calvin hypothesis suggested that the phenomena observed at Berkeley belonged in this class, and had nothing to do with photosynthesis.

A group of workers at the University of Chicago—Hans Gaffron, A. H. Brown and E. W. Fager—have used a second approach, tracing the products formed in light, and obtained less controversial results. They studied the distribution of C^{14} in the plant after a period of illumination, and found that the shorter this period, the more pronounced was the concentration of radioactive carbon in a certain chemical fraction of the plant material—the fraction characterized by solubility in water and lack of solubility in alcohol. The striking thing about the unknown radioactive compound concentrated in this



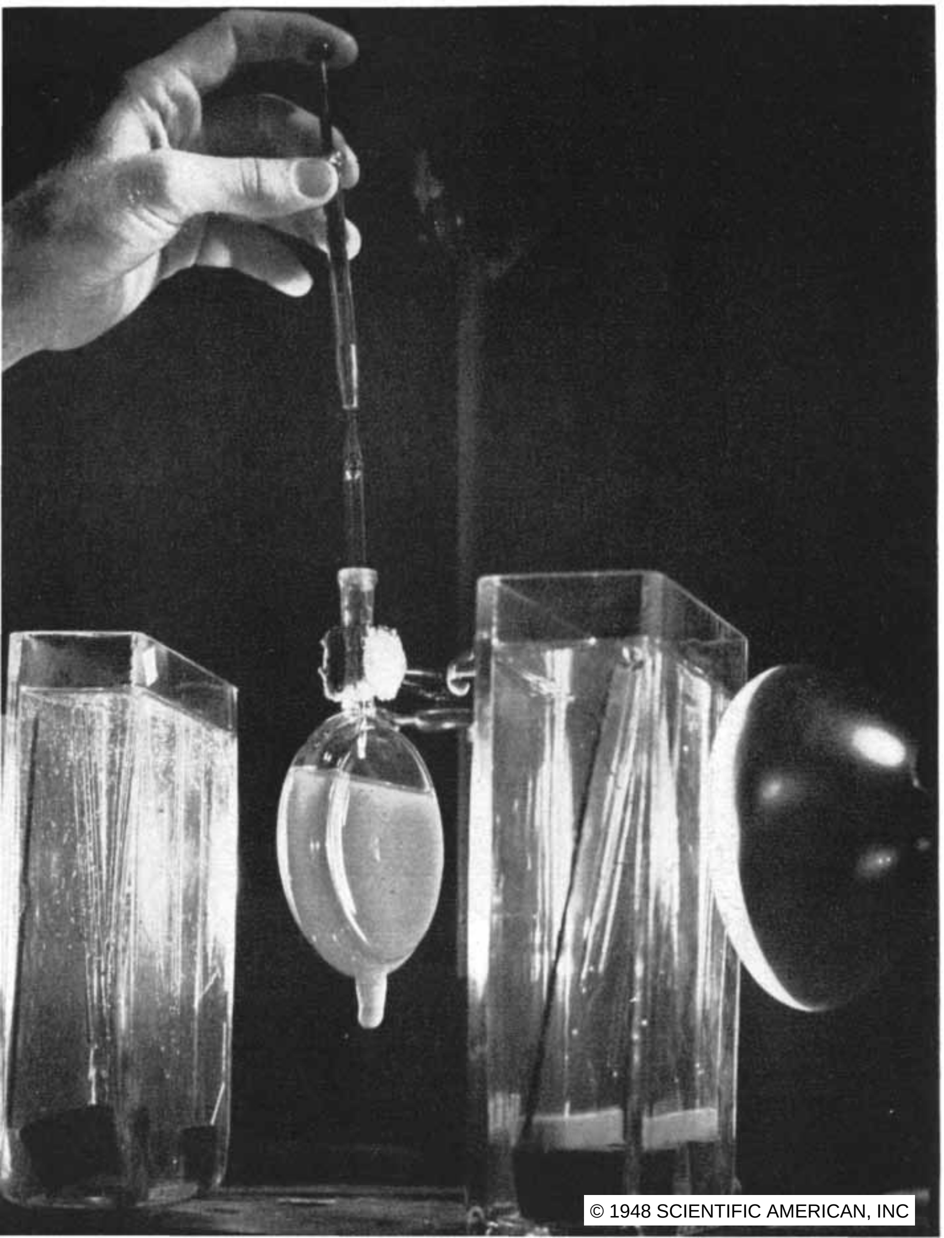
HYDROGEN AND OXYGEN, like carbon, traverse endless cycles in photosynthesis. Plants (*left*) take up water to obtain hydrogen, release water vapor. Animals (*right*) consume plant compounds (*bottom arrow*) and give off water. In diagram below, plants release oxygen in photosynthesis, take it up in respiration and decay. Animals use oxygen, release carbon dioxide.





TRACER EXPERIMENT in the laboratory of Melvin Calvin and Andrew Benson at the University of California begins with the culture of alga *Scenedesmus* in glass flasks. Moving table shakes the flasks above a light source.

ALGAE IN FLASK are supplied by pipette with radioactive carbon in the form of sodium carbonate. Algae grow briefly, using radioactive carbon dioxide released in water. Lights are then shut off and the algae killed.



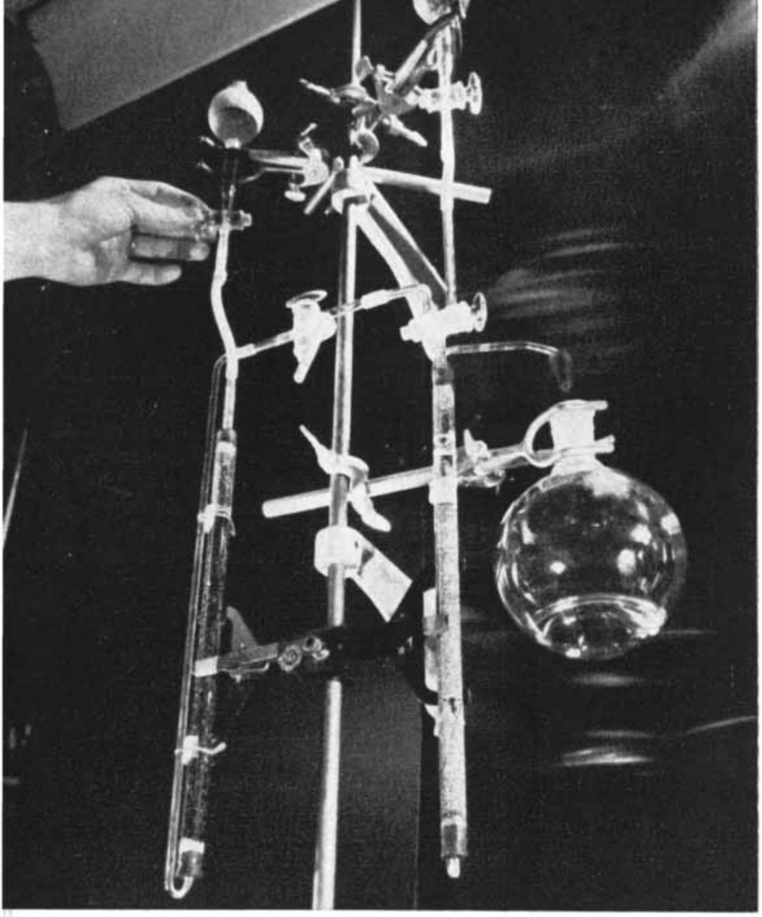
fraction was that it did not budge from the fraction even after hours of dark metabolism; on the other hand, the radioactive carbon passed rapidly into other fractions if light was again thrown on the plants. Here, then, was a true CO_2-reduction intermediate, the first such compound definitely pinned down in a laboratory. The next task is to isolate and identify the new compound. All researchers interested in photosynthesis are looking forward with great anticipation to the result of this tedious but very important analytical investigation.

The isotope O^{18} was employed in a study of photosynthesis by Samuel Ruben and Martin Kamen before the war, and a very significant result was obtained. Using CO_2 and H_2O containing heavy oxygen, they showed that all the oxygen liberated in photosynthesis originated in water; none came from carbon dioxide. (This is a fine example of information that only isotopic tracers can provide!) Their finding was consistent with the hypothesis that photosynthesis is fundamentally a transfer of hydrogen atoms from water to carbon dioxide, with the oxygen left behind.

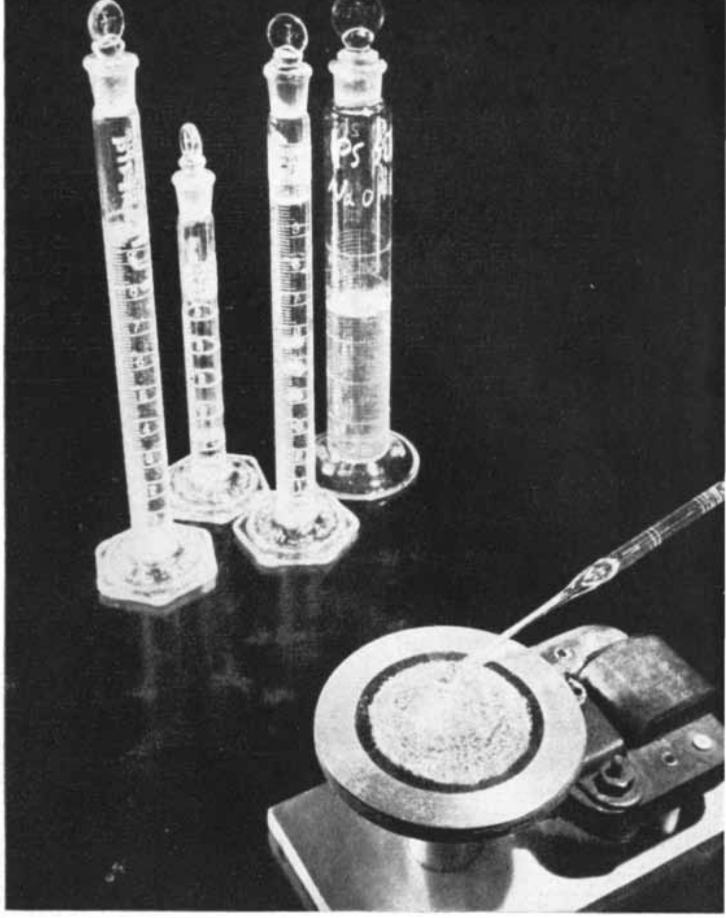
The Mechanism Is Taken Apart

Of all our recent glimpses into the mysterious mechanism of photosynthesis, none appears more promising than the one which was made possible by a discovery made in 1937 by R. Hill of Cambridge University. It had been known for a long time that dried and powdered leaves, when suspended in water and illuminated, sometimes release a small amount of oxygen, although of course they produce no carbohydrates. Hill found that the oxygen production could be increased and sustained for an hour or more if the suspension was provided with a supply of ferric oxalate or some other ferric salt. Later studies by others showed that ferric salts could be replaced by quinone or by certain dyes. All these compounds have one thing in common: they are all rather strong oxidants. They accept hydrogen atoms much more readily than carbon dioxide does. The most plausible interpretation of the results is that when leaves are dried and powdered, a product is obtained which still contains the chlorophyll bridge and the enzymatic system required to produce free oxygen (the right leg in our schematic diagram), but which has lost the left leg's enzymatic system. The suspension therefore can oxidize water and liberate oxygen in light, but it cannot reduce carbon dioxide and produce carbohydrate. Without the aid of enzymes, the carbon dioxide is unable to perform its job of "accepting" hydrogen, but the reaction is kept going by substituting a more willing acceptor (*e.g.*, ferric iron) for carbon dioxide.

Thus we have, in effect, photosynthesis without carbon dioxide! Microscopic studies yield further pertinent evidence.



FILTRATE of dead algae is fractionated by passage through ion-exchange tube. Tiny amounts of each fraction are thus available for an analysis of radioactivity.



FRACTIONATED PRODUCT of photosynthesis is placed on aluminum plate and evaporated by electric heater. Residue now remains for examination in counter.

GEIGER-MULLER COUNTER is used to ascertain the relative radioactivity of various aluminum-plate residues. The counter tube is housed within the lead cylinder at the left to shield tube from incidental radiation. Aluminum plates are placed in tray and pushed into cylinder. Counts are recorded by a device at the right.

The photosynthesizing cells of almost all plants contain chlorophyll (and accompanying pigments) in microscopic bodies called chloroplasts. Closer observations have revealed that the pigments are further concentrated within the chloroplasts in tiny "grana," almost too small to be seen under ordinary microscopes but beautifully revealed under the electron microscope. Analysis of the Hill suspension shows that its particles are whole or broken chloroplasts or isolated grana. The grana, then, are the "bricks" in the catalytic structure of photosynthesis which permit the liberation of oxygen from water in light but do not contain the enzymes needed to take up and reduce carbon dioxide. The essential independence of the two enzymatic systems thus receives striking confirmation.

The "Hill reaction" is perhaps the widest crack that has yet appeared in the former picture of photosynthesis as a unique and indivisible process. We have lifted the hood and taken out the motor and it still runs, even though it has to be supplied with a fuel other than the usual gasoline.

It has not yet been possible to perform the converse of this feat: *i.e.*, to eliminate the right leg of the photosynthetic apparatus and keep the left leg functioning. However, something closely related to this has been found to occur in nature: organisms capable of reducing carbon dioxide in light, but unable to use water as a reductant. As substitutes, these organisms use hydrogen sulfide, thiosulfate, or even free molecular hydrogen.

Certain species of bacteria, purple or green in color, contain a pigment called bacteriochlorophyll which is closely related to the chlorophyll of green plants. They thrive in sulfur waters or other media containing reducing agents. Cornelius B. van Niel, the Dutch microbiologist now at Hopkins Marine Laboratory in California, has shown that they can build their organic matter from inorganic materials in light. He suggests the following general chemical equation for their photosynthesis:

$$2RH_2 + CO_2 \xrightarrow[\text{light}]{\text{bacteriochlorophyll}} [C(H_2O)]_2 + 2R.$$

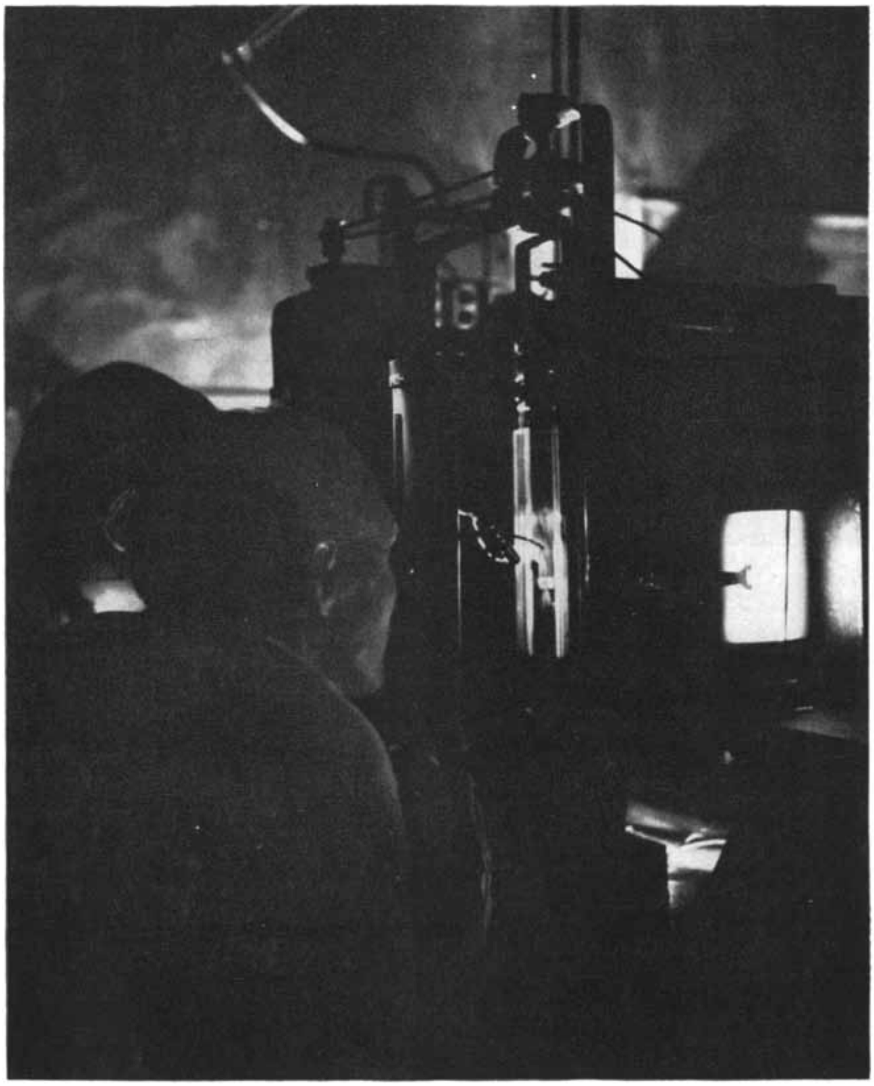
This equation is similar to the one usually given for photosynthesis of green plants, but it is more general, since R can stand for many different radicals, consisting of a single atom or a chemically unsaturated group of atoms. If R is taken as representing an oxygen atom, we have plant photosynthesis; if it is taken to represent an atom of sulfur, we have the photosynthesis of "sulfur bacteria," and so on.

With one stroke van Niel's interpretation of the chemical activity of purple bacteria has removed photosynthesis by green plants from its entirely unique position in biological chemistry and placed it alongside other types of "photosynthetic" processes. Does this discovery indicate that the purple and green bacteria are predecessors of green plants, relics of a time when life was restricted to those places on earth where inorganic reductants were present? A time, perhaps, when the earth's crust was less well stabilized chemically than it is now, and hydrogen sulfide, sulfur, or perhaps even free hydrogen were available in much more abundance?

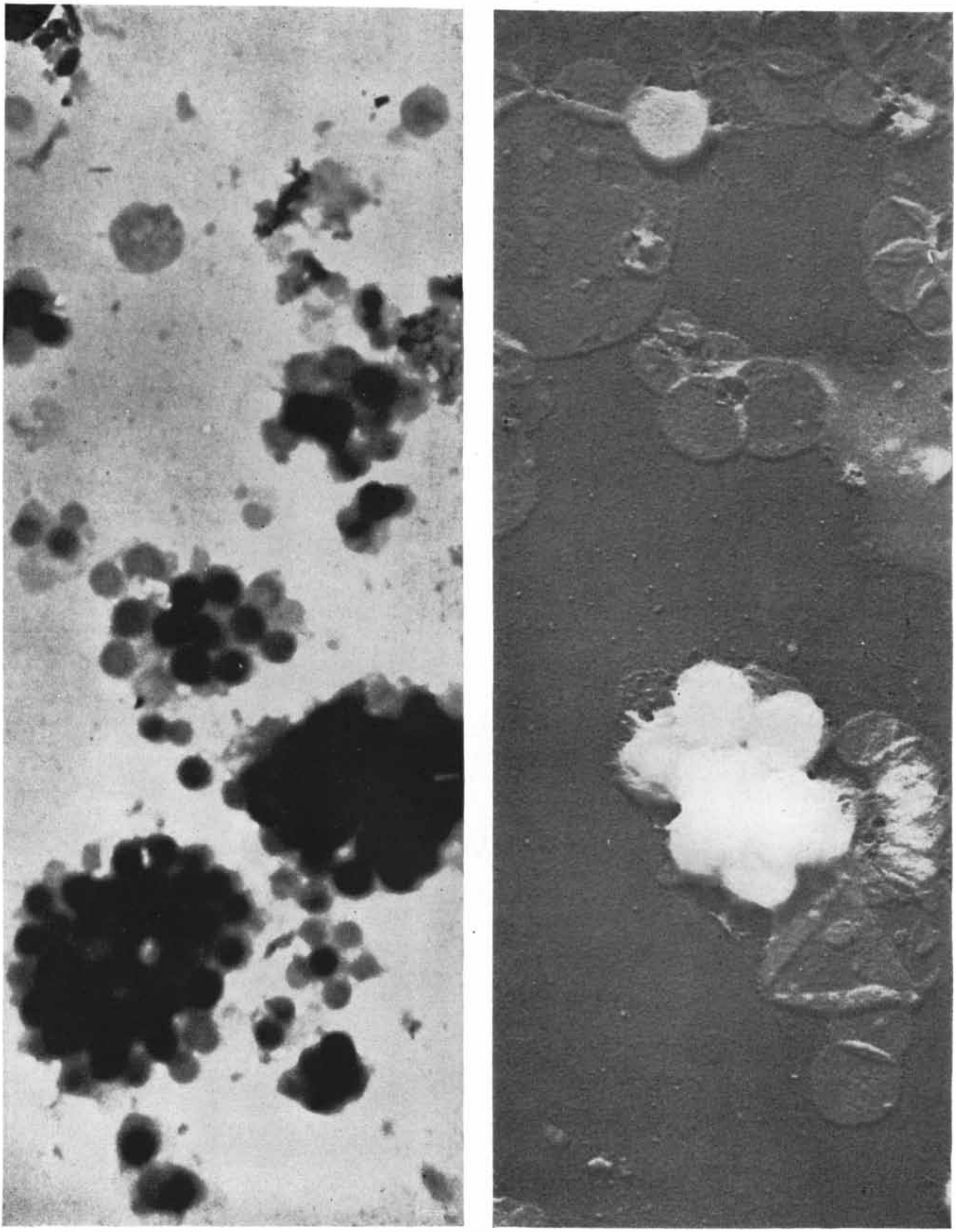
FURTHER exciting vistas are opened by the similarity of the photosynthetic purple bacteria to some colorless bacteria which are capable of reducing carbon dioxide by means of the same or similar reductants but without the help of light. They use instead the chemical energy liberated by enzymatic oxidation of these reductants by the oxygen of the air. This phenomenon is called bacterial chemosynthesis; it, too, may be a relic of the more primitive forms of life. Hans Gaffron found in 1939 that if certain unicellular green algae are deprived of oxygen, they cease to be capable of ordinary photosynthesis but become capable of reducing carbon dioxide in light if hydrogen is provided as a substitute reductant to replace water! It looks as if lack of air causes these algae to simulate purple bacteria, which also can use hydrogen as reductant.

In photosynthesis, we are like travellers in an unknown country around whom the early morning fog slowly begins to rise, vaguely revealing the outlines of the landscape. It will be thrilling to see it in bright daylight!

Eugene I. Rabinowitch, author of the textbook Photosynthesis, *is research professor of botany at the University of Illinois.*



EFFICIENCY of *Chlorella* **in using light is measured by Robert Emerson and Shimpe Nishimura at the University of Illinois. Monochromatic light separated by slit from spectrum at right is beamed on a vessel containing the alga. Researchers then jointly measure its oxygen output with manometer.**



"GRANA" OF PLANT CELL, tiny disks containing chlorophyll, are revealed in electron microscope photograph made by S. Granick and K. R. Porter of Rockefeller Institute. In picture at left, grana magnified 6,300 times are loosely grouped in chloroplasts. In picture at right, grana shadowed with gold film and magnified 16,300 times appear as white wafers. Experiments show that release of oxygen from water goes on in grana.

IN DEFENSE OF BENJAMIN FRANKLIN

The homely Philadelphian, often treated by historians as a politician with a spare-time interest in gadgets, was actually one of the great experimental scientists

by I. Bernard Cohen

ALTHOUGH almost every aspect of Benjamin Franklin's career has been subjected to the microscopic examination of critical scholarship, his place in the history of science. as described in books on American history, remains curiously distorted. In his own lifetime, Franklin was generally acknowledged by contemporary scientists to be one of the truly great scientific luminaries of the age. Joseph Priestley declared that Franklin's book on electricity bade fair "to be handed down to posterity as expressive of the true principles of electricity; just as the Newtonian philosophy is of the true system of nature in general." Franklin was awarded every scientific honor that his contemporaries had the power to bestow. One review of his book, comparing Franklin's writings with Newton's famous *Principia Mathematica*, averred that "the experiments and observations of Dr. Franklin constitute the *principia* of electricity, and form the basis of a system equally simple and profound."

Most writers today, however, either stress Franklin's practical inventions or deny altogether his claim to a place among the great founders of pure science. Typical of the latter point of view is an article that appeared a year ago in the journal *Science*, wherein the author declared that the only reason Franklin is sometimes said to be a great scientist and is occasionally listed in the company of the truly great. such as J. Willard Gibbs and A. A. Michelson, is that he was important in American political history!

All too many discussions of Franklin's scientific career center upon the one contribution that almost everyone knows about: his proof, by the experiment of flying a kite during a storm, of the theory that lightning is electrical in nature. Some, indeed, would deny him even this distinction. The author of an article in a learned journal some months ago argued that the story of the lightning kite had been made out of whole cloth by spinners of legends—despite the fact that Franklin published an account of that experiment, which other scientists then repeated, in the leading scientific journal of the day.

But let us forget the kite. It was a comparatively unimportant episode in Franklin's career. It was not the first experiment he designed to test the hypothesis of the electrical nature of the lightning discharge. Neither was it the first experiment that proved this hypothesis, nor was this particular hypothesis original with Franklin. Benjamin Franklin's place in the history of science rests on surer foundations, among them the vast accumulation of new facts of nature that he uncovered by his extraordinary skill in designing and executing experiments, plus his genius in constructing the first satisfactory unitary theory of electrical action. Furthermore. his consummate success gave the art of experimentation itself a new dignity that was wanting in the 18th century. The principles of electricity that he expounded in his book, *Experiments and Observations on Electricity Made at Philadelphia in America*, are part of the very fiber of electrical theory today. We constantly pay Benjamin Franklin an honor of which we are probably not even aware when we use the words "plus" and "positive," or "minus" and "negative," "electrical battery," and a host of other terms that Franklin was the first to apply to electrical phenomena.

FRANKLIN SEAL was affixed to a letter he wrote in 1750. It bears the legend "Je les unis." (I unite them.)

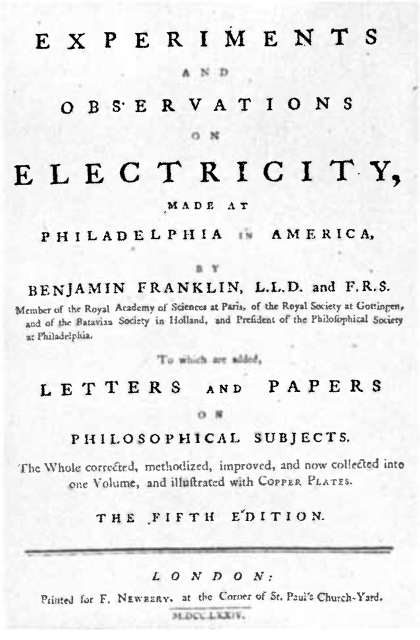
Franklin's treatise on electricity was one of the most widely reprinted scientific books of the mid-18th century. There were five editions printed in English. three in French, one in Italian. one in German. So great was Franklin's scientific reputation that he was elected a Fellow of the Royal Society and awarded its Copley Medal for his experiments in electricity, and in 1773 he was elected one of the eight "foreign associates" of the Royal Academy of Science in Paris. In an age in which scientific accomplishment was esteemed perhaps even more than in our own, Franklin's book was widely studied and his name was on every tongue.

FRANKLIN first became acquainted with the subject of electrical science sometime around 1744. Between 1747 and 1751 he made his major discoveries and began to win scientific acclaim. Contrary to the supposed general rule that the great discoveries in physics are made by men in their twenties and thirties, Franklin began his scientific work at about the age of 40; he had previously been too busy earning a living to devote much time to scientific pursuits. Having been successful in the world of affairs and now finding the pursuit of truth congenial to his tastes and gifts. he decided, as he tells us in his autobiography, to give up his business and to spend his time making experiments. No sooner had he retired from business. however. than a great national crisis arose and he put aside his scientific research in order to participate in the defense of Philadelphia. From then on until he died. he pursued his research only in his spare time. His city. colony and nation never ceased to require his services. At 81 years of age, when his work at Paris was finished and he was ready to come home to America, Franklin wrote to his most intimate scientific cor-

PORTRAIT OF FRANKLIN was engraved from a painting made in France, where he was a noted public figure. Even before he arrived in 1776 to plead the cause of the American Revolution, Franklin was known in France as a scientist and philosopher. In 1773 he had been made an associate of the Royal Academy of Science.

respondent, the Dutch physician Jan Ingen-Housz, that he was once more a free man "after fifty years in public affairs." He hoped that his friend would come with him to America, where "in the little remainder of my life . . . we will make plenty of experiments together." Alas, even this was to be denied him, for ahead there lay not days of joyful interrogation of nature but the trying and tedious work of the Constitutional Convention. Long before, Franklin had been forced to choose between the role of a quiet philosopher and a "public man." He had decided the issue without hesitation, saying: "Had Newton been pilot of but a single common ship, the finest of his discoveries would scarce have excused, or atoned for his abandoning the helm one hour in time of danger; how much less if she carried the fate of the Commonwealth."

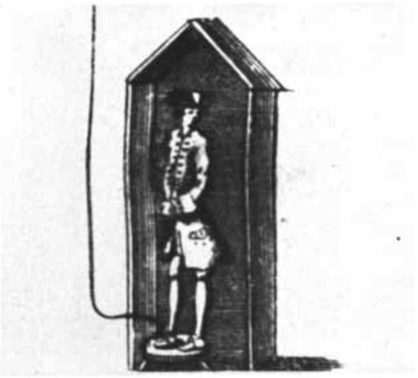
As we read these lines today, we cannot help thinking of our own scientists who, during the late war, gave up their own individual research to serve their nation. But there is a fundamental difference between their problem and Franklin's. In Franklin's day the one outstanding American scientist, the only one with a world-wide reputation, found that he could serve his country best by going abroad to plead its cause, rather than by


EXPERIMENTS
AND
OBSERVATIONS
ON
ELECTRICITY,
MADE AT
PHILADELPHIA IN AMERICA,
BY
BENJAMIN FRANKLIN, L.L.D. and F.R.S.
Member of the Royal Academy of Sciences at Paris, of the Royal Society at Gottingen, and of the Batavian Society in Holland, and Prefident of the Philofophical Society at Philadelphia.
To which are added,
LETTERS AND PAPERS
ON
PHILOSOPHICAL SUBJECTS.
The Whole corrected, methodized, improved, and now collected into one Volume, and illuftrated with COPPER PLATES.
THE FIFTH EDITION.
LONDON:
Printed for F. NEWBERY, at the Corner of St. Paul's Church-Yard.
MDCCLXXIV.

FRANKLIN'S BOOK on electricity was held in high esteem by contemporary scientists. It was compared with Sir Isaac Newton's *Principia*.

applying his scientific skills to devising new instruments of destruction. Yet such was Franklin's stature in science—and he was the Newton of his age—that some suspected the man who dared to tame the lightning bolts of Jove had turned his talents to the perfection of a new and terrible weapon. "The natural philosophers in power," wrote Horace Walpole in 1777, "believe that Dr. Franklin has invented a machine of the size of a toothpick case, and materials that would reduce St. Paul's to a handful of ashes."

Benjamin Franklin made scientific contributions in many fields, including pioneer studies of heat conduction, the origins of storms, and so on, but his most significant work was done in electricity. He worked in electrostatics—the science of electricity at rest or in sudden swift surges. Before



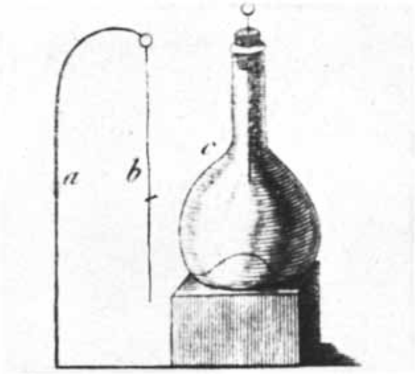
"SENTRY BOX" experiment was devised by Franklin to test his theory that lightning was electrical in nature. It was first performed in France.

Franklin, the known facts of this subject were meager and their explanation was inadequate. When he left the field, a whole new set of observed data had been entered in the record and the Franklinian theory of electrical action had unified all the known facts, preparing the way for the progress of the future.

FRANKLIN'S theory of electrical action is simple and straightforward. It is based on the fundamental idea that there is "common matter," of which the bulk of bodies is composed, and "electrical matter," or, to use other 18th-century terms, "electrical fluid" or "electrical fire." In its normal state, every body contains a fixed amount of the electrical fluid. But a body may, under certain conditions, gain an excess of the electrical fluid or lose some of its normal complement of it. In such a state a body is "electrified" or "charged"; in the first case, when there is an excess of the fluid, said Franklin, let us call the charge "positive" or "plus," indicating that something has been added to it; in the second case, let us call it "minus" or "negative," indicating that something has been lost. When we rub a piece of glass with a silk rag, the glass acquires an excess of the electrical fluid and becomes charged plus. Franklin insisted that electricity was not "created" by friction, as many of his contemporaries believed, but rather was redistributed by the act of rubbing. If the glass gains an excess of fluid, the silk must have lost the very same amount, thereby gaining a negative charge of the same magnitude. Today we call this principle the law of conservation of charge.

Franklin illustrated his theory by the following experiment. He placed two experimenters on insulated glass stools, one charged plus and the other minus. When the two experimenters touched hands, both lost their charge because the excess of one supplied the deficiency of the other. If a third uncharged experimenter touched either of the charged ones, he drew a spark or got a shock, because he had relatively more electric fluid than the man charged minus, and less than the man charged plus.

This was a simple, dramatic demonstration of Franklin's contention that electricity was a single fluid. The chief rival theory held that there were two electrical fluids, which sometimes moved in "efflux" and at other times in "afflux," and which operated by some mysterious rules that were never made clear. A French contemporary pointed out that the beauty of Franklin's theory over its rival was that "Franklin says: do that and this is what must happen; change that circumstance and this will be the result. In this way you can take advantage of a certain thing; in that way you will suffer an inconvenience." The late J. J. Thomson, discoverer of the fundamental properties of moving electrons, wrote only a few years ago: "The service which Franklin's one-fluid theory has rendered to the science of electricity by suggesting and coordinating re-

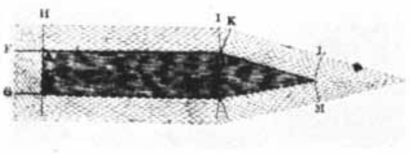


EXPERIMENT with bent wire (a), linen thread (b) and "electrized phial" (c) noted that thread was attracted to phial when latter was touched.

searches can hardly be overestimated."

To understand the application of Franklin's theory, let us follow him through two series of significant experiments. The first begins with one of the many facts first discovered by Franklin and now part of the basic data of the science—the "wonderful effect of pointed bodies, both *drawing off* and *throwing off* the electrical fire." Franklin found that if a pointed conductor such as a needle is brought into the neighborhood of a charged insulated body. the needle will draw off the charge; but it will do so only if it is grounded, that is, in contact with the hand or a grounded wire. If the needle is inserted in wax, a non-conductor or insulator, it will not draw off the charge. He also found that if you try to charge a metal object with a jagged edge or point, the object will "throw off the charge" as fast as you put it on. He discovered further that a charged object could be discharged by sifting fine sand on it, by breathing on it, by bringing a burning candle near it, or by surrounding it with smoke.

FOR AT LEAST 50 years before Franklin's research people had speculated that lightning was probably electrical. But what distinguished Franklin from his predecessors was the fact that he was able to design an experiment to test this hypothesis. He made a small model showing how a discharge might take place between two electrified clouds or between



THEORY of why electric charge tends to jump from the pointed parts of a charged object was set forth by Franklin in drawing from his book.

a cloud and the earth. He then pointed out that since a small pointed conductor could draw off the charge from an insulated charged body in his laboratory, a large pointed conductor erected in the ground might very well draw the electricity from passing clouds. This suggested to his active mind that "the knowledge of this power of points might be of use to mankind, in preserving houses, churches, ships, &c., from the stroke of lightning, by directing us to fix on the highest parts of those edifices, upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground, or down around one of the shrouds of a ship, and down her side till it reaches the water."

The experiment which Franklin proposed to test his hypothesis was described by him in these words: "On the top of some high tower or steeple, place a kind of sentry-box . . . big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright 20 or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing [electrical] fire to him from a cloud. If any danger to the man should be apprehended (though I think there would be none) let him stand on the floor of his box, and now and then bring to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle; so the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him."

This famous "sentry-box experiment" was first performed in France on May 10, 1752 by a man named Dalibard, who had translated Franklin's book into French at the request of the great naturalist Georges de Buffon. (King Louis XV was so fascinated by Franklin's book that he ordered some of the experiments it described to be performed in his presence.) The experiment was soon repeated in England. Glowing testimonials to the Philadelphia scientist speedily increased in number. An enterprising British manufacturer advertised for sale a ready-made machine "for making the Experiment by which *Franklin's* new theory of Thunder is demonstrated." Franklin did not make the experiment himself because he thought that a very high building would be necessary and he was waiting for the completion of the high spire on Christ Church in Philadelphia. After the book was published, but before he had heard from Europe of Dalibard's successful execution of the experiment, the kite project occurred to him as a good substitute and he carried it through instead.

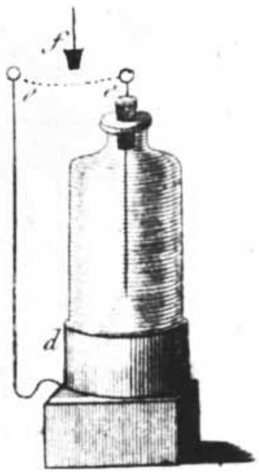
FRANKLIN devised other experiments and instruments to test the charge of clouds, of which one of the most interesting was a pair of bells located in his study. One of the bells was grounded by a rod going into the earth and the other was connected with a rod ending in a point on the roof. A little ball hung between them.

"ELECTRICAL FIRE" of the Leyden jar was made visible when it was allowed to flash along the gold embossing of one of Franklin's books.

Whenever an electrified cloud passed overhead, the ball was set in motion and rang the bells. Franklin's careful studies soon showed him that clouds may be charged either plus or minus, and he concluded, therefore, that lightning probably goes from the earth to a cloud at least as often as from a cloud to the earth—an idea which has been confirmed only in our own time by such research as that of B. J. F. Schonland and his associates in South Africa.

Franklin's studies of lightning and his invention of the lightning rod brought him universal fame, but the scientists of his day were perhaps even more impressed by his analysis of the electrical condenser, which set the seal to his scientific reputation.

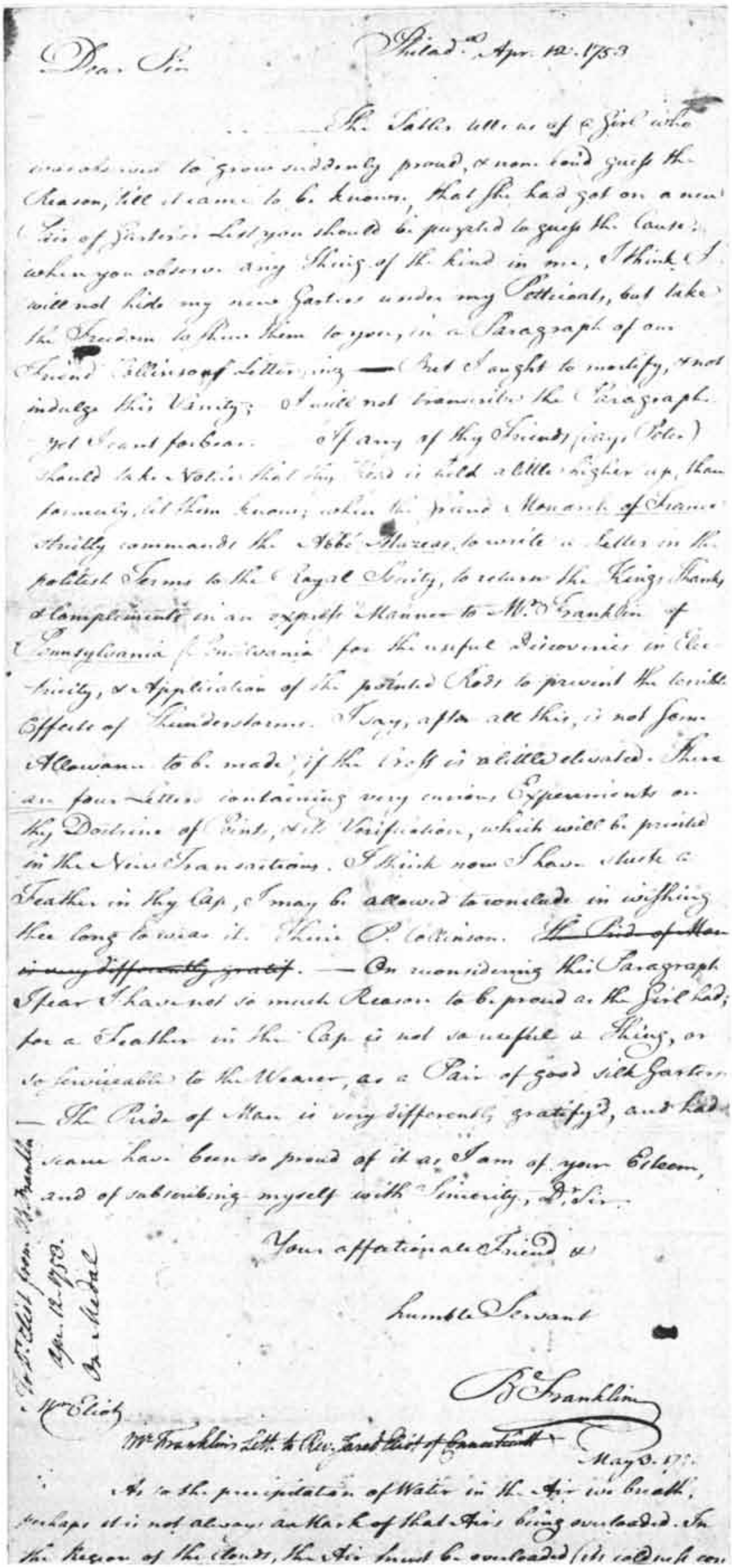
In the form that the 18th century knew it, the condenser was a glass jar coated on the outside with metal foil and filled with either metal shot or water. It was fitted with a wooden cover into which a rod ending in a knob was inserted. From the lower end of the rod a metal chain depended, going down into the water or shot. This device, invented in the late 1740s, was known as a "Leyden jar," because one of its several independent discoverers, Pieter van Musschenbroek, was



LEYDEN JAR discharge was investigated by hanging cork between poles. Cork oscillated during discharge, a useful fact in condensers.

a professor in Leyden. The essential feature of a condenser is the placement of an insulator or dielectric (*e.g.*, air, glass, wax or paper) between two conducting surfaces in close contact with it. In the first Leyden jar the inner conductor was water, the dielectric was the glass and the outer conductor was a man's hand. Musschenbroek developed his version of it while carrying out some experiments with an electrical machine which charged a whirling glass globe by rubbing it against an experimenter's hands. The charge was transferred to a gun barrel, from the end of which hung a wire that was partly immersed in a round glass vessel filled with water. When Musschenbroek held the vessel in his right hand and attempted to draw a spark from the gun barrel with his left hand, he "was struck with such violence that my whole body was shaken as by a thunderbolt . . . . in a word, I thought it was all up with me."

The condenser was a wonderful instrument. By making it bigger and bigger, the shocks it could give were made stronger and stronger. Apparently, somehow or other electricity accumulated in it, and through some little-understood aspect of its construction, it could hold more elec-



LETTER Franklin wrote to a friend in 1753 tells of his pleasure at receiving the notice of the French court and the Royal Academy of Science. In it Franklin mentions his friend Thomas Collinson, who first sent him from England the wonderful Leyden jar invented by Pieter van Musschenbroek (*opposite page*). Franklin was elected to the French Academy some 20 years later.

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Philadelphia
April 12, 1753

Dear Sir

The Tatler tells us of a girl who was observed to grow suddenly proud, and none could guess the Reason, till it came to be known, that she had got on a new Pair of Garters. Lest you should be puzzled to guess the Cause, when you observe any Thing of the kind in me, I think I will not hide my new Garters under my Petticoats, but take the Freedom to shew them to you, in a Paragraph of our Friend Collinson's Letter, viz—But I ought to mortify, and not indulge this Vanity;—I will not transcribe the Paragraph—yet I cant forbear.—"If any of thy Friends (says Peter) should take Notice that thy Head is held a little higher up, than formaly, let them know; when the *Grand Monarch of France* strictly commands the *Abbé Mazeas*, to write a Letter in the politest Terms to the *Royal Society*, to return the Kings Thanks and Compliments in an express Manner to *Mr. Franklin* of *Pennsylvania* (Pensilvania) for the useful Discoveries in Electricity, and Application of the pointed Rods to prevent the terrible Effects of Thunderstorms. I say, after all this, is not some Allowance to be made, if the Crest is a little elevated. There are four Letters containing very curious Experiments on thy Doctrine of Points, and its Verification, which will be printed in the New Transactions. I think now I have stuck a Feather in thy Cap, I may be allowed to conclude in wishing thee long to wear it. Thine P. Collinson."—On reconsidering this Paragraph I fear I have not so much Reason to be proud as the Girl had; for a Feather in the Cap is not so useful a Thing, or so serviceable to the Wearer, as a Pair of good silk Garters.—The Pride of Man is very differently gratify'd, and had scarce have been so proud of it as I am of your Esteem, and of subscribing myself with Sincerity, Dr. Sir.

Your affectionate Friend &
humble Servant
B. Franklin

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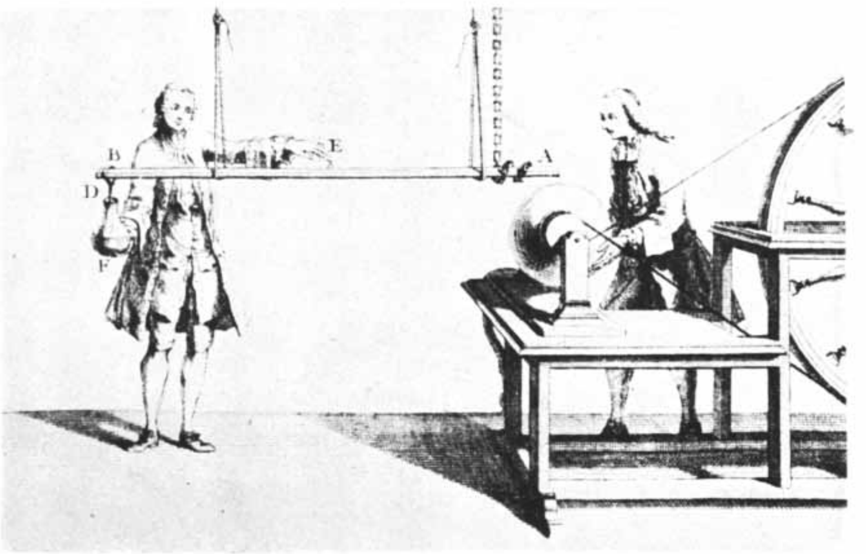
The remaining lines of the letter, a postscript, are not transcribed.

tricity than anything else of its size. The electric fluid or fluids must, it was thought, be condensed in it. Musschenbroek wrote a letter describing this experiment which was published in the *Mémoires* of the French Academy of Sciences. It ended with the famous statement that he would never again receive such a shock, even if he were to be offered the Kingdom of France! For such ignoble sentiments he was publicly rebuked by Priestley, who called him a "cowardly professor" and contrasted him with the "magnanimous Mr. Boze, who with a truly philosophic heroism worthy of the renowned Empedocles, said he might die by the electric shock, that the account of his death might furnish an article for the memoirs of the French Academy of Sciences." Then, referring to one Richman, who had just been killed while performing a variation of Franklin's sentry-box experiment, Priestley concluded, "But it is not given to every electrician to die the death of the justly envied Richman."

ALL THE electricians of Europe wondered what made the Leyden jar work. "Everybody," wrote Priestley, "was eager to see, and, notwithstanding the terrible account that was reported, to *feel* the experiment." In France the new device provided a means of satisfying simultaneously the court's love of spectacles and the great interest in science. One hundred and eighty soldiers of the guard were made to jump into the air with a greater precision than soldiers of the guard displayed in any other maneuvers. Seven hundred monks from the Couvent de Paris, joined hand to hand, had a Leyden jar discharged through them all. They flew up into the air with finer timing than could be achieved by the most gifted corps of ballet dancers. From one end of the world to the other, traveling demonstrators of electrical phenomena made fortunes.

Franklin's step-by-step analysis of the vexing problem of the condenser showed him to be a great master of the technique of scientific experimentation. He found that the inside conductor was always charged in the opposite sign to the outer conductor and that the amount of charge given to both was the same. In other words, after charging of the jar, one of the two conductors gained the exact quantity of "electrical fluid" that the other had lost. "There is really no more electrical fire in the [Leyden] phial after what is called its *charging,* than before, nor less after its *discharging,*" Franklin wrote. To prove it, he affixed a wire to the lead coating of a Leyden jar and placed it so that it was near the knob leading to the water inside the jar, but not near enough to produce a spark when the jar was charged. He than placed the jar on an insulating stand, a block of wax, and suspended a small cork on a string between the wire and the knob.



"ELECTRICAL MACHINE" devised by van Musschenbroek consisted of a glass sphere charged when a man held his hands against it. Charge was then carried along a beam to a Leyden jar. When van Musschenbroek attempted to discharge the jar by touching beam, he was shaken "as by a thunderbolt."

The cork, he noted, "will play incessantly from one to the other, 'till the bottle is no longer electrized." In other words, the cork carried the charge from the plus conductor to the minus until equilibrium was restored.

Most important of all, Franklin showed that "the whole force of the bottle, and power of giving a shock, is in the GLASS ITSELF." How would *you,* reader, go about finding "wherein its strength lay"? Every student knows today that the only way to proceed is to test the instrument one element at a time, and to find the role played by each. But this apparently simple rule was not taken for granted in the time of Franklin, as can readily be seen in the fact that his contemporaries failed to make the kind of analysis that Franklin now proceeded to carry out.

He charged a Leyden jar that stood on glass and carefully drew out the cork with its wire that hung down into the water. Then he took the bottle in one hand, and brought the other hand near its mouth. "A strong spark came from the water, and the shock was as violent as if the wire had remained in it, which shewed that the force did not lie in the wire." If it was not in the wire, then perhaps it was in the water itself. Franklin recharged the Leyden jar, drew out the cork and wire as before, and carefully poured the water into an empty Leyden jar which likewise stood on a glass insulator. The second jar did not become charged in this process. "We judged then," Franklin wrote, "that [the charge, or force] must either be lost in decanting, or remain in the first bottle. The latter we found to be true; for that bottle on trial gave the shock, though filled up as it stood with fresh unelectrified water from a tea-pot." Apparently the essential element was glass, the insulator between the two conductors. But it remained to be demonstrated whether "glass had this property merely as glass, or whether the form [of the jar] contributed anything to it."

The next part of the experiment involved the invention of the parallel plate condenser. Franklin sandwiched a large piece of glass between two square plates of lead, equal to each other in size but slightly smaller than the glass. When this condenser was charged, he removed the lead plates, which had but little charge, and noted that a small spark could be taken from the glass at almost any point that it was touched. When the two completely uncharged plates were put back in place, one on each side of the glass, and a circuit made between them, then "a violent shock ensued." When we demonstrate this phenomenon to students today, we call it the experiment of the dissectible condenser. We explain it by stating that the dielectric, or glass, has been polarized during charging, *i.e.,* it has become an electret. There are certain types of wax that can be polarized in this way simply by being heated and then cooled. Such an electret will give off little or no charge by itself, but if we put a conductor on two sides of it, we have a charged condenser which can be then discharged like any other. Another fact about such condensers that we teach students today was also discovered by Franklin: the amount of charge is greater when the dielectric separating the two conductors is very thin than when it is thick.

Franklin's experiment of the cork that traveled back and forth between the two conductors contained, by the way, the germ of an important idea, although he did not realize it. We know today that a condenser never discharges in one complete stroke, but rather in a series of oscillations—a fact of great importance in radio and modern electronics.

Franklin's extraordinary experiments and his splendid theory marked the beginning of a new era in the subject of electricity. His theory showed its usefulness in many ways. Franklin discovered what is known today as the Faraday effect, namely that the charge on a hollow cylindrical condenser (or a hollow sphere) is on the outside surface only. At first he could not explain this. Later the answer came to him: the "electrical fluid" is self-repellent and the symmetry of the conductor causes it to distribute itself on the outside. From this explanation, Franklin's friend Joseph Priestley deduced that the law of electrical action must be an inverse square law similar to the law of gravitation. This deduction, although published, was overlooked and had to await rediscovery decades later by Charles Coulomb, when it became known as Coulomb's law.

Yet another advantage of Franklin's theory was the ease with which it lent itself to the making of measurements, by concentrating attention on the amount of "electrical fluid" or charge which a body gained or lost. When working with two bodies, it did not matter which one was used, because Franklin's law of conservation of charge meant that the quantity gained by one was exactly the quantity that the other lost. The first electricians to make quantitative measurements—such men as Volta, Bennet, Canton, Cavendish and Henley—built upon the convenient one-fluid theory of Benjamin Franklin, and the law of conservation of charge which followed from it.

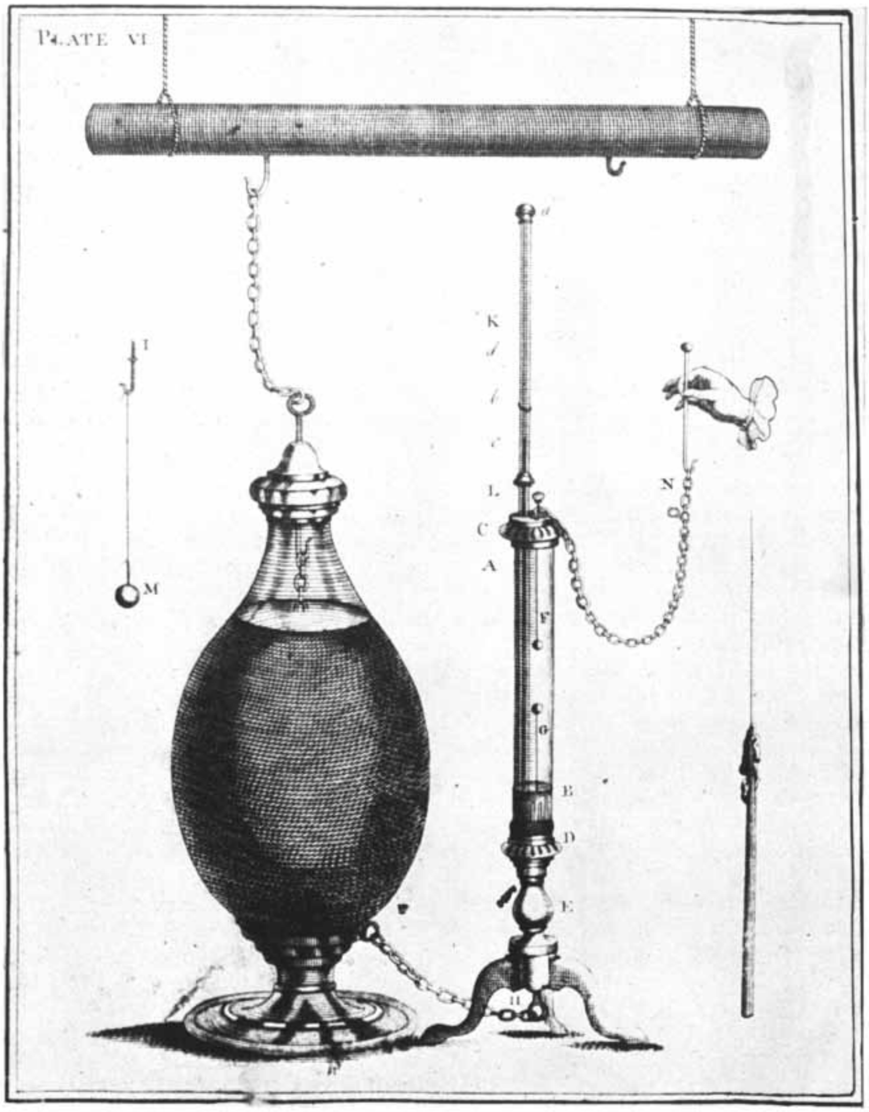
IT IS OFTEN said that Franklin was typically American in his approach to science—a utilitarian interested in science chiefly, if not solely, because of its practical applications. It is true that when he had discovered the action of pointed grounded conductors and proved that clouds are electrified, he applied these discoveries to the invention of the lightning rod. But he did not make these discoveries in order to invent a lightning rod! Franklin's inventions were of two kinds. One type was pure gadgetry; in this class were his inventions of bifocal glasses, which required no recondite knowledge of optical principles, and of a device for taking books down from the shelf without getting up from one's chair. The lightning rod, on the other hand, developed from pure scientific research. If Franklin's approach to science had been strictly utilitarian, it is doubtful that he would ever have studied the subject of electricity at all. In the 18th century there was only one practical application of electricity, and that was the giving of electric shocks for therapeutic purposes, chiefly to cure paralysis. (Although Franklin on occasion participated in such therapy, he did not believe that the shock itself ever cured a case of paralysis. With shrewd psychological insight, he guessed that the reported cures arose from the desire of the patient to be cured rather than from the passage of electric fluid.)

Franklin studied nature because he wanted to discover her innermost secrets, and he chose electrostatics because chance brought him the instruments with which to study this subject, and because he quickly found out that this was a subject well fitted to his particular talents. In a spirit which might well be emulated by all men engaged in research, he wrote humbly at the end of one of his communications: "These thoughts, my dear friend, are many of them crude and hasty; and if I were merely ambitious of acquiring some reputation in philosophy [*i.e.*, natural philosophy, or science], I ought to keep them by me, 'till corrected and improved by time, and farther experience. But since even short hints and imperfect experiments in any new branch of science, being communicated, have oftentimes a good effect, in exciting the attention of the ingenious to the subject . . . you are at liberty to communicate this paper to whom you please; it being of more importance that knowledge should increase, than that your friend should be thought an accurate philosopher."

With the discovery of electrons, protons and neutrons, many modern writers have argued about whether Franklin's one-fluid theory was or was not closer to the modern conception than the two-fluid theory of his rivals. To my mind, such debates are wholly without value. The value of Franklin's contribution to electricity does not lie in the degree to which it resembles our modern theory, but rather in the effect his researches had in getting us along on the road to our modern theory.

At the time that Franklin undertook his studies, the world of science

HEAT OF ELECTRICAL FIRE was proved by this apparatus illustrated in Franklin's book. When charge of Leyden jar at left was allowed to jump between wires F and G in tube, heat was recorded by thermometer.

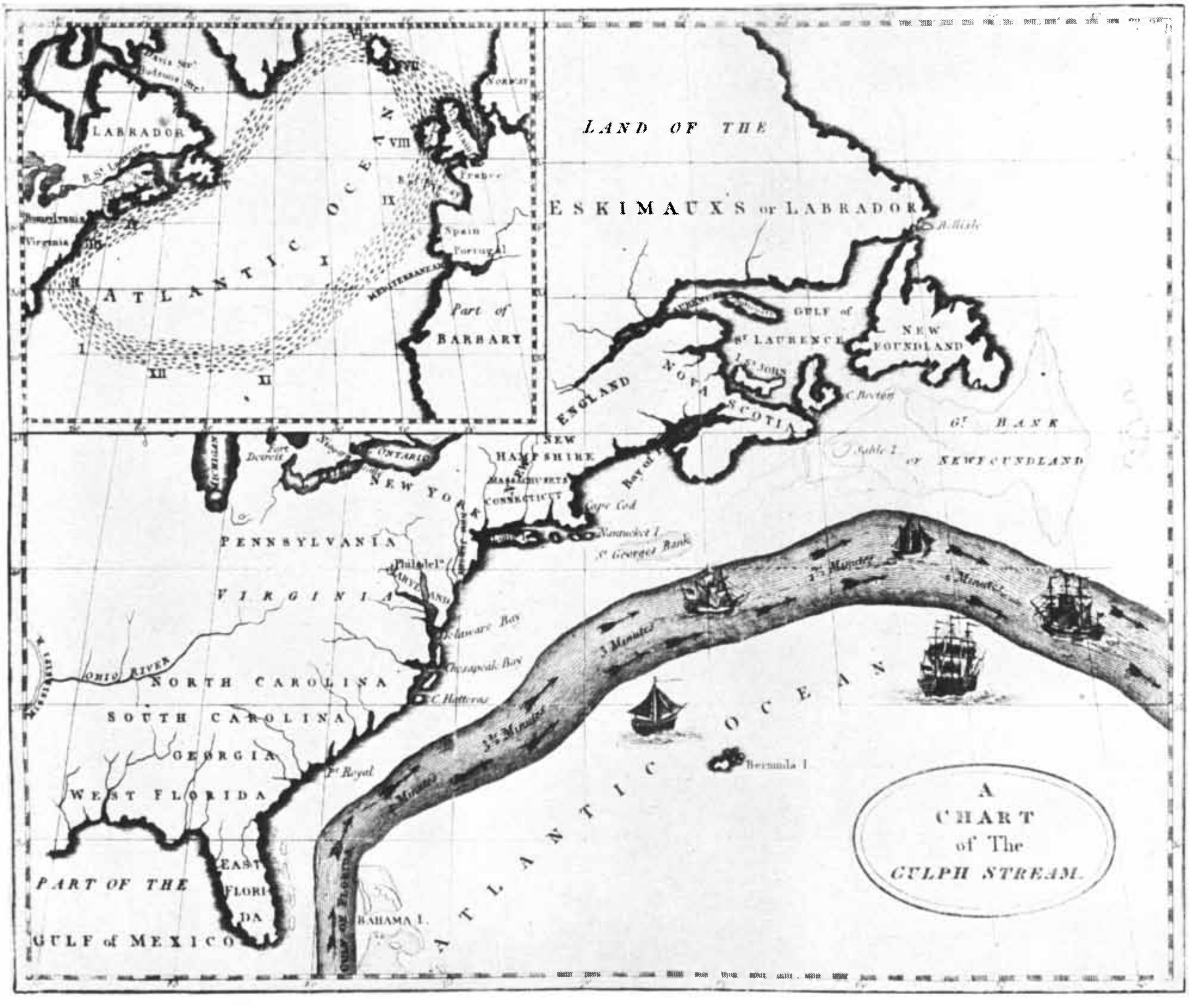


lay under the spell of Isaac Newton, whose great *Principia* had shown that the motions of the universe could be explained by simple mathematical laws. Newton convinced almost everyone that mathematics and mathematical laws were the only key to the understanding of nature. What many people forgot, however, was that Newton's success in applying mathematical analysis to celestial and terrestial mechanics was possible only because the facts had been accumulated and classified, and were in a state where his great genius could make the first great synthesis of the modern scientific era. But when it came to optics, Newton made no synthesis such as he did for mechanics, nor was he able to reduce his quantitative and qualitative discoveries to the form of general mathematical law. In the field of optics, Newton was but one of the giants upon whose shoulders some later synthesizer was to stand. In contrast with the austere *Principia*, whose motto was *Hypotheses non fingo* ("I frame no hypotheses"), his *Opticks* contained a long set of "queries" in which Newton discussed the possible explanations that might be given to his observed facts. These resemble Franklin's speculations concerning electrical phenomena. In Franklin's time, as with optics in Newton's time, the state of electrical science did not yet permit a full mathematical synthesis. What was required were "giants" to uncover the facts of charge, of induction, of grounding and insulation, of the effect of shapes of conductors and so on, giants to build a workable manipulative theory to unify these facts and to draw attention to essential elements that might be measured. Franklin's success paved the way for the mathematical theorists of the 19th century.

But, even more, his mastery of the technique of experimentation, his successful and consistent explanations in terms of a simple physical conceptual scheme, and the many new and curious facts of nature he revealed, gave experimental science a new dignity in the eyes of his 18th-century contemporaries. The French philosopher Diderot wrote, in his essay on the interpretation of nature, that Franklin's book on electricity, like the works of the chemists, would teach a man the nature of the experimental art and the way to use the principles of experimental research to draw back the veil of nature without multiplying its mysteries.

This was the sense, then, in which Franklin's contemporaries believed him to be the new Newton, and this was the first great contribution made by America to the mind of science. In this light, there can be no doubt of Franklin's stature in science, nor that he deserves to stand as the first American scientist.

I. Bernard Cohen is instructor in the history of science at Harvard and author of Science, Servant of Man, *to be published this month by Little, Brown.*



LITTLE-KNOWN WORK of Franklin was the charting of the Gulf Stream. When he was deputy postmaster-general of the colonies, he noted that Rhode Island ship captains shortened their passage from England by cutting across a certain current instead of sailing against it. Franklin extended their knowledge to chart the stream.

HIGH BLOOD PRESSURE

The cause of a fatal constellation of heart and blood-vessel disorders, hypertension is one of man's most critical medical problems

by Irvine H. Page

AMONG physicians and thoughtful laymen there is a growing concern over human vulnerability to high blood pressure and hardening of the arteries. Death certificates show that these associated conditions kill some 600.000 people in this country annually; by 1960, the insurance companies estimate. blood vessel disorders and related diseases of the heart will kill 1,200,000.

To put it another way. 50 of every 100 children born today will die of these diseases. That is three and one half times as many deaths as from cancer. ten times as many as from tuberculosis, and a thousand as many as from infantile paralysis.

High blood pressure (hypertension) and hardening of the arteries (arteriosclerosis) are not, as commonly supposed, merely the concomitants of growing old. Hypertension is by no means limited to middle-aged and elderly people. It is, for example. fast becoming the greatest killer of pregnant women. and. through them, of unborn children. It is estimated that 2,000 mothers and 16.000 unborn infants die of this cause each year. And of the mothers who survive the hypertension originating in pregnancy, 50,000 come to an earlier death as a result.

The statistics alone are sufficiently appalling, and they do not begin to convey the associated human suffering. Yet the public. strangely, seems far from appalled; either it is unaware of this dread mortality or accepts it fatalistically. Hypertension and arteriosclerosis are not glamorous diseases. They work quietly, progressively. and show themselves only late in their course. Their incapacitating effects are most often clearly perceived during the later years of life—the years of wisdom and maturity, lacking which society is the poorer.

Since the 18th century, life expectancy in the U. S. has increased from 39 to 57 years, largely because of the conquest of diseases such as smallpox. typhoid fever. tuberculosis, plague, infantile dysentery, diphtheria and. more recently. pneumonia and streptococcic infections. The reduction of these infectious diseases has permitted people to live to the age when hypertension and arteriosclerosis take their greatest toll. No strict proof exists that the blood vessel diseases are increasing for any other reason than the population's increasing age. I say "no strict proof" advisedly, for it is possible that the faster tempo and increasing frustrations of contemporary living may indeed foreshadow a greater incidence of hypertension independent of age.

Before discussing what hypertension is, it is essential to make clear that the various blood vessel and heart diseases are all parts of a closely interrelated complex, although many people. including many physicians, think of them as separate entities. Actually high blood pressure is very often the cause of hardening of the arteries, and arteriosclerosis in turn may lead

CAPILLARIES, magnified 160 diameters through the skin at the base of the fingernail, form fine loops.

to any one of three types of overt breakdown, depending on the vital area that it damages: 1) apoplexy, or stroke in the brain; 2) coronary thrombosis, or circulatory obstruction and failure of the heart; and 3) failure of the kidneys with resultant uremia. Broadly speaking, all of these conditions must be grouped together as "cardio-vascular-renal" (meaning heart-blood vessel-kidney) diseases, but their connection is generally overlooked. Thus apoplexy is often listed as the cause of death. although the underlying disease which caused the apoplexy may be hypertension or arteriosclerosis or both. Similarly, "failure of the heart" or "failure of the kidneys" may be but a manifestation of the real cause—the destructive effects of abnormally high blood pressure. In other words. a large proportion. perhaps a majority, of failures of the vital circulation of the heart and other organs derives from high blood pressure and hardening of the arteries as the basic causes.

Blood pressure in the human body is regulated by an extraordinarily complex and sensitive mechanism. Blood pumped from the heart flows through ever-narrowing channels (arteries and arterioles) into the smallest blood vessels—the capillaries. Great pressure is needed to pump the blood through the arterial system. But to avoid injury to the delicate capillary bed. the function of which is to provide for the chemical needs of tissue cells. the pressure must be sharply reduced. This job is performed by the small. muscular arterioles, which strongly resist blood flow and, like a series of dam gates, reduce the flow into the capillaries to a gentle trickle. The channels that lead from the capillaries back to the heart broaden as they join and form veins. Little pressure is required to lead blood back to the heart. "Blood pressure," as conventionally measured, is taken as the level of pressure in the larger arteries.

WHEN modern methods of measurement came into use some 45 years ago, arterial pressure in normal adults was found to average 120 millimeters of mercury at the height of the ejection of blood from the heart and about 70 mm. of mercury in the interval between beats. The former is called the systolic and the later the diastolic pressure. and the two are recorded as 120/70 mm. Hg (mercury's chemical symbol).

It is important to remember that perfectly normal people may show wide variations from this average. But establishment of normal values led to the observation that arterial pressure in some people is persistently and abnormally increased. This condition is called arterial hypertension. Any value persistently above 150/90 mm. Hg may be considered abnormal. In some patients the pressure may be as high as 260 to 300 mm. Hg systolic and 140 to 170 mm. Hg diastolic, but the average for well-established hypertension is 220/126 mm. Hg.

Except in a very general way, the height of the blood pressure is not a direct measure of the severity of the disease nor of the outlook for the patient. The outlook is often far more dependent on the quality of blood vessels with which the patient is born, for it is the wear and tear on blood vessels that usually causes death of the patient. Thus the blood pressure reading alone, without other measurements of the condition of the blood vessels and heart, is an unreliable guide.

Since many things may cause persistently high blood pressure, it is necessary to inquire with great care into the origin and the mechanism of the elevation in each case. It is found that some cases are due to disease of the kidneys, such as Bright's disease; some to disease of the adrenal glands, such as tumors; some to diseases of the brain, and so on. But most are due to a cause that is still unidentified. It is this multiplicity of causes and mechanisms which makes for widely different prognoses in individual patients.

The arterioles of patients who have long suffered from arterial hypertension are often thickened, narrowed and fibrous. Some physicians early took the view that this hardening, or sclerosis, was the cause of the increased pressure. They reasoned that the thickening of the vessels impeded the flow of blood, which in turn forced the body to raise arterial pressure lest the tissues receive insufficient blood to nourish them. But other investigators have come to the conclusion that the hardening of arterioles is not the cause but the result of increased arterial pressure. The two diametrically opposed views have resulted in differing approaches to the study of the disease, to treatment and to estimation of the outlook for the patient.

Hardening of the arterioles is believed to be largely irreversible; and so it is, as our present remedies go. The early belief that damage to the blood vessels preceded the rise in blood pressure had gloomy implications, for it suggested that there was little to do but tell the patient that the damage was done, that it would inexorably increase, and, for want of anything better to say, that he had better take it easy.

But the bulk of evidence is now in favor of the second view: that vessel damage is due to the strain of increased pressure. It appears that the beginning of the process is a contraction of the muscles of the arterioles, which narrows the vessels so that the heart must beat harder and pressure must rise to maintain the circulation. This explanation unfortunately does not indicate the basic cause of the contractions. For lack of a better name, the process is called "essential hypertension," meaning that the first abnormality that is discovered is the increase in arterial pressure. Nonetheless this newer view, now well established, is a great deal more heartening than its predecessor, for the contraction of muscles, unlike their hardening, is at least theoretically reversible. It endows the problem of dealing with arterial hypertension with two specific objectives, the first being the removal of the causes of increased pressure and the other the arrest and prevention of vessel damage.

The chain of damaging events proceeds in this wise: The increased force of the heartbeat, in combination with the narrowing of the arterial tree, leads to elevation of the blood pressure. The increase in the power of the heartbeat is accomplished only by dint of increased work. This in turn leads to enlargement of the heart muscle, just as any muscle increases in size when persistently given more work to do. But the time must come when the heart can no longer keep up with the demand made on it, and it fails. Even before that, elevated blood pressure may have done widespread and various damage. If the blood vessels are unable to withstand the increased pressure, they rupture. If they rupture in the brain, a stroke results. Sometimes the blood vessels in the kidneys fail, and uremia results. The kidneys are peculiarly vulnerable because they are composed in large part of blood vessels.

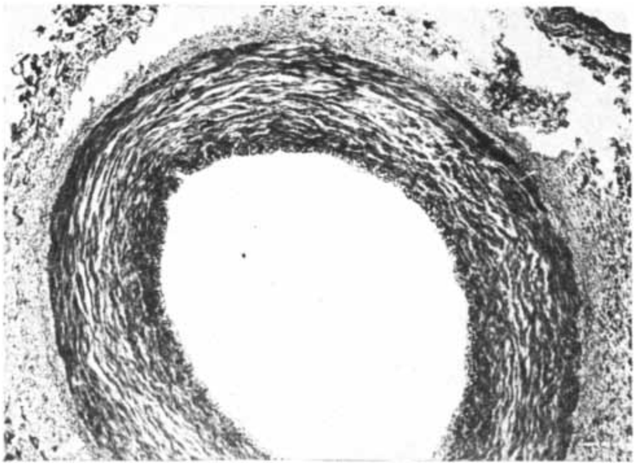
Hypertension can be produced in animals by changing the character of the pulsing stream of blood to the kidneys. Is some similar mechanism at work in the kidneys of man? As yet there is no proof that this is so, but it has provided an important approach for investigation of the problem of the origin of hypertension.

In animals, hypertension may be artificially caused by one of two methods. The first consists of constricting the main artery to the kidneys by means of an adjustable clamp. The second is to envelop the kidneys in a sheet of cellophane or silk. The foreign material acts as a strong irritant, and, in the attempt to wall off the irritation, the body grows a stiff hull around the kidneys which holds them firmly and prevents their normal pulsation. When this occurs, the blood pressure rises.

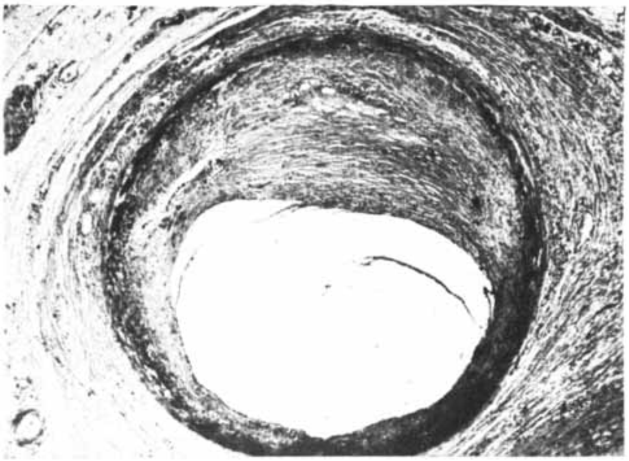
From work on animals with experimental hypertension of kidney origin has come the view that an enzyme called renin, which is contained within the kidney, is liberated into the blood stream. It acts on a protein in the blood to produce a substance called angiotonin, or something very much like it. This angiotonin-like substance seems to be the villain that raises blood pressure. Probably the most important evidence in favor of this view is that the physiological mechanism which seems to operate in the experimental elevation of blood pressure is almost identical with that in patients having essential hypertension.

THE FORMATION of angiotonin is a matter of much interest. It is the first example in which an enzyme seems to be acting as an internal secretion. Possibly other internal secretions will prove to have similar mechanisms. Since the protein on which renin from the kidneys acts is produced by the liver, it is easy to see that the bodily mechanisms for the control of blood pressure are widespread, involving many organs and substances.

The chemical mechanisms which control the expansion and contraction of blood vessels and the amount of blood



HEALTHY ARTERIOLE, magnified 50 times, has a cross section of even, muscular walls. Contraction of muscles regulates blood pressure in the capillaries.



SCLEROTIC ARTERIOLE has hardened and fibrous walls. Progressive sclerosis of the walls narrows the channel for blood flow and contributes to high pressure.

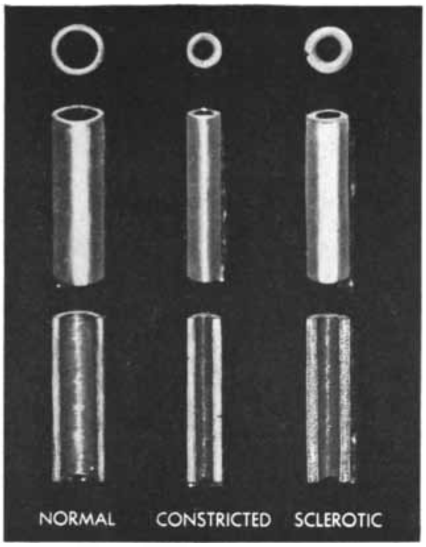
flowing to tissue are exceedingly complex; naturally so, since they have a complex job to do. Each new discovery of a substance which either raises or lowers blood pressure tends to overemphasize the actual importance of that substance, and to lead to disappointment. Thus at one time adrenalin, the internal secretion of the inner portion of the adrenal glands, was believed to be the cause of hypertension. When it was found that this was not true, a nihilistic wave set in which all but left adrenalin without function in the body. Only recently has a truer light been shed on its function.

As an illustration of the complex interplay of the pressure-elevating substances, consider the effect of feeding meat or salt to animals which are given injections of one of the hormones of the adrenal cortex. If salt in particular is withdrawn from the diet, the hormone does not raise blood pressure and seems to produce little injury to the blood vessels. But feed a bit more than the usual amount of salt and the injections now cause a marked rise in blood pressure and severe injury to the blood vessels. It would be easy to assume, of course, that the same is true of patients with hypertension, and to draw the conclusion that salt or meat is the cause of hypertension. There is just enough truth in this view to make it tantalizing. A very low salt diet lowers blood pressure in some patients, but by no means in all. Furthermore, no one has yet proved that the adrenal hormone employed experimentally in animals is present in human adrenal glands, except in minute amounts. Clearly there is much that is highly suggestive in these observations, but the kernel of the problem has not been reached.

Some years ago the research group with which I have been associated was treated to an amusing demonstration of how easy it is to be misled in this field of investigation. We observed that a substance extracted from the urine of supposedly normal physicians working in the hospital greatly raised blood pressure when injected into animals. But this substance could not be found in the urine of our hypertensive patients. An interesting possibility at once suggested itself: the substance might be a blood pressure-elevating agent which normal people got rid of in the urine but which the patients retained. Their inability to get rid of it might be the cause of their high blood pressure. The substance was carefully isolated, crystallized and identified. It turned out to be pure nicotine! The patients had been kept figuratively under lock and key by a strict head nurse who did not believe in the virtue of the minor vices. Smoking was banned for the patients, but not for the physicians. So the mystery was solved, but little was added to knowledge of essential hypertension. There was, however, one incidental addition to our general information. Up to that time, it had been generally believed that nicotine was largely destroyed by the liver; our observation showed clearly that much of it is eliminated in the urine.

RECENTLY an interesting substance has been found in the blood of animals when they are in shock or after crude extracts of kidneys have been injected into their bloodstream. When the substance is injected into normal animals, it produces only a transient rise in blood pressure. But if the kidneys of the animal have been removed a day or two before, then the blood pressure rises greatly and stays elevated for several hours. The substance seems to have its origin in the kidneys and its effect seems to be controlled by the presence of kidneys. But is it concerned in the mechanism of the elevation of blood pressure in man? No one yet knows the answer, but all would admit the challenge of the problem.

A substance such as angiotonin must have blood vessels to act on to produce hypertension. The vessels' response is normally controlled by a variety of factors, among them being the endocrine glands, the liver and the nervous system. The interplay of these various factors influences to a great extent the height of the blood pressure when the organism is acted on by angiotonin. The precise unraveling of the complicated skein is one of the urgent medical problems now being investigated. It would seem reasonable to suppose that as the degree of participation by the various organs in the mechanism elevating blood pressure becomes measurable, a much broader range of methods will be found to modify the level of the arterial pressure.



DIAMETERS of healthy and sclerotic blood vessels show root of hypertension and arteriosclerosis. Constant constriction often leads to sclerosis.

A great deal of evidence derived from bedside examination of patients suggests further that the kidneys play an important part in hypertension. For example, elevation of arterial pressure is the common accompaniment of Bright's disease and pyelonephritis, both diseases of the kidneys. Presumably the kidneys in such cases initiate the rise in blood pressure. But most patients with essential hypertension do not begin with manifest kidney disease. It is believed by many that heightened activity of the nervous system caused by repeated narrowing of the vessels of the kidneys is the trigger that starts the liberation of substances that elevate blood pressure. Indeed, Josep Trueta of London has suggested that nervous stimulation shunts blood away from the cortex of the kidneys, leaving it bloodless, and that this bloodlessness sets in motion reactions, otherwise not occurring, which produce blood pressure-elevating substances. But there seems to be little evidence to support such a concept of the origin of essential hypertension.

The impression should not be created that the kidney theories are the only views currently held by investigators of the origin of hypertension. They are perhaps the most commonly held. Others believe that essential hypertension begins as a result of stress and strain acting on the pituitary gland. They suggest that the pituitary acts on the adrenal glands to stimulate the excretion into the blood stream of a substance noxious to the blood vessels of the kidneys, thus initiating a chain of events which culminates in the appearance of a chemical substance like angiotonin in the blood. This substance in turn is responsible for the narrowing of the arteriolar bed and the stimulation of the force of the heart beat which eventuates in persistent hypertension.

Some believe that hypertension is of purely nervous origin, that the "set" of the mechanism in the brain which regulates blood pressure is altered in an upward direction to cause hypertension.

There is great interest among physicians at present in the view that hypertension is a disease of psychogenic origin, or one of failure of the mechanism of adaptation to respond properly to the unfavorable environment in which most men find themselves. So far no proof has been found that emotional factors are ever the direct cause of essential hypertension. But the fact that hypertensive people commonly show unusual emotional patterns suggests a close if not causal relationship. One thing is certain: the acquisition of equanimity is usually associated with a marked reduction of the level of blood pressure and betterment of the patient's condition. As Plato observed more than 2,000 years ago: "He who is of a calm and happy nature will hardly feel the pressure of age."

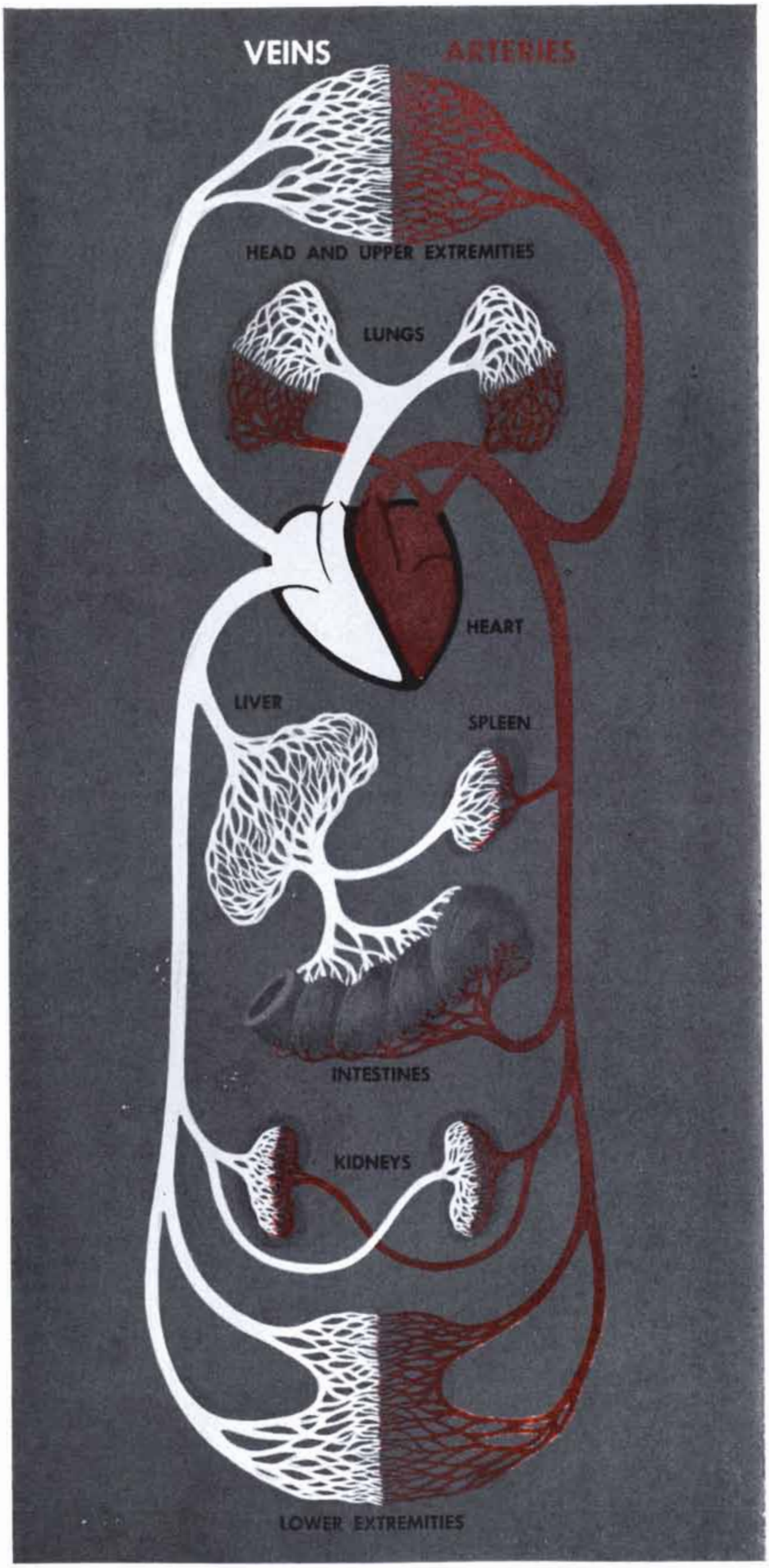
Whether there is such a thing as a hypertensive personality in whom hypertension almost inevitably develops seems doubtful. Certainly the layman's picture of the hypertensive as an overactive, ebullient, expansive. aggressive individual is not correct. Most observers agree on only a few common characteristics: emotional instability, anxiety and resentment often associated with failure to achieve a lofty ambition. Since many hypertensive people have emotional problems, proper care of them always includes intelligent education and guidance, and, in a few, more penetrating psychotherapy such as psychoanalysis.

There is no specific treatment for hypertension, but there are many treatments which can greatly reduce blood pressure and prolong life. Partial or even complete removal of the sympathetic nervous system has been a useful treatment in some patients. Drugs such as potassium thiocyanate are valuable when properly used in the control of intractable headache, and they lower blood pressure as well in some patients. Dihydroergocornine is currently under study and seems to be useful in a limited group of patients. Low salt diets, rice and fruit juice diets are now being actively investigated with. so far, encouraging results. They must be considered. however, as no more than clinical experiments and not established cures.

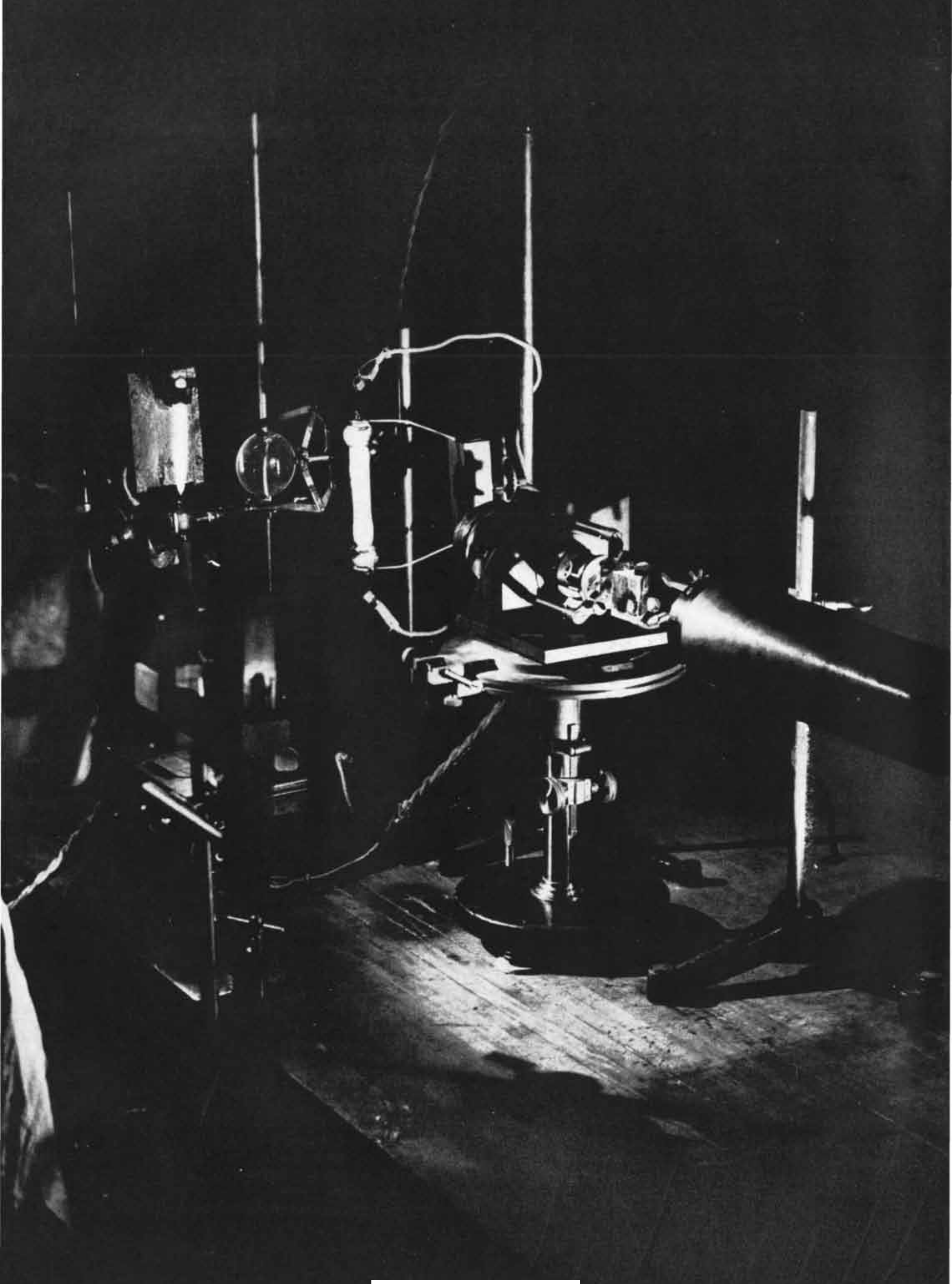
MUCH HAS been made recently of the possibility that hypertension and vascular disease may be caused by an improper adaptation to the frustrations and stresses of civilization. It has been noted that Chinese peasants seem to be relatively free of this disorder. Many years ago George Crile called hypertension a disease of civilization. This view has much to support it, though the final objective proof has yet to be produced. Hans Selye of Toronto has done much to crystallize research which may well lead to an understanding of the way in which the nervous system participates in the genesis and maintenance of high blood pressure. If hypertension and arteriosclerosis are the price we must pay for being civilized. we must find cures for them, or determine what part of civilization exacts such a price. We cannot and will not give up civilization.

The hypertension problem is in a healthy competitive state among its investigators. Further, it has begun at long last to fire the imagination of young researchers and intelligent laymen. The weight of ancient authority is dropping away and in its place critical investigation is appearing, much of it of very high caliber. With continued or, one hopes. much accelerated research. the outlook should be much improved within a relatively short time. Hypertension is a disease which man should be able to conquer. In doing so, he will rid himself of his most lethal enemy.

Irvine H. Page is director of the research division at the Cleveland Clinic and author of medical works.



THE CIRCULATORY SYSTEM and its various organs are outlined in this much simplified diagram. The fine networks of capillaries at the top and bottom represent all those which carry blood to the body's multifarious cells. The branches between the arteries and capillaries are the muscular arterioles.



MEASUREMENT BY MERCURY

The length of a light wave has been our most accurate yardstick. Now the light of a rare isotope transmuted artificially from gold provides the ultimate standard

by William F. Meggers

HOW LONG is an inch? As long as the end joint of a man's index finger, in common lore. The schoolboy and the carpenter define it somewhat more precisely as the distance between two lines on a common wooden ruler. That will do for rough measurement, but we are still far from an exact definition. Rulers are not uniform; they are subject to swelling and shrinking; the coarse lines with which they are marked add a further margin for error. In a fine-structured civilization whose tolerances are measured in millionths of an inch, obviously the inch must be more accurately defined. We need an inch (or a more cosmopolitan measure, the meter, from which the inch may be derived) that is the same everywhere on earth, that remains invariable regardless of time, temperature or other circumstances, and that can be reproduced at will from some fixed, universal standard.

Let us take the most inflexible of metals, cast it in the shape of an end-gauge or calipers and calibrate it to the exact dimensions of our unit. Very good, but our problem has only just begun. Where shall we find the ultimate measure upon which to gauge our instrument? We arrive, finally, at the International Bureau of Weights and Measures near Paris. There in a guarded vault lies a platinum-iridium bar. On it are two fine ruled lines, six to eight microns wide and a certain distance apart. By world agreement, the distance between the centers of the two lines is exactly one meter when the bar is at the temperature of melting ice.

WAVELENGTHS of various spectral lines of mercury 198 are measured by comparing them in the Bureau of Standards laboratory with the lines of cadmium, the best previous standard. Mercury light, produced by the lamp at the left, is made to produce interference fringes by interferometer in right center. Cadmium light, produced by lamp in left center, also passes through interferometer. Fringes are separated by prism (*out of picture to the right*) and compared. Here a small prism has been placed behind interferometer so observer Meggers can make adjustments needed to produce fringes.

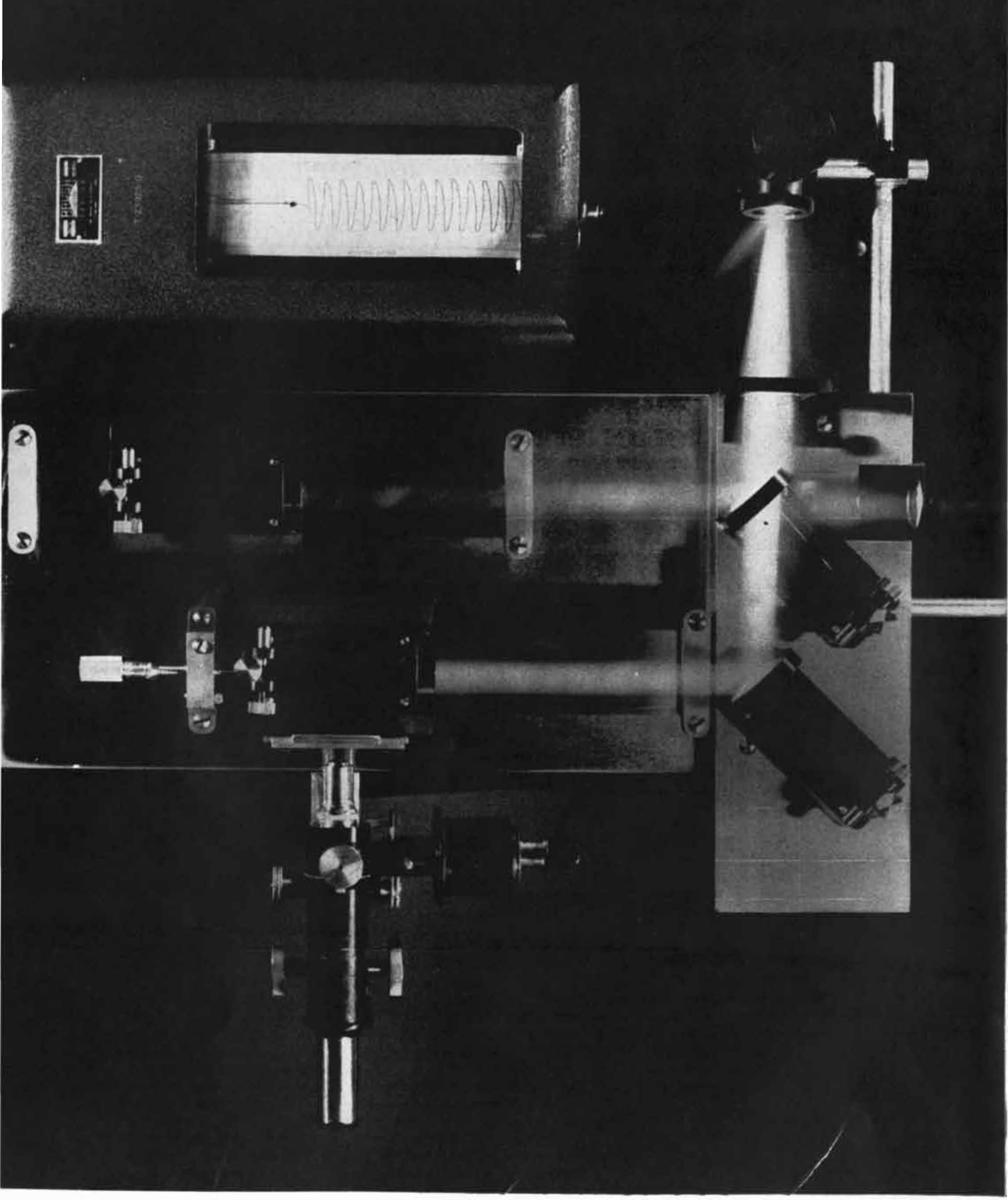
That bar near Paris has been a constant worry to the world. The meter, as everyone interested in scientific measurement knows, was designed in the 1790s to represent one ten-millionth of the earth's quadrant (the distance from the North Pole to the Equator). As early as 1827, a group of natural philosophers meeting in Paris was struck by a disquieting thought: Suppose a comet collided with the earth and changed its size or shape. The standard meter, on which all earthly measurements depended, could not be reproduced from its definition. Before the century's end, earth surveys of greater accuracy showed that the original meter was not exactly one ten-millionth of the quadrant but was one part in 5.000 too short. So in 1889 the meter's definition in terms of the earth was abandoned and it was arbitrarily defined as a certain distance on the platinum-iridium bar almost identical with the original prototype meter. Since then the world's standard of measurement has depended on that frail piece of metal, which has remained the master standard though copies have been distributed to other countries. During World War I there was great fear that a bomb might destroy the master bar. Many scientists agreed that a new standard was urgently required.

Sir Humphry Davy, the 17th and 18th century chemist-poet, had been the first to propose such a change. He suggested as a natural standard of length the diameter of a capillary tube of glass in which water would rise by surface tension to a height exactly equal to the tube's diameter. Jacques Babinet, a French natural philosopher, suggested that a wavelength of light in a vacuum would be a better one. In 1887, the American physicists A. A. Michelson and E. W. Morley translated this suggestion into a practical method. They showed how to measure length by means of the instrument called the interferometer, which they had devised for their celebrated experiments on the motion of the earth through the "ether."

The interferometer is an essentially simple instrument designed to make waves of light overlap and interfere with one another. The simplest interferometer, known as the Fabry-Perot type, consists of two optically flat glass or quartz plates separated by a certain distance and adjusted accurately parallel to each other. The sides of the plates that face each other are coated with thin films of silver or other metal to reflect most of the light but to let part of it through. When a beam of monochromatic light is directed through the instrument, the light that filters through the first plate is trapped between the two plates and begins to bounce back and forth. With each bounce, some light passes on through the second plate to a viewing apparatus. The waves that bounce back combine with following waves. At the viewing end the combined waves form a series of concentric "interference fringes," each fringe representing a wavelength. Bright rings occur where the waves reinforce each other and dark ones where they cancel each other.

THE DIFFERENCE between the diameters of the fringes depends on the double distance (to and fro) between the two interferometer plates, in other words, on the length of each bounce. By varying the distance between the plates, one may alter the pattern of fringes. When the center of the pattern shows maximum brightness, it means that the number of light waves in the double distance between the plates is a whole number, because the successive components are all in phase to interfere constructively. If the center is dark, it means that the number of waves is an integer plus a fraction; at maximum darkness this fraction is ½, that is, the waves are ½ wavelength out of phase and the crest of one wave coincides with the trough of another.

Here, then, is a means of establishing an absolute, invariable standard of length. It rests upon a wavelength of light—an immutable constant of nature under reproducible conditions. Count the first circular fringes, determine the extent to which the waves are out of phase at the center of the circle, and the result is the number of waves, plus the fraction of a wave, that spans the double distance between the two plates. From the known wavelength of the light that is used, it is easy to compute the exact distance between the plates. With monochromatic waves the fraction representing the distance by which the waves are out of phase can be determined to 1/1,000 of a wave-



HOW INTERFEROMETER can translate the length of light waves into units of practical size is shown in this demonstration prepared by the Bausch and Lomb Optical Company. The interferometer here is not the type used in measuring the wavelength of light from mercury 198, nor has mercury 198 been used in this kind of measurement. The demonstration is nonetheless a remarkably clear exposition of the interferometer and its use. As clarified in the diagram at the right, light from the lamp at the top of the photograph is split into two length. and therein lies the unique advantage of measuring lengths with light waves: we are using a scale division 10,000 times finer than the lines ruled on a meter bar.

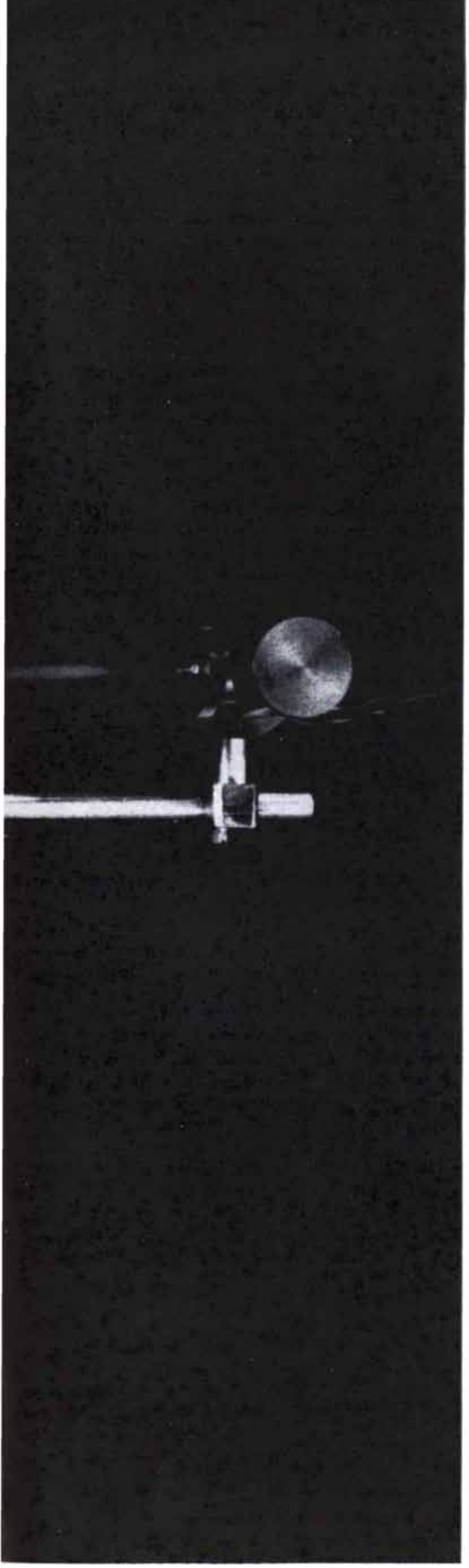
But the problem is less simple than Michelson and Morley at first supposed. We cannot use just any wavelength of light. To attain real accuracy we must employ a homogeneous or monochromatic wave that gives a single sharp spectral line. A complex light source produces fringes that are much too fuzzy. Sixty years ago it was generally assumed that all spectral lines were monochromatic and invariable. Michelson and Morley began by using the wavelength of yellow light emitted by sodium; then they shifted to the green light of mercury, which they suggested would in all probability prove to be the best ultimate standard. Michelson soon discovered, however, that atomic radiations in general were far from monochromatic; the light from each element was made up of a multiplicity of components (now known to be due to the varying nuclear spin of atoms and to the mixture of isotopes that make up almost every natural element). In particular, he found that the green mercury line was one of the most complex in nature. He therefore settled upon the red light of cadmium, which was the most nearly monochromatic among the elements that he studied.

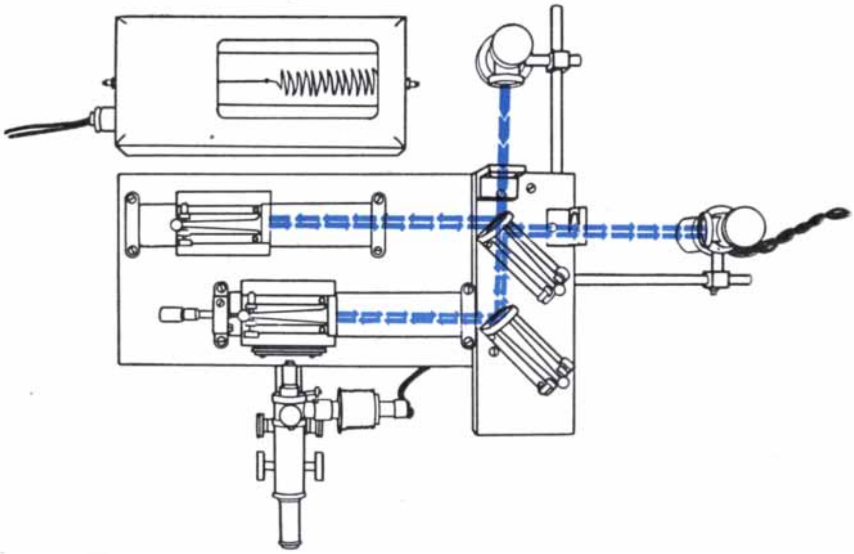
THE NEXT STEP obviously was to measure the cadmium wavelength against the platinum-iridium meter bar. In 1892 Michelson went to the International Bureau of Weights and Measures and made the first such measurement. This experiment has been repeated eight times since then. The average value obtained for the cadmium red wavelength from these nine measurements is 6438.4696 angstroms (one angstrom=1/100,000,000 cm.). The deviations are within the limits of accuracy of the measurements, which would seem to indicate that in half a century the meter bar has changed amazingly little if at all. Yet metal end-gauges, with which it is possible to measure wavelengths more accurately than with a ruled bar, have been found generally to change with time, so there is no *a priori* reason to believe that the international meter bar is strictly immutable. A wavelength of monochromatic light, on the other hand, can reasonably be assumed to be of unchanging length under standard conditions.

Yet the red line of cadmium is a relatively crude measure. It lacks the sharpness required for maximum accuracy. And the counting of fringes demanded by Michelson's method is a labor of fantastic tediousness; there are 1,553,164 red cadmium wavelengths or fringes in a meter!

Since 1931 research has been focused anew on the green line of mercury, which Michelson once considered and rejected. And now at long last we have found the answer in an artificial isotope of mercury obtained by transmuting gold—a reversal of the alchemist's age-old goal. This isotope, Hg^{198}, emits a sharp green line free from complex structure. This wavelength is not only the best standard that has been found but the best that can be found. In mercury 198 we have finally discovered the ultimate standard of length.

Natural mercury consists of a mixture of seven isotopes with the mass numbers 196, 198. 199, 200, 201, 202 and 204 (relative to oxygen 16). Green light from natural mercury consists of 16 components ranging over half an angstrom, that is, more than 100 times the width of a single component. Since isotopes of even mass number have no detectable nuclear spin (one factor which complicates the struc-





beams by a half-silvered mirror in center. The two beams, bouncing back from the two mirrors at left, then unite before entering photocell at right. When the lower of these two mirrors is moved by fine screw adjustment at left, light waves in the two beams are set out of phase to produce circular interference fringes. When the mirror is moved farther, the fringes pass across aperture of photocell and are recorded by device at upper left. Observer at microscope below can then relate the number of fringes to marked scale on movable mirror carriage.

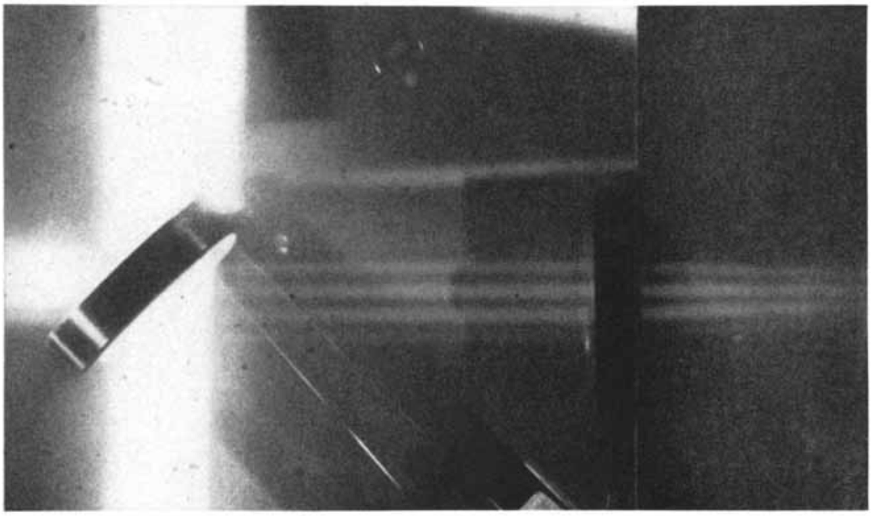
ture of spectral lines), the problem was to isolate an even-numbered isotope that would emit a single, distinct line. Mercury 198, which does not exist in a pure state in nature, was first obtained from gold in 1934 by Enrico Fermi and others. When gold (Au^{197}) is bombarded with neutrons, it yields a radioactive isotope of gold that decays rapidly and becomes stable Hg^{198}. In 1940 Luis W. Alvarez of the University of California demonstrated that neutron bombardment from a cyclotron transmuted sufficient gold into mercury to be detected with a spectroscope. The National Bureau of Standards thereupon purchased 40 ounces of proof gold and requested the University of California to bombard it with neutrons for one or more years. World War II interfered with this project, but near the end of the war there arose rumors of a secret source of neutrons thousands of times more effective than the largest cyclotron. In 1945 the Bureau of Standards gold was transferred to an atomic pile at Oak Ridge, and there, within a year, was produced more than 60 milligrams of highly pure mercury 198.

With this mercury several lamps were made, each using about five milligrams. The simplest is a sealed glass vacuum tube of the size of a cigarette, in which mercury vapor is excited to emit light by high-frequency radio waves. By this method intense light emission can be obtained at extremely low vapor density and temperature, which are necessary conditions for sharp lines. It was at once found that the green light from Hg^{198} produced incomparably sharper fringes than natural mercury.

To use the Hg^{198} fringes for length measurements, the wavelength of the light itself had to be accurately measured. This was done by comparing the Hg^{198} wavelength with that of the red light of cadmium in the interferometer—a method 10 times more accurate than measuring it from the meter bar. Comparison of wavelengths in an interferometer is one of the most beautiful experiments in physical optics; in simplicity and precision it is outstanding among physical measurements. Light from mercury 198 and from cadmium is beamed simultaneously into the interferometer. At the viewing end their interference patterns are shown not as circular fringes but, by projection through a prism and lens, as slit images of diametral sections of fringes without overlapping. The green wavelength of Hg^{198} is easily computed from the red wavelength of cadmium by a method that depends on a comparison of the number of waves of the respective emissions in the double distance between the plates. The green wavelength of Hg^{198} was thus determined to be 5460.752 angstroms, or about 21.5 millionths of an inch. It can be measured by this method with an accuracy of one part in 100 million. And theoretically any length of 10 inches or more can be measured by Hg^{198} and an interferometer with this accuracy.

But how can one be sure that mercury 198 is the *ultimate* standard? The reasons are clear and conclusive. The green line of Hg^{198}, the brightest in mercury's spectrum, coincides almost exactly with the wavelength to which the human eye is most sensitive; it is, for example, 70 times as intense to the eye as the red line of cadmium—a great advantage for the visual adjustment of an interferometer. The weight of mercury is an additional advantage. At low pressures and moderate electrical excitation the monochromaticity of atomic radiations varies as the square root of the atomic mass divided by the absolute temperature. The random motions of radiating particles tend to make spectral lines fuzzy. Naturally these atomic motions are least for heavy particles at low temperatures. Since mercury atoms are nearly twice as heavy as cadmium atoms and radiate strongly at less than half the absolute temperature, mercury waves will be less than half as fuzzy as cadmium waves, other things being equal.

Moreover, to obtain enough cadmium vapor to produce a spectrum, the element must be heated to between 300 and 320 degrees C. This high temperature adds fuzziness to the waves. Mercury, in contrast, has sufficient vapor pressure even at its freezing point (–39 degrees C.) to yield a spectrum through excitation by a high-frequency electric field. Indeed, mercury is unique among all elements in radiating, at low pressure and temperature, a relatively simple spectrum of intense and exceedingly sharp lines, provided that its isotopic structure is eliminated. Furthermore, mercury has another extremely convenient property: by the use of a pair of yellow mercury lines that produces interference coincidences at intervals of 275 waves, the order of interference in the interferometer can be determined without counting the fringes.



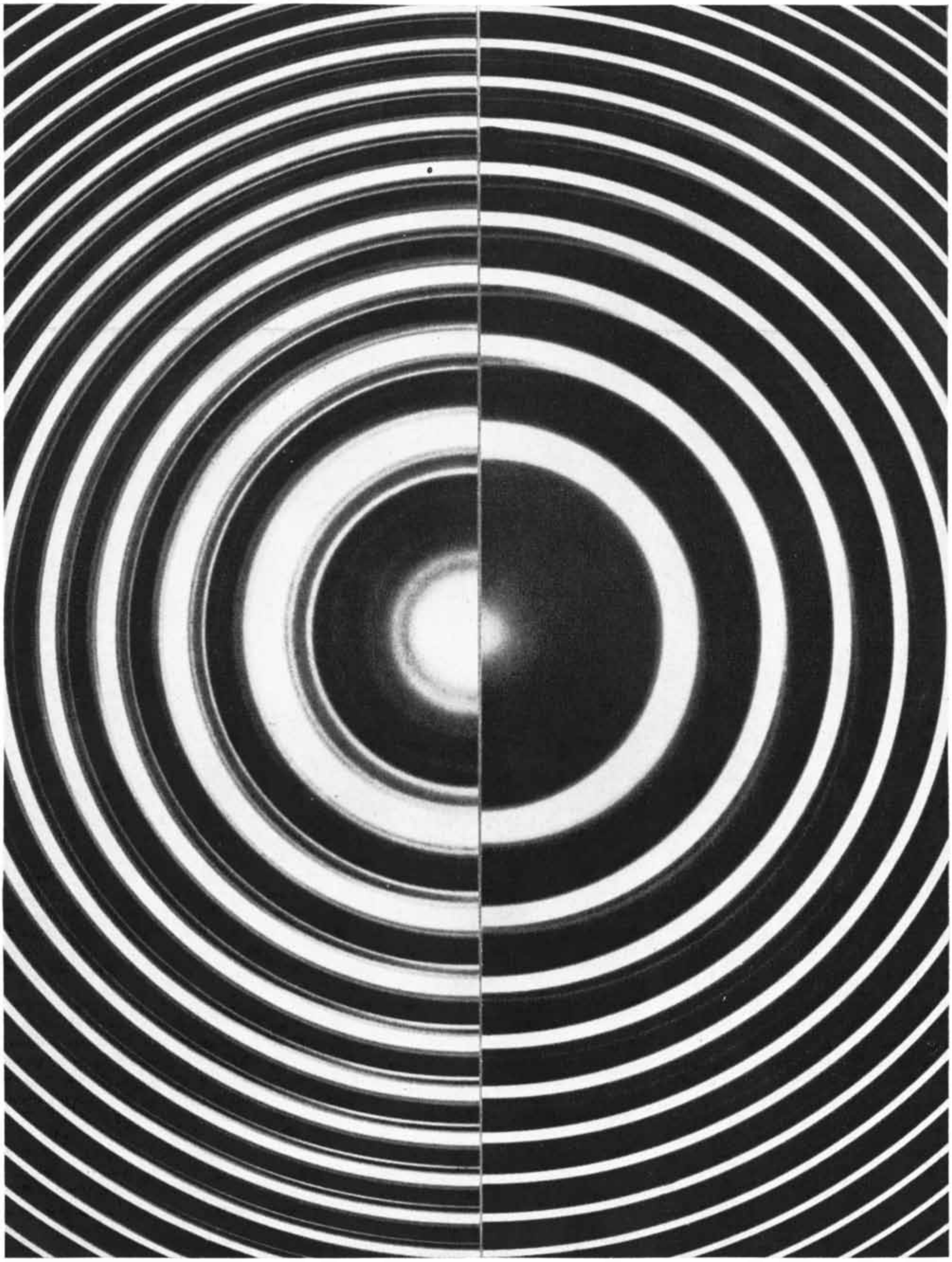
CLOSEUP of interferometer on pages 50 and 51 shows initial beam at top being split in two by half-silvered mirror. Beam returning from the left then passes through mirror. Beam returning from bottom is reflected from mirror back. Picture shows top view of fringes similar to those on opposite page.

THUS THE GREEN line of mercury now stands alone as the most nearly ideal standard wavelength that can ever be obtained from any atoms, natural or artificial. Its unique properties force the conclusion that a progressive scientific world will soon adopt the wavelength of green radiation from Hg^{198} (5461 angstroms) as the ultimate standard of length.

The writer wishes to emphasize that he is not trying to abolish the meter or the metric system. On the contrary, he is anxious to perpetuate both by giving the meter a scientific definition that will make it more accurately reproducible. The meter is here to stay. It remains a very convenient and useful instrument for calibrating ruled scales, with which most length measurements are made. Nonetheless, it is highly arbitrary and unscientific to define the primary standard of length as a distance between two relatively coarse, irregular lines on a metal-alloy bar.

Light waves as a measuring tool can be produced any time, anywhere. They have set new standards of accuracy in measurement. The last possible improvements in this direction can now be made by recognizing the Hg^{198} wavelength as the ultimate standard and by perpetuating a constant and more accurately reproducible meter through its definition in terms of that standard.

William F. Meggers is chief of the spectroscopy section of the National Bureau of Standards.



INTERFERENCE FRINGES produced by the green light of natural mercury (*left half of picture*) and of mercury 198 (*right half*) are compared to show the fundamental advantage of the latter. The fringes of natural mercury are broad and complex. Fringes of mercury 198 are narrow and sharp. Sharper fringes of mercury 198 make possible more precise interferometric measurement and greater flexibility in interferometer's use.

MATHEMATICAL CREATION

An essay written early in this century by the great mathematician Henri Poincaré is still a remarkable insight into the creative processes of the intellect

Edited by James R. Newman

How is mathematics made? What sort of brain is it that can compose the propositions and systems of mathematics? How do the mental processes of the geometer or algebraist compare with those of the musician, the poet, the painter, the chess player? In mathematical creation which are the key elements? Intuition? An exquisite sense of space and time? The precision of a calculating machine? A powerful memory? Formidable skill in following complex logical sequences? A supreme capacity for concentration?

The essay below, delivered in the first years of this century as a lecture before the Psychological Society in Paris, is the most celebrated of the attempts to describe what goes on in the mathematician's brain. Its author, Henri Poincaré, cousin of Raymond, the politician, was peculiarly fitted to undertake the task. One of the foremost mathematicians of all time, unrivalled as an analyst and mathematical physicist, Poincaré was known also as a brilliantly lucid expositor of the philosophy of science. These writings are of the first importance as professional treatises for scientists and are at the same time accessible, in large part, to the understanding of the thoughtful layman.

THE GENESIS of mathematical creation is a problem which should intensely interest the psychologist. It is the activity in which the human mind seems to take least from the outside world, in which it acts or seems to act only of itself and on itself, so that in studying the procedure of geometric thought we may hope to reach what is most essential in man's mind. . . .

A first fact should surprise us, or rather would surprise us if we were not so used to it. How does it happen there are people who do not understand mathematics? If mathematics invokes only the rules of logic, such as are accepted by all normal minds; if its evidence is based on principles common to all men, and that none could deny without being mad, how does it come about that so many persons are here refractory?

That not every one can invent is nowise mysterious. That not every one can retain a demonstration once learned may also pass. But that not every one can understand mathematical reasoning when explained appears very surprising when we think of it. And yet those who can follow this reasoning only with difficulty are in the majority; that is undeniable, and will surely not be gainsaid by the experience of secondary-school teachers.

And further: how is error possible in mathematics? A sane mind should not be guilty of a logical fallacy, and yet there are very fine minds who do not trip in brief reasoning such as occurs in the ordinary doings of life, and who are incapable of following or repeating without error the mathematical demonstrations which are longer, but which after all are only an accumulation of brief reasonings wholly analogous to those they make so easily. Need we add that mathematicians themselves are not infallible? . . .

As for myself, I must confess, I am absolutely incapable even of adding without mistakes. . . . My memory is not bad, but it would be insufficient to make me a good chess-player. Why then does it not fail me in a difficult piece of mathematical reasoning where most chess-players would lose themselves? Evidently because it is guided by the general march of the reasoning. A mathematical demonstration is not a simple juxtaposition of syllogisms, it is syllogisms *placed in a certain order*, and the order in which these elements are placed is much more important than the elements themselves. If I have the feeling, the intuition, so to speak, of this order, so as to perceive at a glance the reasoning as a whole, I need no longer fear lest I forget one of the elements, for each of them will take its allotted place in the array, and that without any effort of memory on my part.

We know that this feeling, this intuition of mathematical order, that makes us divine hidden harmonies and relations, cannot be possessed by every one. Some will not have either this delicate feeling so difficult to define, or a strength of memory and attention beyond the ordinary, and then they will be absolutely incapable of understanding higher mathematics. Such are the majority. Others will have this feeling only in a slight degree, but they will be gifted with an uncommon memory and a great power of attention. They will learn by heart the details one after another; they can understand mathematics and sometimes make applications, but they cannot create. Others, finally, will possess in a less or greater degree the special intuition referred to, and then not only can they understand mathematics

HENRI POINCARE was born in 1854, the son of a civil servant and meteorologist. During his fruitful professional life he devoted himself to pure mathematics and its application to physics and astronomy. Author of several books in these fields, he is also known for his writings in the philosophy of science. Poincaré died in 1912.

even if their memory is nothing extraordinary, but they may become creators and try to invent with more or less success according as this intuition is more or less developed in them.

IN FACT, what is mathematical creation? It does not consist in making new combinations with mathematical entities already known. Anyone could do that, but the combinations so made would be infinite in number and most of them absolutely without interest. To create consists precisely in not making useless combinations and in making those which are useful and which are only a small minority. Invention is discernment, choice.

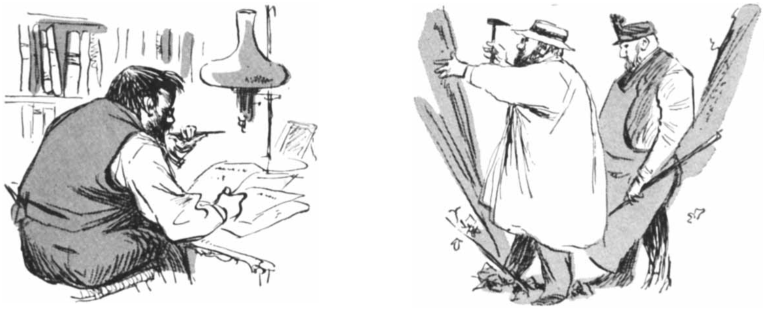
It is time to penetrate deeper and to see what goes on in the very soul of the mathematician. For this, I believe, I can do best by recalling memories of my own. But I shall limit myself to telling how I wrote my first memoir on Fuchsian functions. I beg the reader's pardon; I am about to use some technical expressions, but they need not frighten him, for he is not obliged to understand them. I shall say, for example, that I have found the demonstration of such a theorem under such circumstances. This theorem will have a barbarous name, unfamiliar to many, but that is unimportant; what is of interest for the psychologist is not the theorem but the circumstances.

For fifteen days I strove to prove that there could not be any functions like those I have since called Fuchsian functions. I was then very ignorant; every day I seated myself at my work table, stayed an hour or two, tried a great number of combinations and reached no results. One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. By the next morning I had established the existence of a class of Fuchsian functions, those which come from the hypergeometric series; I had only to write out the results, which took but a few hours.

Then I wanted to represent these functions by the quotient of two series; this idea was perfectly conscious and deliberate, the analogy with elliptic functions guided me. I asked myself what properties these series must have if they existed, and I succeeded without difficulty in forming the series I have called theta-Fuchsian.

Just at this time I left Caen, where I was then living, to go on a geologic excursion under the auspices of the school of mines. The changes of travel made me forget my mathematical work. Having reached Coutances, we entered an omnibus to go some place or other. At the moment when I put my foot on the step the idea came to me, without anything in my former thoughts seeming to have paved the way for it, that the transformations I had used to define the Fuchsian functions were identical with those of non-Euclidean geometry. I did not verify the idea; I should not have had time, as, upon taking my seat in the omnibus, I went on with a conversation already commenced, but I felt a perfect certainty. On my return to Caen, for conscience' sake I verified the result at my leisure.

THEN I turned my attention to the study of some arithmetical questions apparently without much success and without a suspicion of any connection with my preceding researches. Disgusted with my failure, I went to spend a few days at the seaside, and thought of something else. One morning, walking on the bluff, the idea came to me, with just the same characteristics of brevity, suddenness and immediate certainty that the arithmetic transformations of indeterminate ternary quadratic forms were identical with those of non-Euclidean geometry.



CREATIVE PROCESS, described by Poincaré, may go on in the subconscious between periods of conscious work. At work on a problem (*first draw-*

Returned to Caen, I meditated on this result and deduced the consequences. The example of quadratic forms showed me that there were Fuchsian groups other than those corresponding to the hypergeometric series; I saw that I could apply to them the theory of theta-Fuchsian series and that consequently there existed Fuchsian functions other than those from the hypergeometric series, the ones I then knew. Naturally I set myself to form all these functions. I made a systematic attack upon them and carried all the outworks, one after another. There was one, however, that still held out, whose fall would involve that of the whole place. But all my efforts only served at first the better to show me the difficulty, which indeed was something. All this work was perfectly conscious.

Thereupon I left for Mont-Valérien, where I was to go through my military service; so I was very differently occupied. One day, going along the street, the solution of the difficulty which had stopped me suddenly appeared to me. I did not try to go deep into it immediately, and only after my service did I again take up the question. I had all the elements and had only to arrange them and put them together. So I wrote out my final memoir at a single stroke and without difficulty.

I shall limit myself to this single example; it is useless to multiply them. . . .

Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable, and traces of it would be found in other cases where it is less evident. Often when one works at a hard question, nothing good is accomplished at the first attack. Then one takes a rest, longer or shorter, and sits down anew to the work. During the first half-hour, as before, nothing is found, and then all of a sudden the decisive idea presents itself to the mind. . . .

There is another remark to be made about the conditions of this unconscious work; it is possible, and of a certainty it is only fruitful, if it is on the one hand preceded and on the other hand followed by a period of conscious work. These sudden inspirations (and the examples already cited prove this) never happen except after some days of voluntary effort which has appeared absolutely fruitless and whence nothing good seems to have come, where the way taken seems totally astray. These efforts then have not been as sterile as one thinks; they have set agoing the unconscious machine and without them it would not have moved and would have produced nothing. . . .

Such are the realities; now for the thoughts they force upon us. The unconscious, or, as we say, the subliminal self plays an important role in mathematical creation; this follows from what we have said. But usually the subliminal self is considered as purely automatic. Now we have seen that mathematical work is not simply mechanical, that it could not be done by a machine, however perfect. It is not merely a question of applying rules, of making the most combinations possible according to certain fixed laws. The combinations so obtained would be exceedingly numerous, useless and cumbersome. The true work of the inventor consists in choosing among these combinations so as to eliminate the useless ones or rather to avoid the trouble of making them, and the rules which must guide this choice are extremely fine and delicate. It is almost impossible to state them precisely; they are felt rather than formulated. Under these conditions, how imagine a sieve capable of applying them mechanically?

A first hypothesis now presents itself; the subliminal self is in no way inferior to the conscious self; it is not purely automatic; it is capable of discernment; it has tact, delicacy; it knows how to choose, to divine. What do I say? It knows better how to divine than the conscious self, since it succeeds where that has failed. In a word, is not the subliminal self superior to the conscious self? You recognize the full importance of this question. . . .

Is this affirmative answer forced upon us by the facts I have just given? I confess that, for my part, I should hate to accept it. Reexamine the facts then and see if they are not compatible with another explanation.

***ing*), Poincaré went on a geology expedition (*second drawing*). The solution came to him as he stepped into omnibus (*third drawing*), was written later.**

It is certain that the combinations which present themselves to the mind in a sort of sudden illumination, after an unconscious working somewhat prolonged, are generally useful and fertile combinations, which seem the result of a first impression. Does it follow that the subliminal self, having divined by a delicate intuition that these combinations would be useful, has formed only these, or has it rather formed many others which were lacking in interest and have remained unconscious?

In this second way of looking at it, all the combinations would be formed in consequence of the automatism of the subliminal self, but only the interesting ones would break into the domain of consciousness. And this is still very mysterious. What is the cause that, among the thousand products of our unconscious activity, some are called to pass the threshold, while others remain below? Is it a simple chance which confers this privilege? Evidently not; among all the stimuli of our senses, for example, only the most intense fix our attention, unless it has been drawn to them by other causes. More generally the privileged unconscious phenomena, those susceptible of becoming conscious, are those which, directly or indirectly, affect most profoundly our emotional sensibility.

It may be surprising to see emotional sensibility invoked *à propos* of mathematical demonstrations which. it would seem, can interest only the intellect. This would be to forget the feeling of mathematical beauty, of the harmony of numbers and forms, of geometric elegance. This is a true esthetic feeling that all real mathematicians know, and surely it belongs to emotional sensibility.

Now, what are the mathematic entities to which we attribute this character of beauty and elegance, and which are capable of developing in us a sort of esthetic emotion? They are those whose elements are harmoniously disposed so that the mind without effort can embrace their totality while realizing the details. This harmony is at once a satisfaction of our esthetic needs and an aid to the mind, sustaining and guiding. And at the same time, in putting under our eyes a well-ordered whole, it makes us foresee a mathematical law. . . . Thus it is this special esthetic sensibility which plays the role of the delicate sieve of which I spoke, and that sufficiently explains why the one lacking it will never be a real creator.

Yet all the difficulties have not disappeared. The conscious self is narrowly limited, and as for the subliminal self we know not its limitations, and this is why we are not too reluctant in supposing that it has been able in a short time to make more different combinations than the whole life of a conscious being could encompass. Yet these limitations exist. Is it likely that it is able to form all the possible combinations, whose number would frighten the imagination? Nevertheless that would seem necessary, because if it produces only a small part of these combinations, and if it makes them at random, there would be small chance that the *good*, the one we should choose, would be found among them.

Perhaps we ought to seek the explanation in that preliminary period of conscious work which always precedes all fruitful unconscious labor. Permit me a rough comparison. Figure the future elements of our combinations as something like the hooked atoms of Epicurus. During the complete repose of the mind, these atoms are motionless, they are, so to speak, hooked to the wall. . . .

On the other hand, during a period of apparent rest and unconscious work, certain of them are detached from the wall and put in motion. They flash in every direction through the space (I was about to say the room) where they are enclosed, as would, for example, a swarm of gnats or, if you prefer a more learned comparison, like the molecules of gas in the kinematic theory of gases. Then their mutual impacts may produce new combinations.

WHAT IS the role of the preliminary conscious work? It is evidently to mobilize certain of these atoms, to unhook them from the wall and put them in swing. We think we have done no good, because we have moved these elements a thousand different ways in seeking to assemble them, and have found no satisfactory aggregate. But. after this shaking up imposed upon them by our will, these atoms do not return to their primitive rest. They freely continue their dance.

Now, our will did not choose them at random; it pursued a perfectly determined aim. The mobilized atoms are therefore not any atoms whatsoever; they are those from which we might reasonably expect the desired solution. Then the mobilized atoms undergo impacts which make them enter into combinations among themselves or with other atoms at rest which they struck against in their course. Again I beg pardon, my comparison is very rough, but I scarcely know how otherwise to make my thought understood.

However it may be, the only combinations that have a chance of forming are those where at least one of the elements is one of those atoms freely chosen by our will. Now, it is evidently among these that is found what I called the *good combination*. Perhaps this is a way of lessening the paradoxical in the original hypothesis. . . .

I shall make a last remark: when above I made certain personal observations, I spoke of a night of excitement when I worked in spite of myself. Such cases are frequent. and it is not necessary that the abnormal cerebral activity be caused by a physical excitant as in that I mentioned. It seems, in such cases, that one is present at his own unconscious work, made partially perceptible to the over-excited consciousness, yet without having changed its nature. Then we vaguely comprehend what distinguishes the two mechanisms or, if you wish, the working methods of the two egos. And the psychologic observations I have been able thus to make seem to me to confirm in their general outlines the views I have given.

Surely they have need of [confirmation], for they are and remain in spite of all very hypothetical: the interest of the questions is so great that I do not repent of having submitted them to the reader.

James R. Newman is an attorney and co-author (with Edward Kasner) of Mathematics and the Imagination.

BOOKS

Arnold Toynbee's "Civilization on Trial": an analysis of the historian's statement of his views and methods

by Abram Kardiner

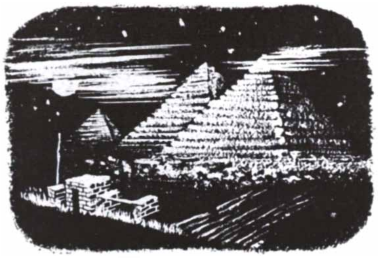
THE strange popularity of Arnold Toynbee, now much inflated, has received a fresh boost from his newly published "Civilization on Trial" (Oxford University Press). It is a popularity that needs to be explained. It cannot be due only to the attention Henry R. Luce has given him in the magazines *Time* and *Life*, nor to the timeliness and importance of the message conveyed by his book. It is more likely due to the desperate public need to get some bearings along the uncharted course of contemporary civilization from anyone who appears qualified to supply them. The Toynbee fad is not world-wide. His native England has not participated in it; only two of the thirteen essays in "Civilization on Trial" were delivered there. It is in the U. S. that Toynbee has become a prophet. His exertions appear to have been called forth largely by the anxiety of Americans.

This being the provocation, it cannot be said of Toynbee that he rose to the occasion. His message, for all its saccharine piety, has neither originality, conviction nor dignity. Perhaps the situation caught him off guard. Perhaps he had difficulty in adjusting his perspective from the telescopic view of history to the microscopic view of our troubled world.

In any event Toynbee has little to say that the responsible student of human social adjustment can take seriously. In this book, as in his vast histories, he remains singularly uninfluenced by the recent advances in anthropology, psychology and sociology. We must hold him accountable for this ignorance. Were he acquainted with these disciplines, Toynbee could not in good conscience avoid using them for the particular subject matter we call "history." Nor could he with good grace argue the timeworn issue of whether our basic intellectual orientation should be scientific or theological.

What then do we find in Toynbee's approach to history? About this Toynbee here is all too candid—much more so than he is in his larger works. He freely tells us of his prejudices and predilections. And with little self-consciousness he tells us how he arrived at the master plan for his conception of history. It came about as a result of his education in the Bible and in the history and literature of Greece and Rome. Toynbee was also influenced somewhat by Oswald Spengler, but dismissed his conclusions because he provided no explanation for the rise, development and decline of civilizations. Spengler, says Toynbee, was too arbitrary and explained nothing. Toynbee rejects the German *a priori* method and offers English empiricism instead.

Toynbee set this empiricism to work on the principal keys of the 19th-century historians: race and environment, neither of which "unlocks the fast closed door of history." Then he turned to mythology, which somewhat embarrasses him. "Had I been acquainted with the works of C. J. Jung [a choice Mr. Toynbee does not explain], they would have given me the clue. I actually found it in Goethe's *Faust*. . . . Because God's works are perfect, the Creator left himself no further scope for His creative powers, and there might have



been no way out of this impasse if Mephistopheles—created for this very purpose—had not challenged God to give him a free hand, to spoil, if he can, one of the Creator's chief works. God accepts the challenge and thereby wins an opportunity to carry His work of creation forward."

Toynbee's first "challenge and response" is thus a wager between God and the Devil, the latter being a creation of God so that He may be kept busy at the job of creating something new. In order to keep the game going "we are bound to assume that the Devil does not always lose." This is how Toynbee's challenge and response, the famous formula that supposedly explains the evolution of civilizations, came into being.

Toynbee feels that there are two ways of looking at history. One is the cyclic repetition of birth and death, accepted by the Greeks and Hindus. The second is the Jewish-Zoroastrian belief that history is a masterful and progressive execution of a divine plan that transcends comprehension. Toynbee settles for a happy fusion of both ideas. There are cycles and a divine plan. Man learns through suffering.

This master plan is a better conception for a literary epic than for an empirical study of history. It is a conception which insists that Toynbee be an unreliable observer and a prejudiced interpreter of facts. The most shocking aspect of Toynbee's master plan is that it takes man's fate out of his own hands, making history a mere sideshow of a divine game in which the motive forces are not concerned directly with man and hence are incomprehensible to him. It is a struggle between Ormuzd and Ahriman (the Zoroastrian spirits of Good and Evil) and is of no more interest than the fate of an anthill.

MAN, STATES Toynbee, may not discover the successes and failures of society by empirical research into the past and present, by examining the success or failure of different types of social organization. Nor may he study the role that psychological conflict and motivation play in social stability and social disintegration. Man must surrender all such grandiose presumptions and yield to a dogma, to the article of faith that God knows best.

In attempting to answer the question of where we now stand in history, after recounting the difficulties of deciding the relative merits of Russian and Western culture, Toynbee says: "Our cue may still be given by the message of Christianity and the other higher religions." If history merely repeats itself, we are doomed both by Toynbee and Spengler. We may, of course, try such stopgaps as world government, or vary free enterprise with socialism. This is all but incidental. Let us, advises Toynbee, put the secular superstructure of society back on a religious foundation. The technological scaffolding of Western society will fall away first because it was initiated in the 17th century as a reaction against 100 years of religious wars. This, says Toynbee, was a mistake. Society threw the baby out with the bath. In trying to free itself of wars it discarded religion.

It would be a great injustice to Toynbee if we did not examine the reasons that lead him to endorse this doctrine of hopelessness. He claims that there are five civilizations left in the world, each of which regards itself as the chosen order. Toynbee rejects a world confederacy. He finds a world state impossible without an exhausting war of conquest and a new *pax Romana*. The giants, the U. S. and Russia, are antagonistic to each other. Toynbee suggests a third power, essentially liberal and not committed to fighting socialism:

a Central Europe without Germany.

Toynbee is not altogether sure that this will work out well, because the world of the air age—transcending oceans, rivers and mountain ranges—may find a new center of gravity. This center will be determined by "human geography," *i.e.*, human numbers, energy, ability, skill and character. The rousing of the world's "neolithic peasantry" is only partly accomplished. It has yet to be effected among 1,500 million unawakened peasants, whose gravitational pull may set the center of the world back again in the vicinity of Babylon. This event will be heralded by a new religion.

It is to religion that Toynbee assigns the job of unifying the world. There appears to be little real conviction in this belief, however. because his view of religion is not consistent. Religion is at once the only serious occupation of man, and "a transitional thing which bridges the gap between one civilization and another." Toynbee finds himself in a dilemma. He says "religion is subsidiary to the reproduction of secular civilization or . . . successive rises and falls of civilizations may be subsidiary to the growth of religion." He leans toward the latter.

TOYNBEE has thus made his position very clear, both in regard to the manner in which his histories are compiled, and in regard to his message for our troubled times. His histories are an arbitrary selection of historical patterns to prove a poetic conception of man's fate on this planet. He knew the master plan first and teaches his doctrine by historical parable.

In "Civilization on Trial" Toynbee proclaims his emotional bankruptcy. He ridicules all efforts to make man an object of scientific study, declares all efforts at political liberalism to be vain endeavors, condemns science as the pastime of fools. In place of all this he asks us to assume a faith he does not himself fully embrace, and asks us to put our trust in a course of action of whose outcome he is extremely uncertain. Toynbee has rationalized himself into the theological position by manipulating the hen-and-egg question of whether civilizations exist in order to give birth to "higher" religions or vice versa. His final decision is made on the basis of a personal bias. There is no logic in his facts because Toynbee doesn't know what factors determine the sequence of social events; nor does he ask any questions about the sequence. Having left himself ignorant of the noteworthy advances in anthropology and psychology, Toynbee argues his few facts with dated pedantry.

To Toynbee religion is not a social phenomenon that must be studied with detachment but a phenomenon that must be given extraterritorial rights. This is not a view to which anyone acquainted with the comparative study of religion can subscribe. The study of the religions of all peoples. primitive and civilized. shows that there is no such thing as a lower or a higher religion. The belief in a superior being who creates the world and man is universal to all religions. What is peculiar to each religion is the means of soliciting the aid of the deity or incurring its displeasure. And this is contingent upon the particular mores and customs that it is the business of religion to maintain. Hence as the mores vary, the religion varies. The so-called higher religions are not the products of what Toynbee calls "deeper religious insights"—whatever that may mean—but are always subservient to social necessities.

A case in point is the religion of Egypt. The political unification of Egypt was occasioned by the necessity to control the water supply of the Nile for purposes of irrigation. Bloody wars were fought for this unification. When the conquest was completed the local gods of the original 42 districts were merged into a hierarchy, but all of these original deities were included in the larger family of the gods. In other words the religion and its dogmas were subject to a synthetic elaboration. When the economic resources of Egypt were preëmpted by a small feudal aristocracy and used to build pyramids—each with its temple, priesthood and perpetual endowment—the Egyptian economy crumbled. The result was a religious revolution and the elevation of Osiris, the god of suffering, to the status of chief deity. Osiris was the champion of the suffering masses. And with his elevation came the democratization of post-mortem rights, heretofore the privilege of the elite. So the masses won their illusion—the right to happiness after death.

This was indeed a religion created by a recalcitrant proletariat; this time an internal proletariat, to use Toynbee's classification. But there is no evidence that the Osirian revolution brought any social reforms. The rise of Christianity was likewise a movement of oppressed masses within the framework of the Roman Empire. No social reforms were possible; the masses had to be satisfied with post-mortem progress.

Even the "higher" religions change. From Job to Calvin we see a steady evolution within a fixed ideological framework. And religions always change in accordance with certain social pressures and needs which they express. For religion indeed has the very important function of stabilizing the social order.

If we adopt this point of view of the social function of religion, it is easy to deduce what it was that displaced its authority. It was not depravity and wanton irreligiosity, but the fact that, for a time at least, human anxiety was diminished sufficiently for the secular state to take over some of the functions once delegated to the church. Salvation was replaced by the ability of social organization to satisfy human needs.

Now that this brief interlude in human affairs appears to be drawing to a close, Toynbee wishes us to recreate social stability by the fantasies of 2,000 years ago, of which only the shadow lives today. This reviewer submits that it is not altogether ethical for our time to recommend that social stability be maintained by fear of the supernatural, while exonerating human society from its share in the creation of suffering.

IF I JUDGE the temper of the time correctly, I do not think that Arnold Toynbee's exhortations are presently in order, or that the illusive satisfactions promised after death will get much of a following. Temporal success, a higher standard of living and freedom from material anxiety are the only currency for social remedies today. To this challenge Toynbee replies by denying the problem, by inviting us to retreat from reason and to surrender to supernatural power. He claims that the ultimate ends of human life are beyond the reach of human judgment. John Dewey, in his "Problems of Men," answers this thesis adequately. "In a time as troubled as the present, a philosophy which denies the existence of any natural and human means of determining judgments as to what is good and evil, will work to the benefit of those who hold that they have in their possession superhuman and supernatural means for infallible ascertainment of ultimate ends, especially as they also claim to possess the practical agencies for ensuring the attainment of final good by men who accept the truths they declare."

And so we come away from Arnold Toynbee's book much disillusioned, but a little grateful that he has so completely revealed himself. Who would have thought that if you scratched Toynbee you would find an epic poet and a missionary? About his explanation of the rise and fall of cultures, the reviewer feels much as he did as a child when his father taught him nursery rhymes at bedtime. The one that baffled him most ran: "The King of France with forty thousand men marched up the hill and then marched down again." The child insisted on knowing why the king marched up the hill and down again. To which his father always said, "Go to sleep."

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THE AMATEUR

Conducted by Albert G. Ingalls

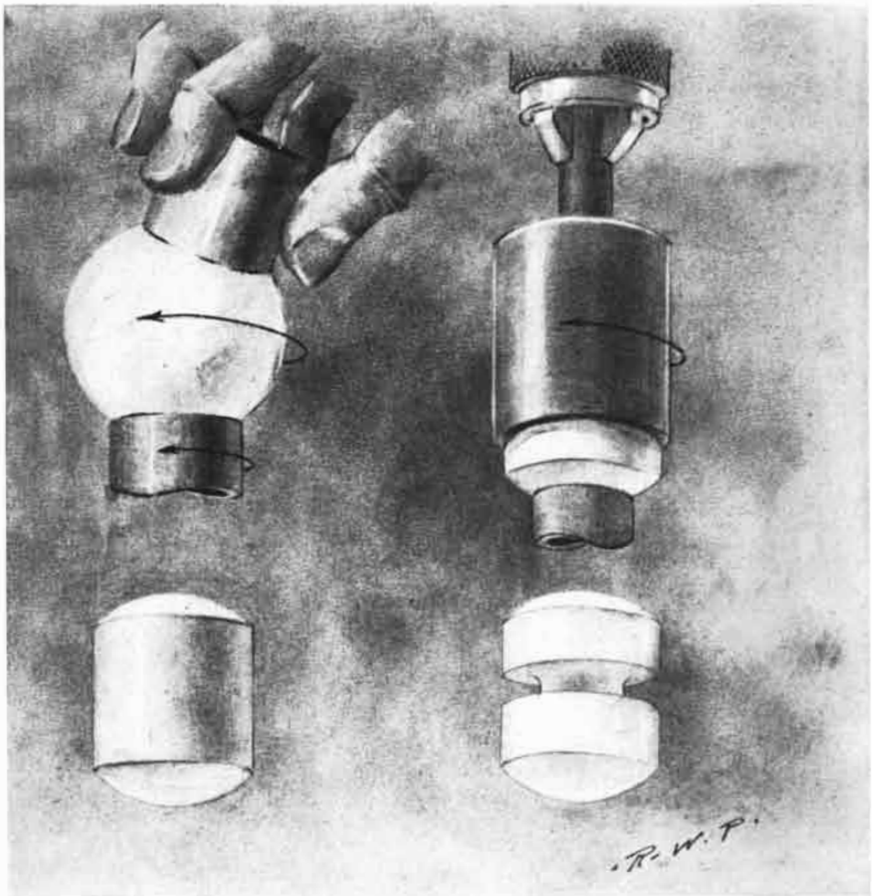
MAKING a telescope eyepiece lens of the simple, old-fashioned Coddington type is "an interesting and instructive experiment," writes John M. Holeman of Richland, Wash., "which is so unusual it should be worth trying. I have just finished trying it. I had some fun and the oculars made are not nearly so bad as anticipated." Invited to describe his adventure, Holeman wrote the following:

First of all, a piece of optical glass is cut down by sawing, chipping, or grinding to an approximate sphere perhaps 7/8-inch in diameter. The source of glass may be an old lens or prism or a chunk of rolled optical glass—borosilicate crown. (War surplus prism blanks sell for a few cents.)

If handy, a wet glazier's abrasive belt sander will make quick work of it. Or the chunk may be rubbed to a rough ball on another piece of glass or metal with coarse abrasive grains and water.

The ball is now ground to a perfect sphere by the method which has been used in China for thousands of years to make quartz gazing crystals. The method is still used by German lapidaries to make agate marbles. The rough sphere is ground between two brass tubes charged with Carbo. The tubes should have walls from about 1/16-inch to 1/32-inch thick and have a diameter two thirds that of the rough sphere of glass. One tube is fastened to a vertical spindle and rotated at moderate speed by a motor. The ball is placed on top of this tube. The other tube is of the same size and is held on top of the sphere at an angle of about 15 degrees. The sphere is charged by means of a paint-brush dipped in coarse Carbo and water. Carbo embeds itself in the soft brass and cuts the glass on a curve. The ball then rotates and is cut on all surfaces by the two tubes. This is the principle of the lens generator, the modern machine which makes spherical surfaces, and of the centerless grinder.

The more the ball rolls the smaller and rounder it becomes. If you did a poor job of shaping the original rough sphere and



Steps in making a Coddington lens

ASTRONOMER

tried to work a jagged chunk having sharp corners and deep fissures you may take solace in the original Chinese treatise on gazing balls which, translated, states: "The going may be a little rough at first but it will soon settle down."

To those who may ask whether the ball gets smaller faster than it gets rounder I can offer the accompanying table of figures on one I made. Grinding was started at 9:30 o'clock and proceeded with interruptions for changing abrasive and making measurements as shown. "Max. diam." was the diameter in inches across the longest axis and "Min. diam." the shortest. "Difference" is the difference between the two measurements and shows how nearly round the sphere was. The table shows that while the sphere loses size it gets

Time	*Max. diam.*	*Min. diam.*	*Difference*	*Abrasive*
10:00	.820	.797	.023	No. 100
10:05	.813	.793	.020	No. 250
10:12	.809	.790	.019	Same
10:20	.802	.788	.014	Same
10:32	.798	.786	.012	Same
10:37	.792	.7835	.0085	Same
10:43	.788	.781	.007	Same
10:48	.7845	.779	.0055	Same
11:00	.7785	.776	.0025	Same
11:07	.7740	.7730	.0010	No. 500
11:10	.7735	.7724	.0009	Same
11:13	.7226	.7220	.0006	Fine Emery
11:15	.7217	.7215	.0002	Same
11:30	.7213	.7212	.0001	Same
11:45	.7211	.7211	.0000	Rouge

rounder much faster than it gets smaller. By continuing the process a reasonable length of time the shape should become perfect so far as can be measured. The table also shows the approximate length of time needed to grind a sphere 3/4-inch in diameter.

Polishing was done as follows. The lower tube was cleaned and heated with a flame until pitch would melt on it, then a thick rim of hot pitch was built up around the edge. While the pitch was still soft a washer of felt, cut out of an old hat, was pressed down on the rim and held in shape by the ground sphere. The top tube was later treated the same way, so that both tools now had a rim of felt attached to their working surfaces. To polish, the felt was charged with rouge and water, and polishing went as with grinding, but more smoothly. Ten minutes gives a good polish.

Now we have a perfect glass sphere which could be used "as is," especially if it is a smaller size. But for larger sizes (and I suggest trying these first) it had better be made into a Coddington lens. The right cylinder diameter for a Coddington $^3/_4$-inch long is about $^3/_8$ inch. To make this, a piece of wooden dowel $^3/_8$-inch in diameter was concaved on one end to fit the sphere and the sphere was cemented to it with hard pitch. Now a "cookie cutter" charged with medium Carbo was brought down on it in a drill press and a cylinder was cut out of the sphere.

THE FINAL operation, after removing the waste from the sphere, is cutting the Coddington field stop. Leaving the cylinder of glass still cemented to the dowel, the glass is rotated against a thin edge of metal or other sheeting armed with abrasive and a thin groove is cut around the cylinder to a constant depth, stopping when the groove begins to infringe on the field. This groove, when blackened with India ink or paint, acts as an aperture stop, giving a sharp edge to the field and removing the poorly lighted and poorly defined marginal rays.

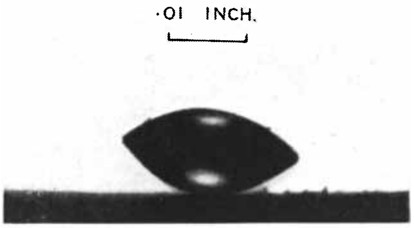
It is interesting to see how small an ocular can be made by this method. If anyone completes one less than 4 mm. in diameter I hope he will let me know and I will send him the straitjacket I am now wearing.

I found that long-focus Coddingtons, which are easier to make, were poor. The one made from a $^3/_4$-inch sphere had a field of about 40 degrees of which only about 20 degrees was good. There was much aberration and color at the edges. Eye relief was satisfactory at about $^1/_2$ inch and seeing in the center was fine. The best one I made has an effective focal length of .31 inch, an angular field of 40 degrees, an eye relief of .2 inch and is usable with eyeglasses. The definition is good, there is no color, and it is grooved down to about a .3-inch waist. It is the best short-focus ocular I have used. The shortest I have completed is .22-inch focus but it didn't turn out well, though it is usable provided you really want an ocular of that short focal length. If we now go a step further and regard the solid ocular as the "triplet" field lens of an orthoscopic ocular and add a plano-convex lens, flat side toward the eye, we have a fairly good imitation orthoscopic design with a larger usable field and more eye relief. For example, if the solid ocular made from the $^3/_4$-inch sphere mentioned above is used in conjunction with a plano-convex lens of about $1^1/_2$-inch focal length and with a spacing of about $^1/_4$ inch between the two, a considerable improvement will be noted in the marginal definition. The resulting eyepiece will be no world beater, but usable.

End of Holeman's contribution.

If the Coddington is approached with great expectations, the probable reaction, unless the worker is objective in his estimate, will be that it is no good at all. But if no miracle is expected the result may equal or surpass the expectation. The project was undertaken by Holeman as a kind of sporting adventure to see whether the very old-fashioned ocular might not have more merit than might be thought, and so it proved. Bell, in *The Telescope*, rates the Coddington as somewhat better than a simple lens.

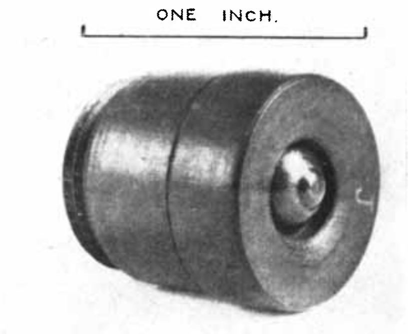
ANOTHER adventure in the unusual is the modern attempt to duplicate some of the tiny high-power eyepiece lenses made by the great Sir William Herschel (1738-1822). These were described in the *Transactions of the Optical Society* (London), Volume 26, by W. H. Steavenson, F.R.A.S., a prominent member of the



In comparison a pinhead is huge

mainly amateur British Astronomical Association. Steavenson has kindly furnished two of the photographs originally published in that periodical. He visited the old Herschel home, examined and carefully tested many of Herschel's mirrors and flats, also the famous "seven-foot" reflector (7 feet, $2^3/_4$-inch focal length, 6.2-inch aperture) so often mentioned in Herschel's writings. In the *Transactions* Steavenson writes:

"Herschel's claims to have used powers between 1,000 and 6,000 on his seven-foot telescopes have been the subject of some



Herschel's highest-powered eyepiece

controversy and not a little incredulity in the past. It therefore seemed to be of particular interest to find out whether he really possessed eyepieces which would yield such powers as these. Quite a short search sufficed to lay any doubts at rest by revealing no less than nine of these eyepieces, whose focal lengths and powers (on the telescope used by Herschel) were found by careful measurement to be as given in the table.

"All these are well-formed bi-convex lenses, with the exception of D_{21} [*identifying notation—Ed.*], which is a simple sphere. Two or three of them, including the smallest, were found to be somewhat astigmatic, and in some cases there were signs of devitrification of the surfaces; but in general they gave sharp images in the micro-focometer used, and their focal lengths were quite readily measured.

"All were tested on celestial objects with a six-inch Wray refractor and were found to form recognizable (though of course dim and diffuse) images of stars and planets. Even D_{26}, despite astigmatism and excessive power (about 10,000 diameters) showed the spurious disk of Vega, with portions of the first diffraction ring, and also exhibited the general outlines of the planet Saturn. The field of view was, however, only about 20 seconds of arc in diameter, and the image could hardly have been examined, or even held in view, without the help of a good clock drive. And yet Herschel, in his experiments on high powers, had nothing better than an altazimuth stand with hand-driven slow motions!

"We are told nothing of the methods employed in making these tiny lenses, the smallest of which is only $^1/_{45}$-inch in diameter. Compared with this, the front lens of a modern 2 mm. oil-immersion objective is a large and clumsy object. It would be interesting to know exactly how a present-day optician would proceed, if required to make a duplicate of the most powerful of Herschel's eyepieces, fashioned in the 18th Century."

In the illustration of the eyepiece, what may look like the lens is the eye end of the eyepiece shell. On that shell is a raised nipple. On the tip of the nipple is a tiny dot, just visible. This dot is the wee lens shown in the other illustration, its diameter one third that of a pinhead.

Herschel's trick eyepieces may have been made by him partly as a stunt. So thinks his granddaughter, Constance A. Lubbock, editor of *The Herschel Chronicle*. Herschel was ever a case of "once an amateur always an amateur," which carries with it an incurable interest in stunts done purely for the fun of it. He probably wanted to see just how small a lens he could make, and probably as he made those described he chuckled, "I'll give 'em 160 years to beat me on these."

If Herschel came to life today, where would you expect to find him after he had explored our optical world? Among professionals (the few remaining who didn't start as amateurs), or down in some amateur telescope maker's cellar shop having fun? New York's Amateur Astronomers Association recently asked this department whether Russell Porter, as one who has associated with astronomers for the better part of his life, might not quite approve the award to him of its Amateurs Medal for meritorious service to the science of astronomy. The answer was, "Never has Porter thought of himself as anything else than an amateur." The amateur's cellar shop in which to look for Herschel would be Porter's.

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