SCIENTIFIC AMERICAN

PHYSICS AND MUSIC (PAGE 32)

FIFTY CENTS

* July 1948

LETTERS

Sirs:

Concerning "social physics"—and your May article of the same name—I should like to register an emphatic protest at the inclusion of this kind of balderdash in your otherwise commendably restyled magazine.

"Now," wrote your associate professor of astronomical physics, "let us apply these equations to populations. In the place of mass or charge we substitute 'population density.' This term is actually derived from the physical concept of surface density; the analogous unit in electrostatics would be the amount of surface charge per unit area of the charged body." And again: "The gas analogy, or some equivalent concept, is necessary to explain the resistance of human beings to social gravitation. . . . Were it not for the expansive force of the human gas, representing the need of individuals for elbowroom, the center-seeking force of gravitation would eventually pile everyone up at one place."

Frankly, social scientists themselves are not without occasional foibles, fancies, strange preoccupations and conceits, but in a number of years of close attention to the theories and researches of persons active in this field I have encountered nothing quite so weird as the notions drummed up by your contributor, the associate professor of astronomical physics.

I am in no sense objecting to his interest in the mathematical description of social behavior. Wherever uniformities in social behavior can be found to exist, symbolically described, and their interrelations generalized, let us by all means do so. That is the end toward which all of our sciences should properly be working. But if there is one most effective way of damning all hope for the continued progress of social science toward this objective, it would almost certainly lie in beginning with the concepts of physical science, then observing social behavior, then jam-packing our findings into the usually quite irrelevant concepts with which we have begun. At best, such a procedure might afford a harmless and no doubt intriguing pastime for occasional professors of astronomical physics. At worst—which is to say, if taken seriously—the same procedure represents a gross and unpardonable failure to approach the data of social behavior at their own level and in the terms which they themselves suggest.

May I offer two suggestions?

First, I would be happy at any time to test my skill at the "social physics" game by devising a new approach to the data of physical science, one which would make use of many concepts that physical scientists have unaccountably ignored, such as "minority groups," "frustration," "aggression," "in-group," "folkways," and so on. Surely the proffer of a physics of sociology deserves a sociology of physics in return, if only to show that practitioners of social science are equally capable of benevolence and versatility.

Or, somewhat more pointedly, it might be suggested that the editors of *Scientific American*, when preparing future articles on social science topics, first secure the views of social scientists concerning the usefulness and validity of material to be treated.

It would be sheer ingratitude not to add that, apart from the perilous flight of fancy in question, the May *Scientific American* was unusually pleasant reading, attractive and interesting.

WALTER H. EATON

Director
Research Associates of Chicago
Chicago, Ill.

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Sirs:

Professor John Q. Stewart, in his article "Concerning Social Physics" in your May issue, does not, alas, carry us into the post-Keplerian stage of social thinking. Rather he transports us to a pre-Heraclitean era where we are asked to believe in unexamined generalities and mysterious pseudo-forces like "population potential" and the "human gas."

I do not think that Professor Stewart's position is defensible even on the facts. The particular area of high population potential which he discusses is the Illinois, Indiana, Southern Michigan, Ohio, Pennsylvania, New York, New Jersey, Connecticut and Massachusetts group of states. While it is true that this is an area exercising relatively strong influence in the country as a whole it is also characterized not only by relatively high population density but also by the following: high purchasing power, large coal deposits, cheap water transport, heavy and early development of rail transport. It also contains much of the best farmland in the country. Thus, what is at issue here is not a force exercised by virtue of population density (or "potential") but a force exercised by virtue of a complex of interrelated factors. It ought to be borne in mind also, it seems to me, that were population potential a deciding factor in the influence of a region on its environment, then the influence of India and China in the world would be overwhelming as compared to our own. But we know that population by itself—without industry—is nothing in the world today.

A further problem is raised by Professor Stewart's concept of the "human gas." It is true that populations have always tended to move from rural to urban areas, *i.e.*, from areas of relatively sparse population to areas of relatively denser population. But this is not due to the pseudo-scientific force invented by Professor Stewart and called "demographic gravitation." In the history of our country, and of much of the world, the rural population has migrated to cities in search of a higher standard of living, or in some cases, as an escape somehow, as in Latin America, from the intolerable misery of the countryside. Thus, to invoke such a "force" as "demographic gravitation" to explain complex emotional phenomena obscures rather than illuminates the issues.

But the wanderings of an occasional astronomical physicist into the uncharted (for him) interstellar space of society, are really not as important as the implications of his kind of *thinking*. Mechanistic treatment of social phenomena distracts attention from the real problems of social living. The consideration of persons as particles paves the way for those who would treat them as assembly-line items, to be organized and handled as any political party wishes. This problem of the relationship between the physicist and society is of crucial importance because so many physicists have been swept into pivotal social positions on the wave of popularity that—ironically enough—followed on the most catastrophic demonstration of the power of the physical sciences in history. Personally, I think that Professor Stewart's kind of thinking is the backdoor to tyranny.

JULES HENRY

Associate Professor of Anthropology
Chairman, Basic Social Science Program
Washington University
St. Louis, Mo.

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Sirs:

I have been trying to read the May issue of your magazine.

Man, oh man. You have ruined the finest

shop and hobby magazine in the world. Gone high-brow. Filled it with a bunch of uninteresting junk which anyone can find in any well ordered library—assuming he wants to find it.

Most of the subscribers of the old *Scientific American* can meet these qualifications. But even the college graduate is sometimes glad to know that a eutectic bismuth alloy can now be had for making cheap molds for short runs of plastic parts or to learn, from the column written by Mr. Albert G. Ingalls, what abrasive to use for polishing glass or metals. And thousands of other helpful hints which can be used from day to day.

I note that Mr. Ingalls is being kept on as one of the editors of your new magazine. I'll give odds that he is the only one of the new editors who has ever cleaned his hands on a piece of dirty waste. I'll gamble also that, with his age and experience, you will find Mr. Ingalls is dry behind the ears. As long as my subscription lasts I shall welcome and find interest in Mr. Ingalls' column.

Gone from your subscription lists will soon be your present subscribers and gone from the greasy work benches throughout the world will be the magazine of a thousand helpful hints which we liked so much, and which your new magazine can never replace.

Gone also is the idea which has endured for over a hundred years, that a magazine can be helpful to people of *all* walks of life. Comes now the idea that only those who qualify as "intelligent laymen"—"at, say, a college level"—can understand science. Tsk, tsk. What a crime—what a shame. And what a conceit.

The old friends of the old *Scientific American* may not write many letters to you but they will have the same feeling as do I, which can be best expressed in the language of the prize ring, "We wuz robbed."

PHILIP E. DAMON

Ames, Iowa

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Sirs:

The new *Scientific American* is perfectly splendid! It is just what a scientific magazine ought to be! And I (and legions like me, I am sure) am delighted that the historic periodical is returning to its birthright.

May I humbly beg that you will keep it from again becoming too metallurgical, commercial? I know you will safeguard it. My father drew his chief interest in life from the pages of the older, broader form it had; and to which it is now so happily returning. We all thank you!

LEON A. HAUSMAN

Department of Zoology
New Jersey College for Women
New Brunswick, N. J.

50 AND 100 YEARS AGO

JULY 1898. "On June 6. 1898. the discovery of yet another element was announced, in a communication made by Prof. Ramsay, of London, to the Academy of Sciences, of Paris. This new element is the gas krypton, and makes a fifth constituent of the atmosphere; it is, however, present in very minute quantities, viz., one part in ten thousand of its volume. Krypton belongs not to the argon, but the helium group; its density is greater than that of nitrogen, being, according to the corrected measurement, 22.47."

"The present war has served as a great upsetter of theories. Seagoing Spanish torpedo boat destroyers, that were to have wiped out our mosquito fleet and then proceeded to sink our battleships in detail, have proved helpless against our unarmored cruisers, and Spanish forts that were to have crumbled to dust at the attack of our 13-inch shells have persisted in holding up their heads with a stubborn endurance of which these medieval traps of stone and mortar were theoretically quite incapable. We find that some pet theories will have to be renounced, if the earlier operations of the present struggle are a sure indication. Conspicuous among them is the oft-repeated statement that warfare has become such an exact science as to leave little room for the exercise of mere courage and daring."

"The auxiliary steam yacht 'Windward' left New York on July 2, for Sydney, Cape Breton, in command of Capt. John Bartlett, who has made four trips to the Arctic regions. Mr. Peary and other members of his party will join the 'Windward' at Sydney. From Sydney the yacht will go to Cape York, Greenland, where she will take aboard a party of 60 Esquimaux with their sledges and dogs."

"Prof. Koch has announced the results of his investigations on the plague. He declared that the view entertained some two years ago that the plague no longer threatened mankind must be abandoned, for there are now no less than four plague centers, the last of which Prof. Koch discovered in the Hinterland of German West Africa."

"Further evidence of the existence of man before the glacial period in England has come to light. In his address before the Biological Society, of London, Dr. Hicks states that the evidence which has been obtained from bone-bearing caverns in the glaciated regions of England shows conclusively that the remains of the extinct mammalia found in them must have been introduced before any of the glacial deposits now in or upon them could have been laid down. From caverns, he says, in glaciated areas in North and South Wales, where paleolithic implements have been found in association with remains of extinct mammals, facts have been obtained which make it certain that the implements were those of man living at the same period as the extinct animals in those periods, and therefore of pre-glacial age."

"Our readers are already familiar with the harrowing details of the loss of the 'Bourgogne', with 560 lives, in the North Atlantic. Contrasted with the detestable cowardice and villainy of the crew, it is a mournful gratification to know that the officers did their duty to the last and to a man perished with the ship. The awful suddenness with which the ship went down as the result of the failure of her watertight compartments will shake the confidence of the public, already rudely strained, in the system of watertight bulkheads as a means of keeping an injured vessel afloat."

"The director of that stupendous enterprise, the Trans-Siberian Railway, announces that the whole line will be opened to traffic in 1904. It will then be possible for the 'globe trotter' to circle the earth in thirty days or less."

JULY 1848. "At the Isthmus of Tehuantepec one river named Coatzocales, flows into the Gulf, and the river Chicapa flows into the Pacific. Both these rivers originate on an elevated table land near the centre of the isthmus, about 656 feet above the ocean, and the length of the route would be 200 miles, therefore we need never expect a canal to be built there; but the Isthmus of Panama can be cut and built into a splendid canal at an expense of no consequence at all, as the distance from sea to sea is only about 40 miles, and the country is traversed for nearly the whole width by the great river of Chagres and its tributaries."

"It has been officially stated that there are 3,719,000 persons engaged in agricultural pursuits in the United States; in manufacturing, 781,800; in commerce, 119,600; in learned professions, 65,200; in ocean navigation 55,000 and in internal navigation no less than 33,000."

"The Italians have beaten the Austrians in a severe engagement—one King knocking down another. There is a prospect of peace between Denmark and Prussia. The crops in England look well. France is still disquieted and it is reported that Prince de Joinville has been taken prisoner incog. in Paris. France will it is supposed, yet relapse into the arms of monarchy. With all the noise lately made in Europe, there is but one crowned head the less—only one vacant throne. There is every appearance of Spain and England coming to blows. This is a prelude to the conquest of Cuba—let us see if this be so, or not."

"The hanging bridge of Kerentrech is spoken of as one of the most remarkable objects of modern art in France. It is thrown over the little river Scorfi, at the place where it crosses the road from Lorient to Paris, at the bottom of the beautiful avenue of Chazelles. The bridge differs from all those which have been heretofore built, inasmuch as its power of suspension rests entirely on cables of iron wire."

"He who created heaven and earth,
And gave the rolling thunder birth,
Who hold'st the ocean in his hand,
Whose waves are stayed at his command,
Who made the gorgeous sun to gild
The humblest cot that man can build,
Who strewed the earth with lovely flowers,
And gave to man gigantic powers,
Hath kindly unto Morse revealed
What heretofore had been concealed.
He doth the rapid lightning tame—
A Telegraph he calls its name—
And with a single vivid flash,
A dot—a space—a line—a dash—
Can send around the earth the news,
Or stop it, just as he may choose,
What a mysterious mighty power!
No noise is heard—no cloud doth lower,
And yet the lightning wings its way,
And tells whate'er we have to say."

"It is stated that Daniel Webster speaks at the rate of from eighty to one hundred and ten words per minute; Gerrit Smith, from seventy to ninety; Dr. Tyng, from one hundred and twenty to one hundred and forty; Mr. Botts, from one hundred to one hundred and twenty; Mr. Clay from one hundred and thirty to one hundred and sixty; Mr. Choate and Mr. Calhoun, from one hundred and sixty to two hundred."

RUBBER RECIPE

Rubber compounds to the tune of some 35 million pounds a year go into Bell System plant. Each compound must meet many requirements for resistance to humidity, oxygen, ozone, light and abrasion. The right properties depend on skillful selection and compounding of ingredients; this is one of the jobs of Bell Laboratories.

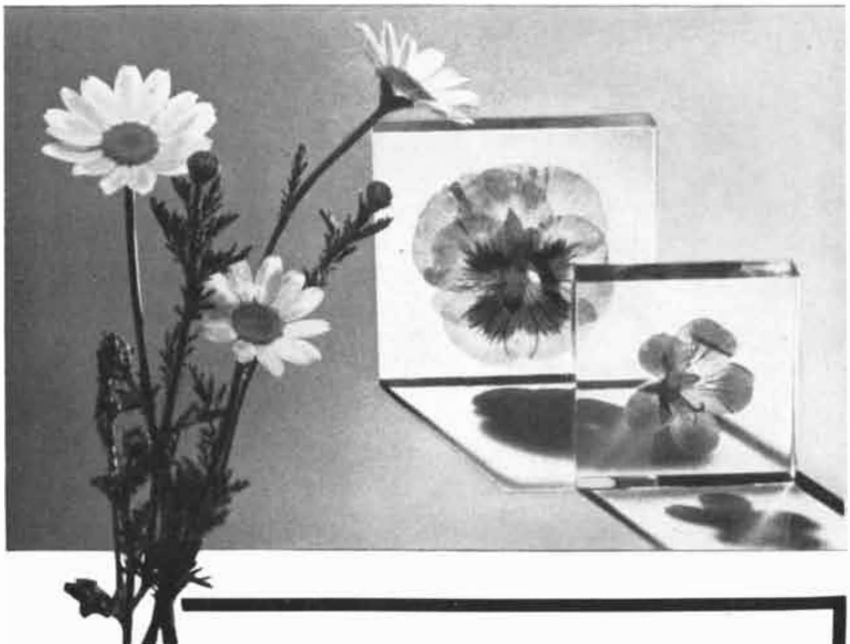
Sulphur, one essential ingredient of rubber, can also be corrosive. That seemed to rule out rubber on telephone cords. But Bell chemists found that if they held sulphur to the bare minimum, corrosion ceased. Now your handset cord has long life, is less susceptible to moisture as, for example, from a wet umbrella.

Connecting your home to the telephone wire on the street is a "drop" — one hundred feet or more of rubber-insulated wire. Once this wire was protected from ozone, light and abrasion by an impregnated cotton braid; but water leached the impregnant, and the braid rotted. Bell chemists tested scores of synthetics, and selected neoprene as an exterior covering with many times the life of braid.

Rubber is only one of many types of insulation developed by the Laboratories for the Bell System; insulation is only one of the Laboratories' problems in providing a quick, economical path for your voice.

BELL TELEPHONE LABORATORIES

EXPLORING AND INVENTING, DEVISING AND PERFECTING FOR CONTINUED IMPROVEMENTS AND ECONOMIES IN TELEPHONE SERVICE.



THE COVER

The cover painting for this issue illustrates one of the methods in the physical study of music, the place of which is discussed in the article "Physics and Music" on page 32. At the left a cello sounds a note which is recorded on the oscilloscope at right.

Scientific American, July 1948: Vol. 179. No. 1. Published monthly by Scientific American, Inc., Scientific American Building. 24 West 40th Street, New York 18, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York. N. Y. Post Office as second-class matter June 28. 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

Editorial correspondence should be addressed to: The Editors, SCIENTIFIC AMERICAN, 24 West 40th Street. New York 18, N. Y. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Charles E. Kane, Advertising Director. SCIENTIFIC AMERICAN. 24 West 40th Street. New York 18, N. Y.

Subscription correspondence should be addressed to T. J. Lucey, Circulation Director, SCIENTIFIC AMERICAN, 24 West 40th Street, New York 18, N. Y.

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SCIENTIFIC AMERICAN

Established 1845

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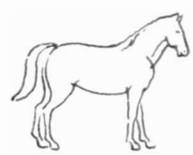


It's an old superstition that men go mad in the moonlight, but did you ever hear of moonbeams blinding a horse? In 400 A.D., the Romans gave the name "moon blindness" to an equine eye disease because they believed it was caused by lunar changes.

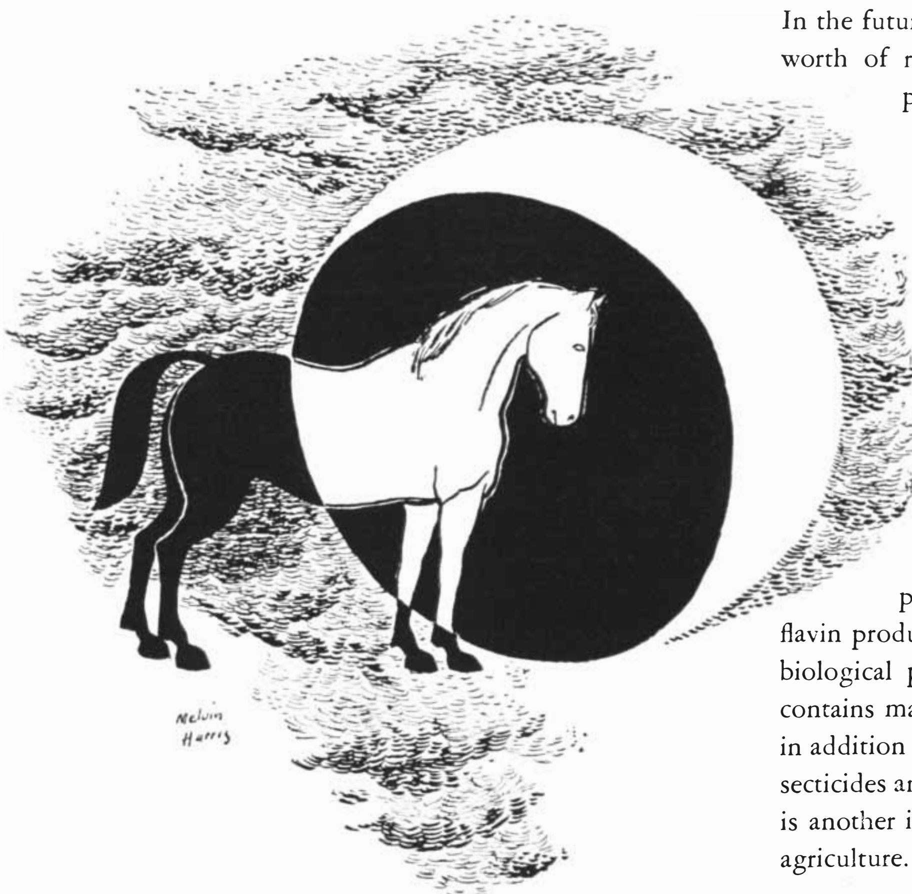
the horse that went blind in the moonlight...

Recent veterinary studies made by the Army show that moon blindness is a vitamin deficiency. Responsible for more blindness in horses and mules than all other causes combined, it occurs when diet lacks riboflavin.

Moon blindness now costs American horsemen more than $17,000,000 a year. In the future, breeders will add a penny's worth of riboflavin to each feedbag to prevent this destructive disease.

Riboflavin is essential to the health of poultry and livestock. Without it, chickens develop curled-toe paralysis, lay eggs that will not hatch, and lack vigor. Riboflavin promotes healthy growth and sound development in young cattle, pigs, dogs, and fur-bearing animals.

For years feed men have preferred B·Y-21, a natural riboflavin product made by an exclusive CSC biological process. This natural product contains many valuable nutritive elements in addition to riboflavin. Like the new insecticides and veterinary penicillin, B·Y-21 is another important CSC contribution to agriculture.



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SCIENTIFIC AMERICAN

JULY 1948 VOL. 179, NO. 1

RECOVERY OF EUROPE

A UN survey presents the balance sheet: Despite its remarkable postwar comeback, the Continent must yet find a way to reduce its $7.5 billion import deficit

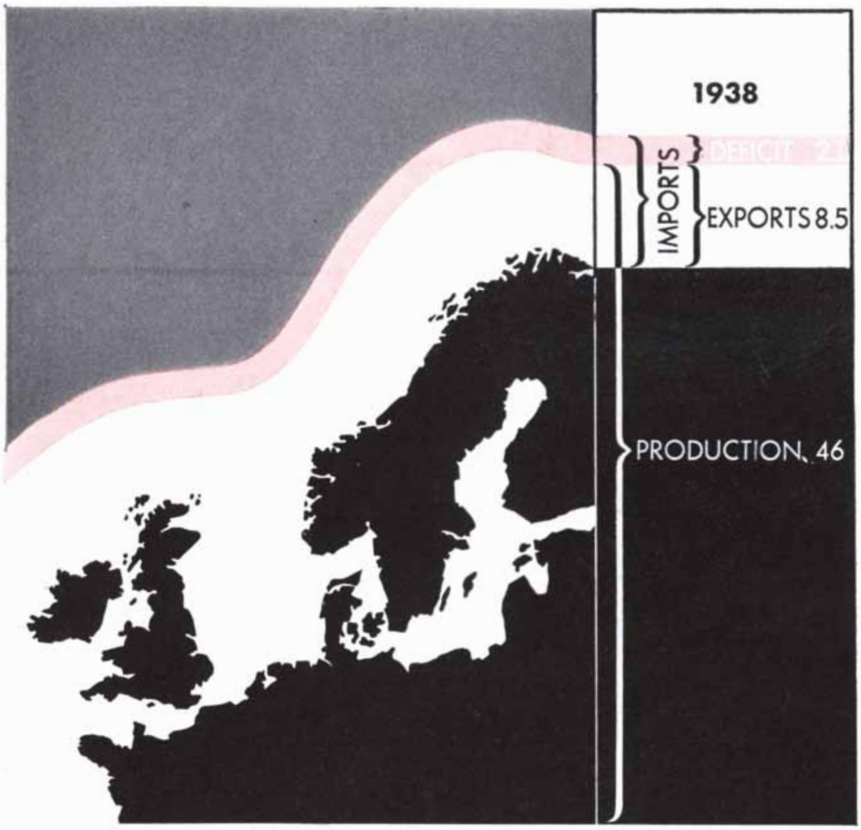
The "E. C. E. Report," here summarized, is designed as a guide to the postwar recovery of Europe. Prepared by the Research and Planning Division of the Economic Commission for Europe under directive of the Economic and Social Council of the United Nations, it was published at Geneva in April under the title A Survey of the Economic Situation and Prospects of Europe. *The Commission's executive secretary is Gunnar Myrdal, noted Swedish economist. The U. S. and all European members of the UN are full members of the Commission. Practically all European countries are participating, however, in the work of its technical committees, and all of them, with the exception of Spain and Portugal, attended the recent meeting of the full Commission held in Geneva. During the first year of its operations, the Commission's numerous technical committees have succeeded in effecting improvements in a number of critical areas of the European economy, even though its powers, like those of all other special UN agencies, are limited to recommendations. The Commission greatly assisted railway transportation, for example, by recommending an improved system of freight car exchange which promoted traffic across international boundaries. As another example, it increased European steel production by 1.5 million tons in the current year through allocation of coke and coal among the European countries.*

The present Report was a working document of the recent meeting of the Commission. This summary, prepared by the editors of Scientific American, *sets forth the essential findings of the 200-page Report. It should serve as a valuable source of information for U. S. citizens and help them to understand the economic situation of Europe, in which their country has assumed such heavy responsibility.*

IN THE 38 MONTHS since VE Day, Europe has made a remarkable recovery. This recovery, overshadowed by political events, has been largely unheralded, but it is solidly shown in the record of production. The industrial output of the Continent, excluding defeated Germany, has already reached prewar levels. The record is particularly impressive in those industries—iron and steel, chemicals, machine tools and heavy construction—which are the underpinning of Europe's economy. By the third quarter of 1947 these industries had surpassed the levels of 1938, Europe's last prewar year.

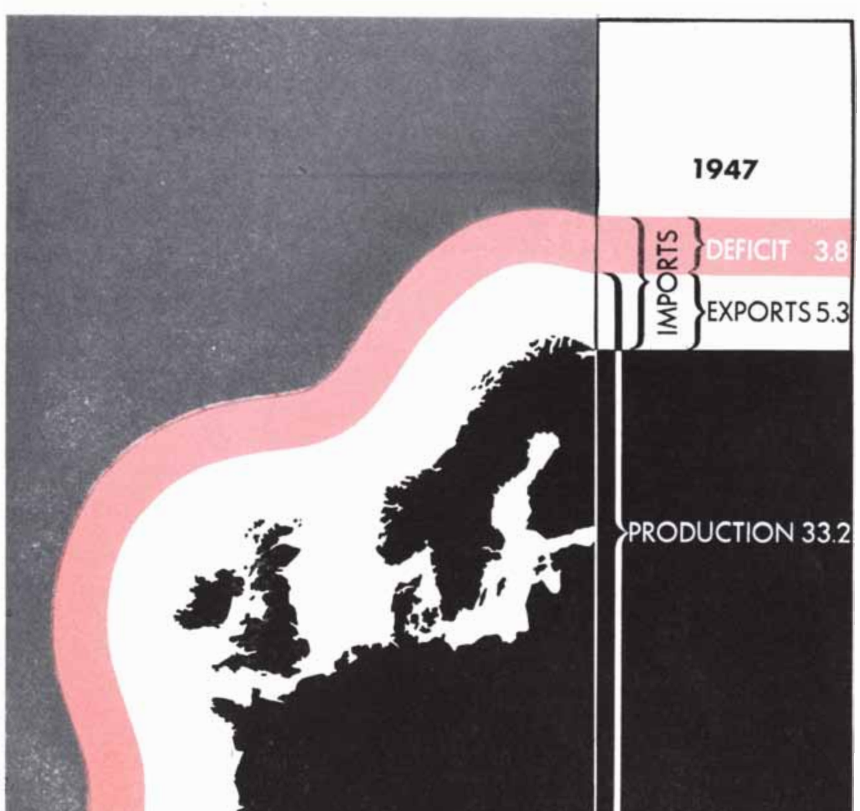
Comparison with the aftermath of the First World War gives the measure of this achievement. The Second World War lasted longer, killed more people, devastated greater stretches of territory and consumed a much larger percentage of

RECONSTRUCTION IN FRANCE has brought production of large refinery at Petite-Couronne back to 400,000 tons of petroleum products per year. Dependence upon overseas oil sources is a weakness in recovery plans.



EUROPE'S DEFICIT (MILLIONS OF 1938 DOLLARS)

Excess of imports over exports is the core of the European recovery problem. "Invisible exports," *i.e.*, the income from foreign investments, tourism, shipping, etc., covered the $2.1 billion excess of imports over exports in 1938. The wartime loss of invisible revenues leaves the larger 1947 deficit uncovered.



the Continent's wealth. In the wake of prolonged enemy occupation the civil organizations of 13 European nations were left in chaos. Nonetheless, all of Europe except Germany has bounded back to prewar industrial production levels in less than half the time required for equivalent recovery after the First World War. Even if Germany is included, the Continent's industrial recovery index, 86 per cent of 1938, exceeds the 75 per cent recovery achieved in the comparable period after the First World War.

The comparison holds good for other departments of European economic life as well. Food production, railroad carloading and exports all show a much higher rate of increase. All indices plainly indicate that this time the recovery of Europe is far better organized and planned than after 1914-18.

I. The Deficit

Europeans have not, however, taken time off from their labors to celebrate. There are dangerous weaknesses in their convalescence. Their standard of living, particularly in nutrition, has not yet recovered greatly from its wartime decline. They are confronted, furthermore. with a new and menacing problem which they did not face after the First World War. It is expressed succinctly by the $7.5 billion deficit in foreign trade that was entered on Europe's books in the year 1947: the Continent had to import $7.5 billion more than it was able to pay for by its exports to other countries. (*See charts at left.*) It must incur an even larger deficit during the coming year, and must sustain substantial losses year after year for a long period thereafter.

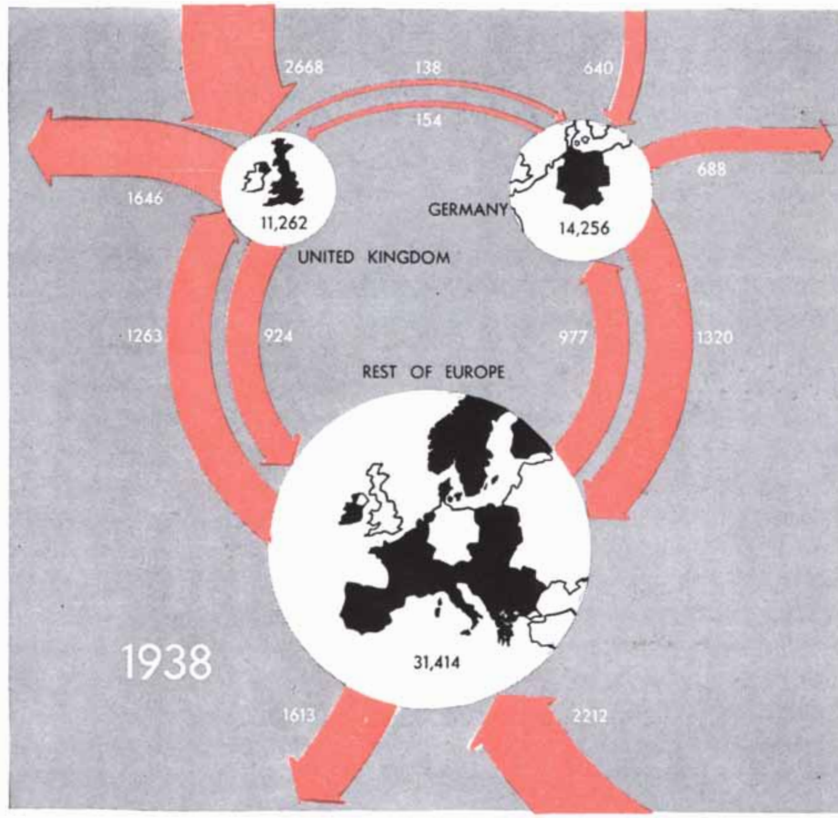
The foreign-trade deficit has a hard and practical immediacy. In Paris, it bears directly on whether businessmen can meet next week's payroll. England faces starvation as well as unemployment if it cannot import food and industrial raw materials. For the Continent as a whole, return to prewar standards of living depends ultimately upon finding some way to pay for essential supplies from overseas. Finally, since the nations of Europe, as the world's largest producers and largest importers and exporters of merchandise. were the center of gravity of the prewar world economy. their deficit in international trade has repercussions in national economies the world over.

Europe's deficit is only partly accounted for by the short-term requirements of postwar rehabilitation and relief. In a much larger measure the deficit's causes are historic. Europe long ago ceased to be a self-sufficient continent. Since the beginning of the Industrial Revolution it has imported more goods from overseas than it has exported. Its population for many years has exceeded the capacity of its crowded land area to grow food. Its industries have depended upon the rest of the world to supply them with raw materials.

In the past Europe has paid for most of its imports by exporting manufactured goods. But its tangible exports have rarely paid in full. Before 1939 the resulting deficit was covered by "invisible exports." Europe paid the deficit in part with the cash income from the riches which it had accumulated overseas during the centuries of its imperial history. (For example, Britain in 1938 held $2.7 billion worth of assets in U. S. natural resources and industries.) It paid the rest in services: tourist trade, shipping, world-wide banking and insurance. In 1938 all these yielded a net revenue of $2.1 billion.

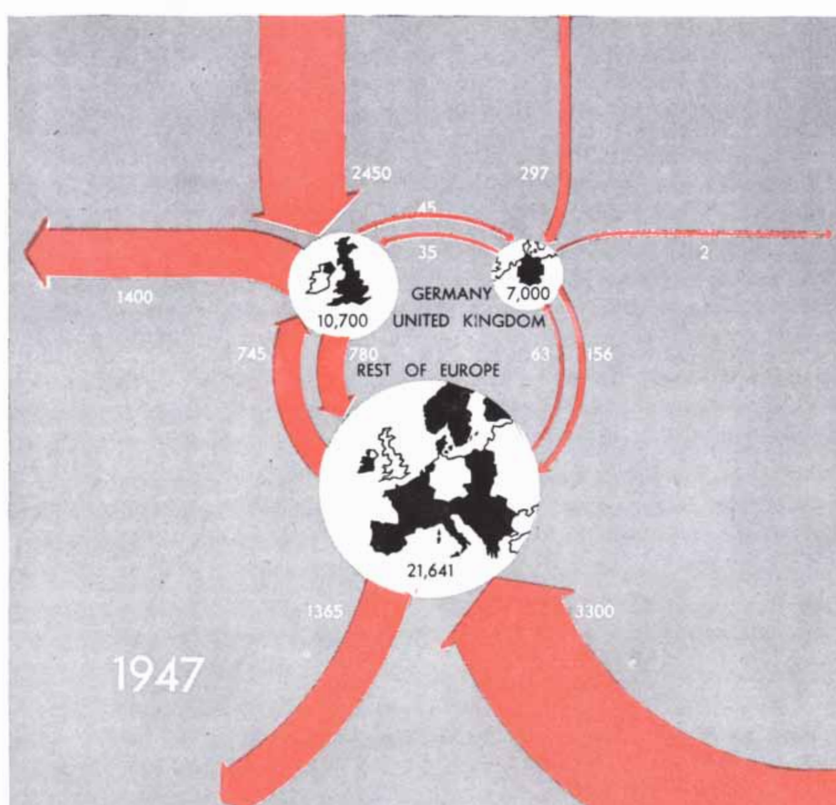
Today Europe's overseas investments have very largely been liquidated. (Britain's assets in the U. S. are down to $58 million.) The European merchant marine is ruined. Tourism is in the doldrums. London, Paris and Berlin have yielded their leadership in world finance to New York and Washington. To make matters worse, the European countries had to make heavy outlays in 1947 for the hire of foreign merchant vessels, chiefly U. S.. and for overseas military operations. particularly in the Near East and southwest Pacific. Invisible exports therefore became "invisible imports" in 1947, adding a net total of $600 million to Europe's international deficit.

Thus the dimensions of Europe's problem are clear. Its current $7.5 billion deficit represents (1) emergency needs for relief and reconstruction, and (2) a long-range need for sources of income to replace its lost invisible revenues. An exact breakdown of the deficit between emergency and long-range requirements is difficult; if it is assumed that Europe's present "normal" deficit is no greater than prewar, that $2.1 billion deficit is now $4.4 billion in 1947 dollars. To achieve solvency without permanent sacrifice of its prewar standard of living, Europe must ultimately close this wide gap. It is unlikely to regain its former invisible revenues in anything like the prewar volume. To close the gap, Europe must increase its prewar exports by 56 per cent, or cut imports by 36 per cent, or (more likely) arrive at an equivalent combination of import reduction and export expansion. It must do this in the face of the fact that the U. S. is not now a customer for European manufactured goods and that other non-European countries with which the Continent might trade also have an unfavorable balance with the U. S., so that Europe cannot obtain from them the dollars necessary to discharge its huge deficit *vis-à-vis* the U. S. With world markets for consumer goods shrinking as the result of overseas industrialization, it appears that the most effective way for Europe to re-establish its foreign markets is to expand its heavy industries. It is estimated that to close the deficit gap Europe must ultimately increase its heavy



EUROPE'S TRADE (MILLIONS OF 1938 DOLLARS)

Flow of trade was maintained in 1938 by Britain and Germany. The rest of Europe financed its excess of imports from Germany by an excess of exports to Britain. The German economic collapse and Britain's loss of "invisible exports" (*see diagrams on opposite page*) paralyze Europe's trade in 1947.



industries exports by about 100 per cent.

But first it must meet the immediate postwar emergency. To a considerable extent, the Continent's short-range and long-range problems overlap, but its recovery plans can conveniently be considered in two phases.

II. Short-Range Problems

The major immediate problems following from the war are: Germany, food, inflation. Of these, the most dramatic is the economic collapse of Germany. In 1938 the German people, representing 15 per cent of the European population, produced 25 per cent of Europe's manufactured goods. They were the largest suppliers of manufactured goods to the rest of Europe and, in turn, the largest buyers of food and raw materials. Today German production is little more than one third of its prewar level. Intra-European trade, in consequence, has fallen to 47 per cent of the 1938 level. Germany's prostration is not due solely to its defeat in the Second World War. The First World War cost Germany a commanding economic position in the European economy which it never entirely regained. Despite its extraordinary comeback during the period between wars, the German economy steadily lost ground in relation to its neighbors. Since Germany is not expected to make nearly the same comeback this time, the absolute and relative decline of German output must be compensated for by an increase in the industrial capacity of other nations.

From the point of view of the average European, food is of course the most urgent problem. A poor harvest in 1946 and an untimely drought in 1947 have held the Continent's food production to a level less than 75 per cent of that in 1938. The decline in food production is greatest in the eastern European countries, which before the war were Europe's principal food exporters. Because the decline has been considerably greater in meats and fats than grains and other carbohydrate constituents of the food supply, the European diet has suffered in quality even more than in quantity.

The inflation problem vastly complicates the measures that must be taken to deal with Europe's other difficulties. Because of currency inflation, Europe's exports, so vital to its recovery, go into the world market under a serious competitive handicap, and the Continent is suffering a crippling dollar shortage. Within Europe inflation hampers production and tangles the web of trade. It dries up credit and forces nations into separate, bilateral trading arrangements with one another that require a strict export-import balance in each case. It stimulates business in nonessentials, such as jewelry, cosmetics, couture, furs and wines. It diverts steel from much-needed tractors to automobiles. Most European countries have found it necessary to erect import barriers against traffic in luxuries, yet the same countries have also adopted the device of the tie-in sale in order to force surplus luxury goods on their customers. A country with grave reconstruction problems may have to exchange part of its limited exports for lace in order to get a little machinery. The European nations have thus been led into the position of consuming one another's luxuries. Sweden and Denmark, for instance, trying to conserve steel for exports, severely restrict the production of vacuum cleaners for sale at home; yet under their bilateral trade agreement each agrees to import vacuum cleaners from the other.

III. Reconstruction

In attacking their recovery problems, most European governments have assumed a considerable degree of control over their respective national economies. This control extends, in varying degrees, to prices, foreign trade, the allocation of scarce materials and, in some cases, to the distribution of manpower. Even those governments which refrain from active intervention in current business operations accept major responsibility for capital investment. A large percentage of new investment is directly financed by government, and private capital investments are, in the majority of countries, directed by the state through controls on the long-term capital markets, on building and construction materials and on the location of new plants. Thus, as far as economic development is concerned, most countries are operating under the guidance of a central plan of some kind.

In general the plans are directed at solving the short-term aspects of the deficit problem: the complications caused by inflation, decline in agricultural output and the disappearance of Germany as Europe's producing and trading center. (*See* Forecast of European Production, *page 15.*) Most of the plans look to 1951 as the target year. By that time the European nations hope to bring their agricultural output up to 1938 levels. The industrial objectives are far more ambitious: a 50 per cent over-all increase in the output of the heavy industries of western Europe (excluding Germany). Germany will be displaced as the center of gravity, and part of its former surplus of industrial power redistributed among its neighbors on the east and west.

The stepping up of heavy industries will give Europe a new role in the world economy. Textiles and other consumer goods will give way in Europe's exports to industrial equipment and capital goods. Europe will thereby create overseas competition for the spinning mills of Lancashire and Lyons. But that competition is already foreshadowed by the worldwide trend toward industrialization. By exporting capital equipment instead of consumer goods, Europe will take advantage of the trend to re-establish itself in the world market.

The deficit of the Continent today, as always, is largely the deficit of western Europe. The plans of the western nations are therefore predicated upon overseas aid. Since they are among the world's most highly industrialized nations, their plans are focused first on the sources and distribution of energy, then on the basic industries such as steel, next on the capital-goods industries and finally on food production.

Coal, the principal source of industrial energy, has been the principal bottleneck in the recovery programs of western Europe. Britain, by dint of mechanization and a consequent increase in production per man-hour, managed in 1947 to restore its coal output to the prewar rate. The Ruhr, however, has lagged by 11 million tons. As a result, western Europe, once a major exporter to the world, must now import large tonnages of coal from the U. S. To meet the increased demands of heavy industry, Britain, France and Belgium are carrying through a two-billion-dollar mechanization program in their mines and are counting on the U. S. to furnish $105 million worth of equipment. Despite this effort, western Europe will

DESTRUCTION IN GERMANY has reduced its industrial production by still be 37 million tons short in 1951, but it is expected that Poland will ship 31 million tons of coal that year and thereby reduce the area's dependence upon U. S. mines and dollars.

The growing energy requirements of western Europe will nonetheless continue to burden the Continent's import budget, for its heavy industries will demand a huge increase in oil. Since Europe possesses only minor petroleum resources, it will have to import the bulk of this new requirement from Middle East and U. S. sources.

Percentagewise, the most ambitious program of the western European nations is expansion in electric power. It calls for an investment of $5 billion and a 100 per cent increase in power production by 1951. In addition to steam plants, nine large hydroelectric power stations are to be installed in Austria, Germany and Italy. Achievement of these goals will require heavy import of electrical machinery from the U. S.

But all other programs in western Europe hinge on steel—the *sine qua non* of heavy industry. Western Europe plans to lay out $2.25 billion to achieve a 30 per cent increase over prewar steel capacity. Such an increase would make up for the curtailment of German steel production and would represent a 10 per cent increase over the prewar capacity of the Continent as a whole. This program, however, has already collided with a major obstacle. As originally projected, it assumed heavy shipments of crude steel and scrap from the U. S. Because the U. S. has undertaken to ship finished and semi-finished steel rather than raw materials, the prospects of success are clouded.

Another potential bottleneck is timber, vitally necessary to meet the goals for housing, transport and shipbuilding. The timber import requirements—25 million cubic meters annually through 1951—are only slightly above prewar. But the prospect now is that only half the requirements will be met unless the eastern European nations are able to secure timber-hauling and processing equipment which they require.

If timber and steel bottlenecks do not interfere, western Europe plans to build 621,000 railroad cars during the next four years to relieve the strain on its railways. In the field of shipping, it faces quite another problem. There are plenty of ships on the seas; the U. S. has 14 million tons of idle shipping capacity. Nonetheless, because the imbalance in Europe's foreign trade requires that it make its merchant marine again a significant earning asset, the western European nations plan to invest precious materials and man-hours in an ambitious shipbuilding program. They have been unreceptive to U. S. suggestions that the ERP countries take over the U. S. surplus of low-speed Liberty and Victory ships. Low-speed vessels with a high operating cost might permanently damage Europe's competitive position.

In the matter of food, western European nations can never be self-sufficient, but they plan to meet a higher proportion of their requirements by further mechanization of agriculture. Before the war, mechanization stood at something like six per cent of the total power used on farms (including draught animals). Last year it rose to more than 12 per cent, and further steep increases are planned. Western Europe's food output, except in meat, is to equal or exceed the prewar level by 1950-51. But the population will be at least six per cent larger, so food imports from overseas will have to continue considerably above prewar if the average European is to eat as well as he did then.

IV. Eastern Europe

The food problem points up the interdependence of eastern and western Europe in the economic unity of the Continent as a whole. As food production recovers in the East, the West's present extreme dependence upon overseas food imports will be relieved. In a typical prewar year the eastern nations exported 4 million tons of grain, 1.4 million head of

nearly two thirds. Bremen, shown here, was one of Germany's major port cities, a center for the processing of raw materials imported from overseas. The conical air-raid shelters are only intact structures in this picture.

pigs and cattle, 87,000 tons of meat and 78,000 tons of eggs, taking manufactured products in return.

Right now, eastern Europe's food exports are negligible. This is partly because of the war's destruction. But in even larger measure it is the consequence of postwar social revolutions which have smashed the feudal, one-crop agricultural economy of the region. Since 1945 some 20 million acres of feudal estates have been split up into small farms; the peasant-tenant has become a yeoman freeholder. The result, for a while at least, is the disappearance of exportable surpluses of grain and beef. The resumption of exports will also be delayed by state plans of the region which call for radical changes in the structure of its agricultural economy. Farming in eastern Europe is now to be diversified—in accord, incidentally, with the recommendations of the League of Nations Nutrition Committee in 1936—with the objective of maintaining soil fertility, supplying a balanced diet to the people on the land and raising farm incomes. If the new pattern of agriculture is to produce surpluses for export, there must be a big increase in mechanization.

This is the principal objective of the ambitious industrialization programs of the region. In addition, rational distribution will require the formation of cooperative or collective producing and marketing organizations. Diversification of output will bring important changes in the composition of eastern Europe's food exports; grain shipments will fall off in favor of meats and fats, canned fruits and vegetables. In line with these objectives, the western European nations are expected to provide substantially increased supplies of fertilizer and agricultural equipment. They have already scheduled the shipment of half of their tractor output to the East during the next four years.

Hand in hand with the diversification and intensification of agriculture go even more far-reaching changes in industry. Before the war, eastern Europe was not only a feudal but also primarily an extractive economy. Its natural resources yielded only a minimum of revenue because the produce of its mines and forests was exported largely as unprocessed raw materials. In return, the East purchased the more expensive manufactured goods of its customers. The industrialization programs of the eastern European nations are designed to redress this unequal exchange. By processing their raw materials themselves, they will get greater value from their natural resources and, incidentally, provide employment for their surplus rural populations. Yugoslavia, for example, used to send Germany most of its bauxite, instead of converting it into aluminum. It also exported its copper, lead and zinc in the form of concentrates or ores. From now on it will process a much larger proportion of the metals itself and thus supply materials for the various other expanding industries at home.

Like western Europe, the East has ambitious plans for industrial expansion. For example, industrialized Czechoslovakia, the principal steel producer of the region, plans a 50 per cent increase in ingot capacity by 1953. One consequence of this program will be a sharp increase in trade among the countries of eastern Europe. There is no evidence, however, that this increase in trade within the region and with the U.S.S.R. will reduce trade with western Europe or overseas. In the first half of last year, for example, Czechoslovakia did less than 20 per cent of its trading within the region. Poland, with a 300 per cent increase in coal exports projected for 1949, is committed to send far more coal to western Europe than in prewar years.

Western and eastern Europe are interdependent. The West needs the East's food and raw materials; the East, if it is to meet its production goals, must get fertilizers and machinery for its farms, and capital equipment for its industries, from the West. This interchange is not likely to be blocked permanently by political forces that tend to divide the natural economic unity of Europe. The resumption of intra-European commerce on very much the old basis, which seems possible by the early 1950s, will bring a reduction in the Continent's dependence on imports.

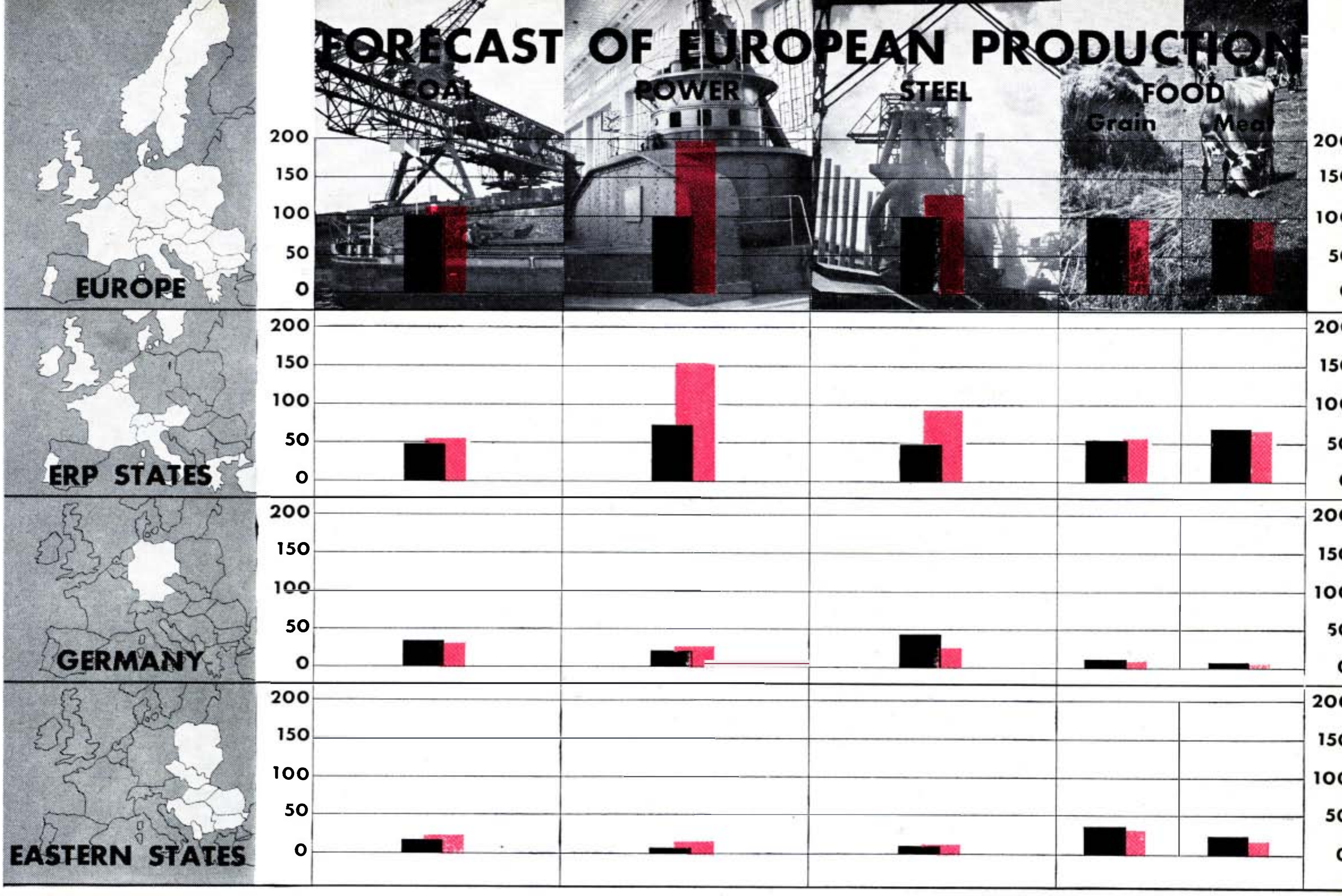
But Europe's success in meeting the balance-of-payments problem will depend most of all on the success of the western nations in reaching their industrial production goals. The prospect of attaining these goals is fairly bright if two provisos are met. First, trade and credit arrangements must be developed within Europe to permit a more rational utilization of the Continent's resources. (Belgium, for instance, could now export substantial numbers of railway cars if other countries could pay for them; France and Italy could easily produce more ball bearings if they could pay Sweden for the needed chrome steel.) Second, there must be no interruption in the flow of overseas supplies to Europe during the next four years. As the chart at the bottom of the opposite page indicates, the bulk of these will have to come largely from the U. S.

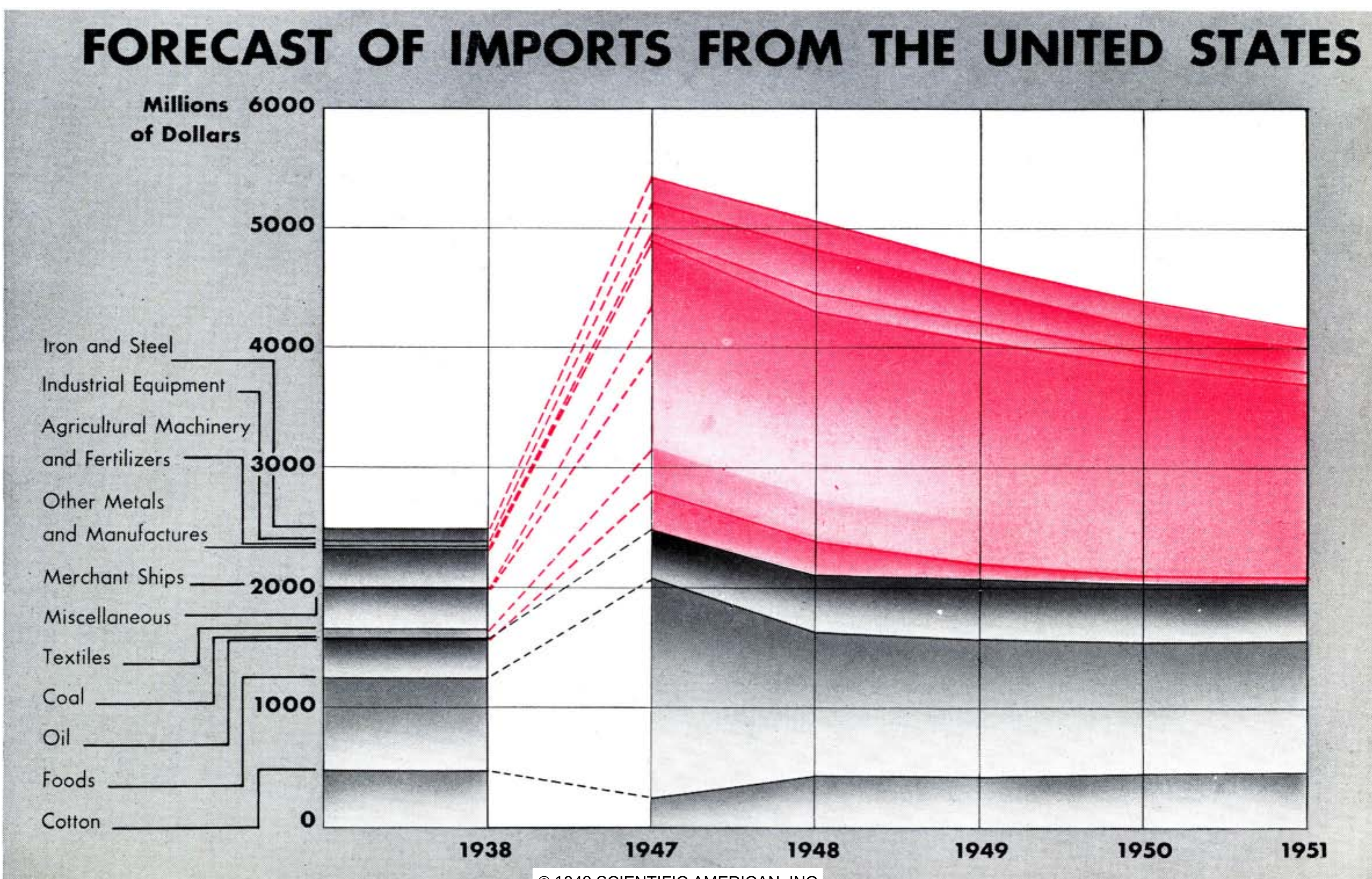
Assuming the success of its production program, Europe by 1951 should slash its imports-exports deficit by 50 per cent. This would mean that Europe had successfully achieved the short-term goal of recovery from the war. Its unfavorable foreign trade balance would still be more than $4 billion. Discounting inflated prices, this would be equal to the $2 billion deficit in real commodities which used to be covered by invisible export revenues. If all goes well, therefore, the Europeans in 1951 will be able to focus their energies on the long-range problem of balancing production, imports and exports in order to re-establish Europe once more as a self-sustaining unit in the world economy.

RECONSTRUCTION plans of European nations look to substantial increases over 1938 levels of industrial output and restoration of prewar production in agriculture. To bring out structural changes in the European economy, this chart takes the 1938 output of the Continent in each category as 100 per cent. The industrial decline of Germany is shown to be absolute as well as relative. Coal and steel production targets of western Europe are high enough to make up for German decline and bring over-all increase in the output of the Continent as a whole. Bigger supply of these basic materials is key to plans for a 50 per cent expansion in the output of other heavy industries. Disproportionately large increases in production of electric power indicate that European industry will move to higher levels of technology as well as higher levels of production. Industrial expansion in eastern Europe is directed primarily at increase in agricultural output and depends upon imports of industrial equipment from western Europe. Achievement of agricultural objectives will, in turn, permit eastern Europe to resume export of food to the West. Increase in eastern coal output is primarily Poland's and will help reduce Europe's coal imports from the U. S.

●

U. S. AID is critically essential to the achievement of the reconstruction plans outlined above. This chart shows the major requirements as forecast at the Paris conference on European economic cooperation in 1947 by the 16 nations participating in Marshall Plan aid. The dollar values in the chart are adjusted to 1947 prices. The gray band segregates the commodities—food, raw cotton and oil—which made up the bulk of prewar European imports from the U. S. Recovery in agriculture will substantially reduce European dependence upon the U. S. during the next 12 months. The commodities in the red band are those required to meet the demands of Europe's present emergency and for reconstruction. Principal emergency items are coal and finished textiles, which were minor items in prewar trade and which will decline sharply during the forecast period. The bulk of the remaining categories—iron and steel, industrial equipment, machinery and other metal manufactures—will go into the reconstruction and expansion of Europe's industries and will help to reduce all other categories of imports from the U. S. The first Marshall Plan appropriation by Congress last month met the $5 billion need forecast for coming year.


FORECAST OF EUROPEAN PRODUCTION
COAL
POWER
STEEL
FOOD
Grain
Meat
200
150
100
50
0
EUROPE
ERP STATES
GERMANY
EASTERN STATES


FORECAST OF IMPORTS FROM THE UNITED STATES
Millions of Dollars
6000
5000
4000
3000
2000
1000
0
Iron and Steel
Industrial Equipment
Agricultural Machinery and Fertilizers
Other Metals and Manufactures
Merchant Ships
Miscellaneous
Textiles
Coal
Oil
Foods
Cotton
1938
1947
1948
1949
1950
1951

ANTIQUITY OF MODERN MAN

The discovery of a broken skull in a French cave proves, after a long debate, that Homo sapiens walked the earth with Neanderthalers

by Loren C. Eiseley

TEN SKULLS of Ice Age Europe, covering roughly the period from 50,000 to one million years ago, have baffled a generation or more of geologists and anthropologists. The mystery concerns the fossils' age, and this, in turn, affects the entire question of how the human line has evolved. The key questions in the mystery are whether the beetle-browed Neanderthal man was really our ancestor or an unhappy cousin doomed to extinction, whether *Homo sapiens* is a recent arrival or a hardy species that has stood the test of evolution for several hundred thousand years. In short, how old is modern man? How far back can his characteristic features—our features, the friendly faces that greet us at the club—be traced?

One man gave up a major part of his career to working on the puzzle and finally, in the closing years of his life, became convinced that his theories were mistaken—though time was to prove him right. Those 10 grinning skulls have seen the right men wrong and the wrong men right for five decades.

Last August, in a quiet French village, the mystery was solved. In the cave of Fontèchevade in the Department of Charente, a few fragments of an old skull were brushed carefully out of the ancient clays. The world press gave it no notice. There was no battery of cameras; no one spoke over the radio about "missing links." Indeed, there was no reason why anyone should. It was an old skull and very broken. The only curious fact about it was that it was a skull very much like your own.

To an anthropologist, that was astounding enough. The great French prehistorian Henri Vallois came and marveled. A few letters were exchanged among scientists. One whose theories had been blasted protested harshly that there must be some mistake. Before there had always been some reason to dismiss such findings as the fumblings of amateurs or an accident of nature that had misplaced the fossils. But this time there could be no mistake, and the doubters grew angrily silent. It was the end of an era, and a new interpretation of human history was now in order.

At Fontèchevade Mademoiselle Henri-Martin, a quiet, amiable French scientist, daughter of a famous archaeologist, continued to busy herself with the restoration of the skull she had discovered. No inquiring reporters intruded. and it was just as well. After six years of laborious effort in the earth one did not want to be hasty; one should establish one's evidence beyond doubt. The evidence was clear; and this time of all times the right people were present.

The story of the skull is a strange tale out of the past—the story of a human being dead when now-extinct elephant and rhinoceros species roamed the environs of Paris. Like all true stories, it is difficult to tell because the threads are many and lead to strange places and even stranger characters. You can say it began with Darwin or the priest MacEnery, or with the eccentric American doctor Robert Collyer. It is all of this and more, because it concerns man's infinite yearning to know the truth about himself, and that truth he will never possess until he has trekked backward into time far enough to see his own footprints merge humbly into those of the lesser beasts.

Archaeology is just a little over 100 years old, and in that century, man's notions about his history have altered tremendously. Looking back, we can discern two periods of firmly held preconceptions about human origins and we can see also their successive rejection. Three episodes sketch the stages through which this controversy has passed.

A little over 100 years ago, a Catholic priest, Father J. MacEnery, began to carry on some excavations in Kent's Cavern, a famous old cave in the south of England. One has to know something of the history of archaeology to catch the irony of this situation. The time was one in which the Biblical conception of creation still reigned. Mankind, it was thought, could be no older than 6,000 years. Georges Cuvier, the great French paleontologist of the time, is reputed to have tossed out of the window in disgust a human jaw brought to him by someone who thought it associated with fossil animals of the distant past. Scientists and laity alike slapped their thighs and roared with laughter at the ideas of lunatics who talked about tools and bones older than the world itself. Nevertheless that world was changing. Strange things had been found in caves in Germany and France—unbelievable things, of course—but Father MacEnery was curious. He left his contemporaries chortling in their taverns and set out with a shovel to investigate.

In the echoing galleries of the cavern, behind the town of Torquay, the priest found his answer. From the cavern floor he unearthed implements of stone and

CHARENTE MAN, discovered by Mademoiselle Henri-Martin in the cave of Fontèchevade, is represented by broken brain pan. Added evidence that it is *Homo sapiens* is provided by fragment of another skull found with it.

bone lying in the same stratum with the bones of extinct animals—the great cave bear, the mammoth, the rhinoceros. Father MacEnery, Roman priest, had stepped across an invisible threshold; he had entered the Pleistocene.

It is true he was not quite the first to dig in the English caves. Dean Buckland, then reader of geology at Oxford, had dug at Paviland. Then in his *Reliquae Diluvianae* of 1823 he had given the lie to all he had seen by maintaining that the strange associations of men and beasts he had found were the result of human remains that had been swept into the caves at the time of the universal Deluge. Dean Buckland was an authority. He had reconciled theology and science.

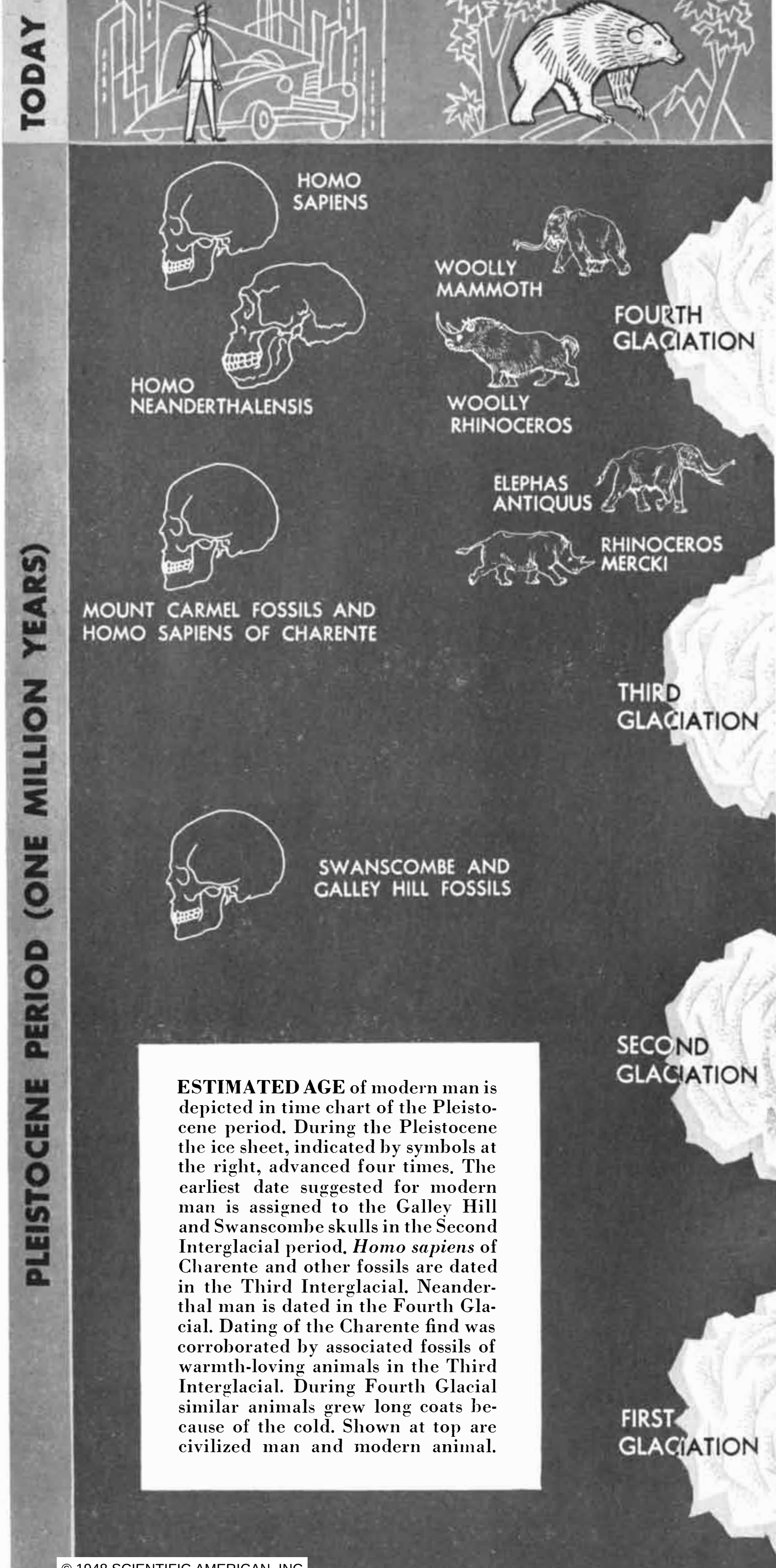
But MacEnery shook his head. No, he maintained. The evidence pointed otherwise. Men had lived here long ago. Men had lit their fires here and cooked their food. Men far away in time, contemporaries of the great gray mammoths.

Father MacEnery spoke, but the Dean thundered. He was the leading authority on caves. Someone took Father MacEnery aside. Someone must have said to him, "My dear fellow, this controversy is growing public. Consider your cloth, consider your vulnerability, consider your position."

Father MacEnery did consider. He laid aside his book in manuscript. His beloved *Cavern Researches* was not published until long after his death. He dug no more. Only in the loneliness of his own fireside and without companions could he relive again that magnificent moment when, first of all mankind, he had lifted up his torch and looked full into the world of the ice.

It was 30 years before science accepted what he had seen in that blinding vision. Father MacEnery had lived in a primitive period—the world of little time. At the end of a cavern he had found the way out. He did not survive to see his views accepted; he never realized that in the vast depths of time he had uncovered there shambled uncouth and anthropoidal men. He knew only that for a single moment in Kent's Cavern time had suddenly opened out like space and that nothing had seemed quite the same afterward. It took the rest of the century and the long thought of a biological genius, Charles Darwin, before the idea of eons of time became acceptable, and the bodies of men and animals were seen to melt and flow and change from age to age like the hills they moved upon.

EVEN THEN, perhaps, the vision was still beyond us. The human mind always tends to erect new dogmas, to shelter itself in hastily erected systems against what is not known or what proves at last to be unknowable. The forms of paleoanthropic, big-browed fossil men began to be discovered. Though their numbers were few, scientists fitted them into a system—a single line of ascent leading to modern

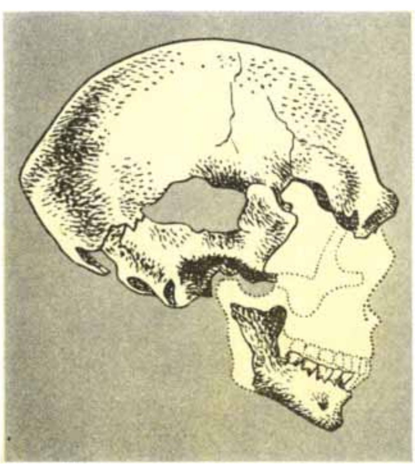


ESTIMATED AGE of modern man is depicted in time chart of the Pleistocene period. During the Pleistocene the ice sheet, indicated by symbols at the right, advanced four times. The earliest date suggested for modern man is assigned to the Galley Hill and Swanscombe skulls in the Second Interglacial period. *Homo sapiens* of Charente and other fossils are dated in the Third Interglacial. Neanderthal man is dated in the Fourth Glacial. Dating of the Charente find was corroborated by associated fossils of warmth-loving animals in the Third Interglacial. During Fourth Glacial similar animals grew long coats because of the cold. Shown at top are civilized man and modern animal.

man. A form like Pithecanthropus, for example, led on in the following age to Neanderthal man. and the latter was regarded as our own direct ancestor. At the other end of the succession. the beginning, was an ape generally conceived of as differing little from a modern chimpanzee.

The sequence was thought of as short and very direct. The time scale was still being underestimated, and western Europe, actually marginal to the Asiatic land mass, was unconsciously overemphasized as an evolutionary center for mankind. In addition, certain preconceptions were making it difficult to survey the problem of the origin of modern man in an unprejudiced light.

The most obvious of these preconceptions was, of course. the idea that since the remains of Neanderthal man had been found in European deposits immediately underlying our own species, we must be a later breed. Thus there could be no valid remains of *Homo sapiens* that were as old as Neanderthal man in Europe. Aleš Hrdlička, for example, in his Huxley Memorial Lecture of 1927 at London, scoffed at the idea that modern man might have developed before Neanderthal. In his mind there was no doubt that Neanderthal man, placed in the Mousterian period some 100,000 years ago, had slowly been transformed into a creature like ourselves sometime during the middle of the last great ice sheet. The final transformation he attributed, rather crudely, to the selective effect of a rigorous glacial climate.



GALLEY HILL skull, found in a terrace of the Thames, may date back 400,000 years. But because it was uncovered by amateurs, its authenticity has never been completely accepted.

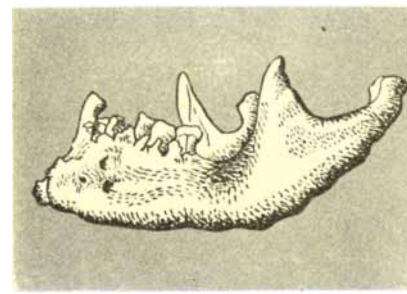
Curiously enough, however, almost from the beginning there were faint clues that pointed in another direction. For illustration the case of Robert Collyer might be cited. He was an American physician residing in London and actively interested in everything from hypnotism to bones. Intrigued, perhaps, by the Darwinian controversy, he purchased a human jawbone and published a paper about it in 1867. The fossil was submitted to T. H. Huxley and other famous authorities of the day. None seems to have been particularly impressed.

Collyer's claim for the antiquity of his specimen lay in its fossilized state and the fact that it had been obtained from a gravel pit near Foxhall at a depth considerably below the surface. Perhaps the fact that it had once changed hands for a glass of beer did not inspire confidence in its origin. At all events, after it had passed under many eyes, interest waned. *largely because the jaw was modern in appearance.* The disappointed doctor is believed to have turned homeward to America. With him went the Foxhall mandible. Together they vanish from the sight of science. An engraving of the jaw which has come down to us, however, suggests that it did indeed look like modern man's.

THE IRONY of the tale lies in the fact that long, long afterward, in 1922, the English archaeologist Reid Moir relocated the old Foxhall quarry and established an early Pleistocene cultural horizon within it. If the jaw actually came from this level. as Moir believed, we would have undoubted evidence that a form of man like ourselves was wandering on the European continent long before the time of Neanderthal man.

Now of course such a striking reversal of all our accepted notions of prehistory can never be carried out on so flimsy a basis. The story of Robert Collyer's Foxhall jaw points a moral. however. The find was potentially one of great importance. The quarry in which the discovery was made should have been investigated immediately. Instead, so inhibiting were the prevailing preconceptions as to what an early human fossil should look like that apparently no one sought to investigate the site itself or pursue excavations there. Attention unfortunately centered on the mandible itself and. since there was nothing about it that the anatomist could surely regard as primitive, interest quickly faded. Only time will tell how many other ancient human relics may have been discarded simply because they did not fit a preconceived evolutionary scheme. It cannot be too often emphasized that if the type of man that now exists should prove to be very old, only geology and the study of man's associated tools and implements will have established the fact. None of this, seemingly, was grasped at the time. Perhaps the circumstances were such that it would have made no difference. Nevertheless one wonders. And the story of the Foxhall pit continues to be told and retold wherever archaeologists gather—told with that wistful wisdom of people speaking 80 years after the event who say to themselves, "If only *I* had been there . . ."

The finds accumulated. Sir Arthur Keith. the great English scholar. catalogued many of them in his work *The Antiquity of Man* in 1925. There was the Galley Hill skull from the 100-foot terrace of the Thames, a fossil that seemed to date back as far as the Second Interglacial. some 400,000 years ago. It, too, was found by amateurs. It, too, failed to gain unqualified acceptance, though it was vigorously defended by Sir Arthur. There were other finds in France, in Italy and again in England. Always the doubt remained. Nor was it all mere prejudice. Our digging luck had been bad. When one finds a Neanderthal man, one knows one is handling ancient material. With our own human type, the bones may tell nothing or may speak in riddles. We must have other evidence of an irrefutable character.



FOXHALL JAW, supposedly found in an English quarry, was publicized by the American physician Robert Collyer in 1867. If authentic, it might have dated back to early Pleistocene.

Sir Arthur recognized this when he wrote, a little wearily, of the Galley Hill specimen: "The anatomist turns away from this discovery because it reveals no new type of man, overlooking the much greater revelation—the high antiquity of the modern type of man, the extraordinary and unexpected conservatism of the type. The geologist regards the remains with suspicion for two reasons—first, he has grown up with a belief in the recent origin, not only of modern civilization, but of modern man himself. He expects a real anatomical change to mark the passage of a long period of time. . . . Moreover, a very primitive type of man survived in Europe. . . . Hence the rejection of all remains . . . which do not conform to this standard."

There the argument stood. The Peking men were discovered—low-browed, small-brained, more primitive than Neanderthal. Their datings were not much older than the time suggested for the Galley Hill skull. Yet to imagine these two forms as standing so close to each other on the time scale with the one directly ancestral to the other strained credulity. The authenticity of the Galley Hill cranium seemed even less plausible than before. Then, in 1935 a strange thing happened. In a gravel pit at Swanscombe, England, 24 feet beneath the surface, the fragments of another skull were found.

The details of that discovery need not

detain us. Here we are concerned only to note that these fragments, which unfortunately did not include the face or forehead, suggested y strongly a true *Homo sapiens* type. And this was associated with the Acheulean culture in geological deposits dated in the Second Interglacial! By comparison, Neanderthal man was alive just yesterday. There was no reasonable doubt of the skull's position, no reasonable doubt as to its geology or the sort of tools found with it. The anatomist W. E. Le Gros Clark allowed that the skull gave evidence that already in early Paleolithic times the human brain had "acquired a status typical of *Homo sapiens*."

Nevertheless, the evidence was not complete. The face was missing. Were we sure. after all, that the face was like our own? Might it not have carried the heavy brow ridges of at least an advanced Neanderthal type? To confuse us further, finds in Palestine, at the much later date of the Third Interglacial. something over 100,000 years ago, suggested a Neanderthal type evolving in the direction of *Homo sapiens*. It was either that or a hybrid mixture between an already existing modern type of man and his heavy-browed relative. Once more argument raged. Even Sir Arthur Keith seemed to waver in his espousal of the antiquity of modern man. It is, then. by this involved and twisted pathway that we come to Mademoiselle Henri-Martin and the deposits in Charente.

The cave lies at the side of a small valley near the village of Montbrun. It had long been known to students of prehistory as having yielded a succession of stone industries extending from Mousterian times to the much later Magdalenian period of the post-glacial era. At the base of the Mousterian cultural layer—everywhere associated in Europe with Neanderthal man—earlier workers had struck a solid floor of stalagmite. There they had stopped.

Mademoiselle Henri-Martin was not so easily deterred. Near the mouth of the cave she broke through the stalagmitic floor and found, in the red, sandy clay underneath it, an older, cruder flint industry marked by large flakes which the French prehistorian Henri Breuil has termed Taycian. It is regarded as a flake culture transitional between the Mousterian and an earlier period.

Many cultural horizons contain no human remains. but here. abandoned among flint chips and the bones of animals, lay a human skull. One can imagine the eager brushing away of earth, the careful manipulation of tools. Here, certainly, must lie an ancestral Neanderthal. This is the Third Interglacial time. The long, cold night of the Fourth Glacial is still far away in the future.

The skull is too worn, too delicate to free quickly from the encasing earth. The hours go on. It is seen not to be complete; finds of such great antiquity rarely are. Nevertheless. the two parietal bones forming the major part of the sides of the head appear. Part of the occipital bone at the back becomes visible, and a fragment of the frontal. It is not, however. the part of the frontal that can tell us about the brow ridges. But for all that, this skull has an oddly familiar look.

In the bony debris painstakingly gathered by the workers, another human fragment is discovered—a very odd fragment that might easily be tossed aside by the inexperienced. Apparently belonging to a second individual, it is the final key to a story that might otherwise have ended like the debate over the Swanscombe skull. This is a glabellar fragment—a little piece from just over the root of the nose and including a little part of the orbit of the eye. There is no trace of a brow ridge. The orbital edge has the delicate sharpness of a modern woman's. This is *Homo sapiens!* This fossil woman saw with living eyes the warmth-loving fauna of the Third Interglacial. In the trench with her lie scattered the remains of *Rhinoceros mercki* and a warmth-loving Mediterranean turtle. The woolly mammoth and the woolly rhino of the last glaciation have

SWANSCOMBE SKULL, also found in England, is dated in Second Interglacial. Its identification as a fossil of modern man, however, is difficult because brow ridges are missing.

not yet come. In the opinion of Henri Vallois, the fossil seems to validate the authenticity of the Swanscombe discovery and, over and beyond. to confirm the existence of a non-Neanderthaloid type on the Continent prior to the Mousterian period.

The skull is markedly long-headed—hyperdolichocephalic, as the anthropologists say. The thickness of the skull bones is marked but not excessive. It is a small skull within the size range of living females. There is nothing Neanderthaloid about it. This woman could have sat across from you on the subway yesterday and you would not have screamed. You might even have smiled.

AGAIN and again, in the case of previous discoveries, the question of intrusive burial had arisen—the possibility. in other words, that the bones were younger than the cultural stratum in which they were found. But Dr. Hallam Movius. a leading authority on the Old World Paleolithic, says: "There can be no question concerning the fact that these finds were *in situ* [in their original site] when discovered by Mademoiselle Henri-Martin: they come from an undisturbed horizon sealed below a thick, unbroken and continuous layer of stalagmite that underlies the Mousterian level at this locality. Furthermore. the fauna demonstrate that these deposits were accumulated under conditions of the warm temperate climate of Third Interglacial times. And the archaeological material is definitely older than the Mousterian from a typological point of view."

Frederick Zeuner. the geochronologist. once wrote that the Pleistocene is a period characterized more by extinction than by creation; that it takes something like 500,000 years for one species to diverge clearly and recognizably out of another. The Pleistocene covers a scant million years. Have we expected too much to transpire in it? Is our vanity offended because, in spite of the great age of our race, it is only in the lattermost part of that epoch that our cultural activities have taken on a highly creative character? Has man, the living species, or something very closely approximating him, drowsed through endless millenia a little as the Australian aborigines were doing until Western explorers stumbled upon them?

There are thousands of questions one yearns to ask, and the answers are very few. What, one might inquire, is our relationship to those thick-skulled, heavy-browed Neanderthals who seem at the onset of the last ice sheet to have dominated western Europe? Were they already "living fossils"—structural ancestors of ours in an earlier time?

Darwin and Huxley certainly were not wrong in their evolutionary theory. We bear in our bodies the traces of our lowly origin. But the lady of Charente takes modern man back to the Third Interglacial of over 100,000 years ago. The Swanscombe cranium very probably carries our human type into the long summer of the Second Interglacial. Year dates grow meaningless when they begin to reach the 400,000-mark. Nevertheless, somewhere far below in the unplumbed depths of the Pliocene of one to seven million years ago, the trail converges backward. It is a trail shared apparently by giants and by dwarfs, by all manner of strange humanity. Year by year their bones accumulate in our museums. Year by year we sort and rearrange and ponder.

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GALAXIES IN FLIGHT

If the island universes are indeed racing away from one another, the fact may shed light on the primordial formation of nuclei and atoms

by George Gamow

IN THE YEAR 1929 the Mount Wilson astronomer Edwin Hubble made a very remarkable discovery. He found that the giant accumulations of stars known as galaxies, which are scattered in great multitude through the vast expanses of the universe as far as the best telescopes can see, seem to be running away from one another at fabulously high speeds. From this observed fact originated the famous theory of the expanding universe. Although the theory is still not finally proved, it seeded a whole generation of fruitful study, not only in astronomy but also in geology, physics and chemistry. It gave us a new start for investigating the age of the universe and the creation of the stuff of which it is made. If our far-flung cosmos came originally from a dense hot core of material concentrated in one place, then we can reasonably assume that this tightly packed core must have consisted in the beginning of elementary building blocks, most of them probably neutrons, out of which all the chemical elements later were made. I shall discuss briefly some recent studies of this phase of the expanding-universe theory which have been made by Ralph Alpher, Hans Bethe and George Gamow. The main sub-

GREAT NEBULA in Andromeda is full-size galaxy closest to Milky Way. Photograph by Lick Observatory.

SPIRAL nebula in Canes Venatici is seen along a line perpendicular to its long axis. Photograph by the 60-inch reflector at Mount Wilson.

EDGE of galaxy N.G.C. 4594 in Virgo faces the Milky Way. Below: "barred" spiral N.G.C. 5850 suggests galaxy in earlier stage of formation.

ject of this article, however. is the basic theory itself, and how it stands up today, 19 years after Hubble's discovery.

The idea of stellar galaxies is a comparatively recent discovery in astronomy. The celestial shapes that we now recognize as galaxies had been observed for a long time as faint nebulosities of various regular forms, but they were generally believed to be simply luminous clouds of gas floating in the spaces between the stars of the Milky Way. Observations with more powerful telescopes, however, resolved these "nebulosities" and showed that they were not clouds but huge collections of extremely faint stars. These giant stellar aggregates were far beyond the outer limits of our own stellar system, the Milky Way; in fact, it soon became clear that they formed systems very similar in shape and structure to the Milky Way galaxy itself.

The nearest and most familiar external galaxy is the great nebula in Andromeda, which can be seen with the naked eye as a faint, spindle-shaped speck of light in the upper part (from the Northern Hemisphere) of the constellation of Andromeda. Photographs made with large telescopes show that this galaxy has a rather complicated structure consisting of an elliptical center, or "galactic nucleus," and "spiral arms" flung into the surrounding space from the central body. The photographs also show two nearly spherical nebulosities close by, probably satellites of the central system.

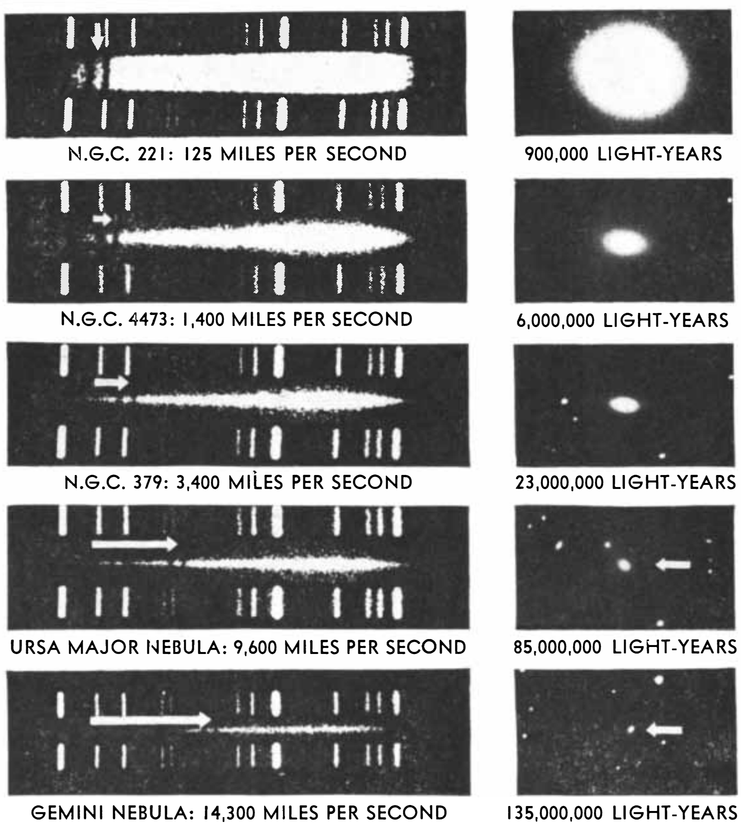
Among the myriads of stars in the arms of the Andromeda Nebula are many pulsating ones, of the type called Cepheid variables. They brighten and fade in a regular rhythm, and their pulsation period provides a method of determining their absolute brightness. By comparing their apparent brightness (which depends on their distance from us) with their calculated absolute brightness, Hubble was able to prove that the Andromeda Nebula is some 680,000 light-years from the Milky Way. To a hypothetical observer in the Andromeda galaxy, the Milky Way would look much the same as the Andromeda system looks to us, except that the spiral arms of the Milky Way are somewhat more open. Our sun, with its family of planets, would be seen through a telescope within the Andromeda Nebula as a rather faint star near the end of one of the spiral arms, some 30,000 light-years from the Milky Way center.

THE GALAXIES generally are shaped like a discus. The Andromeda system looks like an elongated spindle to us because it is tilted to our line of sight, but there are many other galaxies that we see from the top or straight on edge. Most galaxies have the same sort of spiral arms as the Milky Way and Andromeda, but there are also some armless ones. Individual stars are much more difficult to distinguish in armless galaxies and in the nuclei of spiral ones than in the spiral arms. It was only several years ago that Walter Baade of the Mount Wilson Observatory succeeded in resolving these interior stars by using special photographic plates and carrying out the exposures with great care. His pictures revealed an unexpected fact: the stars forming the nuclear regions of spiral galaxies, and all stars of the armless galaxies, have very different physical characteristics from those in the spiral arms. The meaning of this difference in stellar population is not clear, but there is no doubt that it has an extremely important bearing on stellar and galactic evolution.

The galaxies are scattered more or less uniformly through space as far as our telescopes can probe. The average distance between neighboring nebulae is about two million light-years. The limit of our vision with the 100-inch telescope. the largest with which observations have yet been made, is about 500 million light-years. Hence in the observable region of space there are some 100 million galaxies. The new 200-inch telescope on Mount Palomar, which will double the distance we can see into space, may reveal an enormously larger number. Most galaxies are isolationist, dwelling in remote and solitary splendor, but we find a number that group themselves together to form more or less compact clusters. In the constellation of Corona Borealis, for example. there is a cluster containing some 400 galaxies. Our Milky Way is a member of a small cluster which embraces, among others, the Andromeda Nebula and the two galaxies known as the Magellanic Clouds, which are of a relatively rare type that has no well-defined shape.

The distances of all but the nearest galaxies are so great that even the most powerful telescopes fail to resolve them into individual stars. Astronomers' calculations of their distances depend entirely on their apparent brightness. Hubble. studying a group of about 100 well-known neighboring galaxies, established the fact that on the average they were of about the same size and the same intrinsic luminosity. Using this standard, we can estimate the distances of remote groups of galaxies by comparing their mean apparent brightness with that of nearby galaxies whose distances are known. Such measurements give the value of 7.5 million light-years for the distance of one of the nearest groups of galaxies in Virgo. Similar galactic groups in the constellations of Coma Berenices, Corona Borealis and Boötes are respectively 30 million, 100 million and 180 million light-years away.

NOW WHAT was it that gave Hubble the notion that the galaxies are running away from one another and that the universe is expanding? His basic discovery was made with that indispensable tool of the astronomer, the spectrograph, which analyzes the color components of the light coming from stars. Studying the spectra of distant galaxies, he noticed a curious fact: all the lines in their spectra. regardless of the wavelength or color of the line. were displaced toward the red end of the spectrum. Furthermore. the amount of this "red shift" was always directly proportional to the distance of the galaxy from us. The most natural explanation of this shift was that the source of the light was moving away. This is the so-called Doppler effect. of which the classic and most familiar example is the change in pitch of a locomotive whistle as the train approaches us and then speeds away. A light wave. like a sound wave, appears to shift to a longer wavelength when it reaches us from a receding source. And the speed with which the source is moving away is directly proportional to the shift in wavelength. Since the red shift of the galaxies also varied as their distance from us, Hubble concluded that the speed of the receding stars was proportional to their distance; the farther away they moved from one another, the faster they traveled. The red shift of the most distant galaxies that have thus far been observed is 13 per cent, which suggests that they are receding from us at the terrific velocity of 25,000 miles per second.



RED SHIFT of various galaxies is illustrated by comparing their spectra with that of helium *(above and below each nebular spectrum)*. Shift is demonstrated by length of arrows pointing to spectral lines of calcium. Letters N.G.C. before galaxies stand for New General Catalogue.

You must not conclude from this that we stand at the center of the universe and that all the rest of it is running away from us. Picture a slowly inflated rubber balloon with a large number of dots painted on its surface. An observer on one of the spots would be under the impression that the other dots were racing away from him in all directions, and so indeed they would be, but the same thing would be true no matter which dot he was on. In the case of the galaxies, we are dealing with the effect of a uniform expansion throughout all of space.

If you pick an arbitrary point in space, say the earth, and divide the distance of a given galaxy by its recession velocity. you get a figure which represents the length of time that the galaxy has been receding from that point. The strange and wonderful consequence of Hubble's observations is that the figure will be the same no matter what pair of galaxies you pick. Thus it works out that at a fixed, calculable time in the past all the galaxies now so widely scattered were packed tightly together in one place. And the time figure you arrive at is the age of the universe, measured from that instant when the original condensed lump of universal matter was torn apart by the primordial "explosion" that started its headlong expansion.

To get this figure, we must know the exact values for the distances and the recession velocities of distant galaxies. This is less simple than it sounds. The velocities. as we have seen. can be computed from the observed red shift. and the distances. presumably. from the galaxies' apparent brightness. But there is a catch: the apparent brightness of the stars is affected not only by their distance but also by the fact that the light coming from them is redder, and therefore carries less energy. than if the light source were stationary. To illustrate this, suppose for a moment that you are shot at by a gangster operating a submachine gun from the back window of a speeding car. Since the vehicle is receding, the bullets move more slowly toward you than they would from a stationary gun, and they strike your bulletproof jacket with less energy. A receding light source produces exactly the same effect; its emitted light quanta strike the eye with less energy and therefore look redder than they should. An astronomer must make the same correction for the weakening of light intensity as a ballistics expert would make in estimating the muzzle speed of the bullets.

There is a further complication. If the submachine gun shoots, say, one bullet per second, its bullets will strike you at longer and longer intervals as the gun recedes, for each successive bullet will have farther to travel. Similarly. light quanta from receding stars enter the observer's eye with less frequency, and this fact calls for another correction of the observed brightness.

Applying both corrections, and taking the most accurate possible observations. Hubble calculated that the universe began to expand less than one billion years ago. This result stands in contradiction to geological evidence, which indicates that the age of the solid earth crust, estimated quite reliably from radioactive decay in the rocks. must be at least two billion years. Since numerous pieces of evidence in various sciences support the two billion-year estimate. Hubble was forced to reconsider the expansion theory and consider the possibility that the red shift was due not to the normal Doppler effect but to some unknown physical factor which caused light to lose part of its energy during its long trip through intergalactic space.

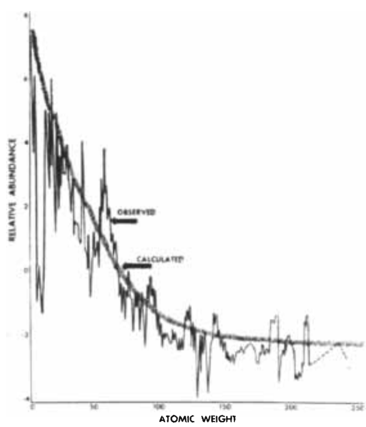
Such a conclusion would ruin many beautiful scientific developments that have flowed from the hypothesis of the expanding universe. It would confront physicists with the difficult task of explaining the red shift in non-Dopplerian terms—which would seem to contradict everything we know at present about light. Fortunately. there is a simple way out of the dilemma which is usually overlooked by the proponents of the "stop-the-expansion" point of view. The point is that Hubble's method of estimating the distances of faraway galaxies assumes that at the moment when they emitted their light they were just as bright as the galaxies we see closer at hand. It must be remembered. however. that the light we see from the distant galaxies was emitted at a fantastically distant time in the past; the light now coming to us from the Coma Berenices cluster. for example. started on its way some 40 million years ago. and the most distant galaxies used by Hubble in his studies are seen as they were almost half a billion years ago!

Do we have the right to assume that the galaxies. which are evolving like everything else in the universe, have kept their luminosity constant over such long periods of time? In view of the known facts about the evolutionary life of individual stars. which maintain their luminosity by the expenditure of nuclear energy. such an assumption would be very strange indeed. Actually. we can remove the entire difficulty in Hubble's time scale by remembering that the nuclear processes that fuel the stars are not endlessly self-perpetuating but are accompanied by a gradual dissipation of the originally available energy. The assumption that an average galaxy loses a mere five per cent of its luminosity in the course of 500 million years would bring the age of the universe to the two billion-year figure demanded by other astronomical, geological and physical evidence.

THIS CONCLUSION finds strong confirmation in recent work by Joel Stebbins and A. E. Whitford at the Mount Wilson Observatory, who have studied the apparent luminosities of distant galaxies on special plates sensitive to red light. To everyone's surprise, they found these galaxies much brighter in the red part of the spectrum than they had previously appeared to be on ordinary photographic plates, which are sensitive mostly to the blue rays. It looked at first as if this phenomenon was due to the same kind of optical scattering which makes the sun look red during dust storms; light from the galaxies, it was thought, was reddened by the clouds of fine intergalactic dust through which it passed. Calculations showed, however, that to account for the observed reddening would take a fantastic quantity of dust—100 times as much as the total amount of matter in the galaxies themselves. Such an assumption would come into serious conflict with many facts and theories about the structure of the universe.

It therefore seems more reasonable to suppose that the distant galaxies look redder simply because they actually were redder when they emitted the light which is now reaching our telescopes. This could be explained if we assumed that young galaxies contain more red stars than more mature ones. Further studies by Stebbins and Whitford should yield important information about the evolutionary life of individual galaxies. Already they have demonstrated quite clearly the danger of building any conclusions on the hypothesis of constancy of galactic brightness.

Having made this fiery defense of the right of our universe to expand. let us consider the physical consequence of the expansion theory suggested at the beginning of this article. What physical process was responsible for the present relative quantities of the various chemical elements that make up the universe? Why,



ELEMENTS are distributed in relative amounts according to their atomic weight. Author's theory coincides with elements observed in stars.

for example, are oxygen. iron and silicon so abundant; and gold, silver and mercury so rare?

We know that. except for the lightest elements (such as hydrogen, helium, nitrogen and carbon, involved in the sun's nuclear cycle). transformation of one atomic nucleus into another requires tremendous temperatures such as do not exist at the present time even in the hot interiors of the stars. Consequently there can not have been any revolutionary change in the relative abundance of the various elements since the expansion of the universe began. On the other hand, there has been some change, for a number of atoms are radioactive and have gradually decayed into more stable elements.

Considering the latter case first, we note. for example. that the lighter isotope of uranium, U-235 (atomic bomb stuff). constitutes only .7 per cent of a given amount of uranium found in nature; the rest is the heavier isotope U-238. The half-life of U-235 is only .7 billion years. while that of U-238 is 4.5 billion years. If we make the reasonable assumption that at the original formation of the universe both isotopes were produced in about equal amounts. the age of the universe figures up to about four billion years. Similar calculations based on the naturally radioactive isotope of potassium (relative abundance—.01 per cent; half-life—.4 billion years) yields the figure of 1.6 billion years. While there is a discrepancy, both figures agree roughly in order of magnitude with the age of the universe as estimated from the red shift and other evidence. Thus we have fairly good reason to suppose that the radioactive elements were formed at the beginning of the universe.

Actually, the picture presented by the expanding universe theory, which assumes that in its original state all matter was squeezed together in one solid mass of extremely high density and temperature, gives us exactly the right conditions for building up all the known elements in the periodic system. As I have mentioned. Alpher, Bethe and Gamow have attempted to reconstruct in some detail the processes by which the various elements may have been created during the early evolutionary stages of the expanding universe.

OUR STUDIES indicate that, under the tremendous temperatures and densities prevailing in the nucleus of the universe during the stage of its maximum contraction, primordial matter must have consisted entirely of free neutrons moving much too fast to stick together and form stable nuclei. As the universe started to expand, this primordial gas began to cool. When its temperature dropped to about one billion degrees, neutron condensation began. The neutrons collected in aggregates of varying numbers of particles. It is known that neutron aggregates are intrinsically unstable unless about half of their particles carry a positive electric charge. Hence they must have emitted electrons until they achieved a state of electrical equilibrium. The electrons fell into orbits around the nuclei and formed electronic envelopes around them; thus atoms were created.

I shall not attempt here to go into a detailed description of the rather involved mathematical theory of atom-building, but shall simply present a graph which compares the abundance curves of the chemical elements as observed and as calculated by our theory. The theoretical curve corresponds pretty well with the observed values; the fluctuations of the empirical curve are due to minor periodic variations of nuclear properties and can be explained by a more detailed form of the theory.

According to our calculations, the formation of elements must have started five minutes after the maximum compression of the universe. It was fully accomplished. in all essentials. about 10 minutes later. By that time the density of matter had dropped below the minimum necessary for nuclear-building processes. All the elements were created in that critical 10 minutes. and their relative abundance in the universe has remained essentially constant throughout the two or three billion years of subsequent expansion.

George Gamow, professor of physics at George Washington University, is author of Birth and Death of the Sun *and other popular scientific books.*

FOUR GALAXIES of different types recede from the Milky Way in a mighty company. They are N.G.C. 3185, N.G.C. 3187, N.G.C. 3190 and N.G.C. 3193. The evidence that these aggregates are in the same cluster is that the galaxies have the same average size and intrinsic luminosity. Groupings of galaxies are not uncommon. The Milky Way galaxy and the Andromeda Nebula, plus several smaller aggregates, form a system of their own.

ALLERGY: A DEFINITION

The original meaning of the word has been obscured by the unpleasant reactions associated with it. Without allergy, in fact, the human species could not survive

by Bela Schick

THE TERM allergy, which came into our language less than 50 years ago, has everywhere been adopted with amazing alacrity. It is now a household word, yet few persons know its true meaning. Laymen and even physicians often use the term as if it applied only to asthma, hay fever, eczema, hives and related conditions. This is a misconception. The term has much wider meaning. We are well acquainted with the allergies that make us miserable, but what we do not realize is that allergy is one of our chief defenses against fatal diseases. Without allergy the human race could not long survive.

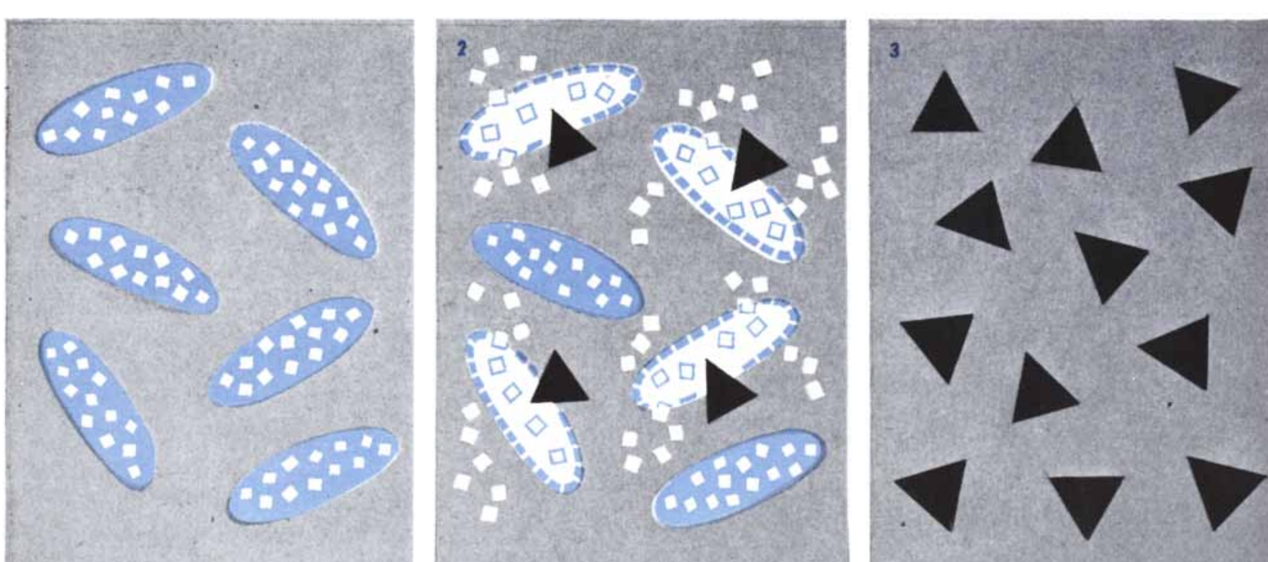
The fundamental meaning of the term can be easily explained and readily understood. It comes from two Greek words, *allos*, meaning different or altered, and *ergeia*, meaning work or, in its biological usage, reaction. It signifies simply that when the human organism is exposed to the same germ or foreign substance more than once, it reacts differently to the second dose than it does to the first.

It was Clemens von Pirquet, professor of children's diseases at the University of Vienna, who coined the word and did the original research in this subject. His allergy concept grew out of studies which he began in 1902 of the incubation period in diseases. As everyone knows, a person exposed to infection by a germ does not get sick immediately. It takes several days at least for the first symptoms of the disease to appear—this is the so-called incubation period. Why does it take so long? One explanation, it was discovered, is that the invading germ at first multiplies without inhibition, continuously producing a toxic secretion, and the disease begins to show symptoms only after the toxin accumulates in sufficient quantity. The classic example of such a disease is diphtheria. It has a relatively short incubation period.

There are other diseases, such as typhoid fever, measles and smallpox, which have a considerably longer incubation; every experienced mother knows that it takes about 14 days after exposure for a child to come down with measles. The manner in which these diseases develop must be different from that in diphtheria. The usual and most plausible explanation is this: the invading germ does not excrete a toxin, but it does multiply copiously and without hindrance within our system. If this process were not eventually checked, the result would be fatal. The germ or virus would multiply so enthusiastically that it would fill up our blood vessels and finally obstruct our circulation.

Fortunately our system is equipped with defenses that are called into play before multiplication goes too far. The invading germs stimulate the body to produce antibodies which destroy the germs. The destruction process liberates toxic substances called endotoxin within the germs. It is these toxic substances that produce the symptoms of disease. We must pay with disease to free ourselves from the invading germ. Indeed, if the invasion and multiplication of germs is very intensive, the antibodies may liberate so much poison that the patient dies—a kind of involuntary suicide. But invasions of such severity are exceptional, and in some diseases we can mitigate their intensity by the use of modern drugs—the sulfas, penicillin, streptomycin—which help the antibodies by retarding the multiplication of germs.

In measles, typhoid and smallpox, the



INCUBATION PERIOD of diseases such as measles, typhoid and smallpox is explained by series of events in these three drawings. In first drawing germs that have invaded the body multiply unhindered. In second body has manufactured antibodies (*triangles*) that attack germs. The germs then liberate endotoxin (*small squares*), which causes symptoms of disease. In third drawing germs have been destroyed by antibodies. These, or at least the ability to produce them, remain as defense against the later incursion of the same germs.

incubation period represents the time required by the body to mobilize the antibodies. In diphtheria, as we have seen, incubation is the period during which toxin accumulates to the point of producing symptoms. But Pirquet observed a disease to which neither of these explanations of the incubation time applied. This is the disease known as serum sickness. It develops after the classic treatment of diphtheria with horse serum. The serum is derived from horses which have been injected with the toxin of the diphtheria bacillus. The horses then produce an antitoxin against this toxin. When their antitoxic serum is injected in a child suffering from diphtheria, it neutralizes the toxin in the child's system. Soon after the discovery of the serum in 1894, it was observed that eight to twelve days after it was injected in children they broke out with hives and fever. This was puzzling. The liquid serum itself is not toxic, as proved by the fact that even if 100 to 200 cubic centimeters is injected it produces no immediate effects; the serum sickness does not start until eight to twelve days afterward. There is no germ in the serum which could multiply or produce toxin, or release an endotoxin. What, then, is the cause of serum sickness, and why is its appearance delayed?

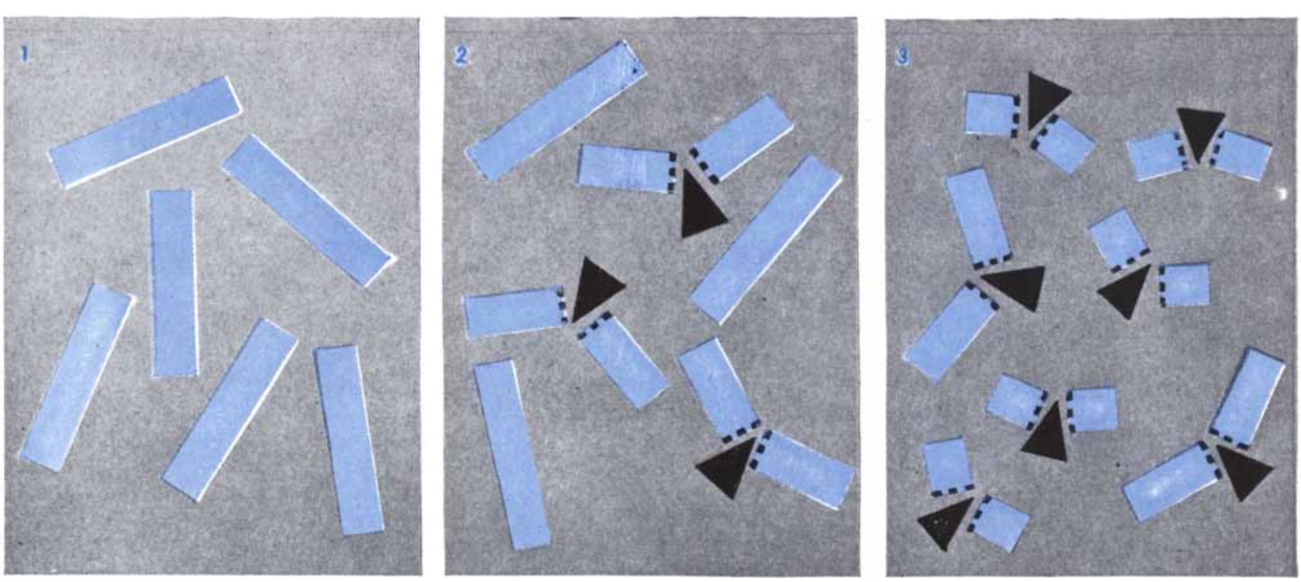
TO FIND the answer to this question, Pirquet carefully observed a child who had been treated with the serum. After the usual incubation time, the child developed hives and other familiar symptoms of serum sickness. Three weeks later this child required a second injection of serum. To Pirquet's surprise, the child came down with serum sickness within a few hours. In other words, the incubation period had been eliminated! What had happened? The serum injected was the same. There were no germs in the serum, so the second injection did not produce a cumulative effect. There could be only one explanation: the difference must be in the reaction of the child. The first injection had somehow altered the child's reaction time. It had developed what Pirquet called an "allergy."

Pirquet and I, collaborating in further studies of this phenomenon, found that if the second injection of serum was made four months or more after the first, instead of only a few weeks afterward, there was still another reaction. This time serum sickness developed not within a few hours but after four to six days. The incubation period was not eliminated but shortened. To explain this allergy or altered reactivity, we formulated this theory:

Serum sickness is due to the foreign protein (from the horse) which is present in the serum. The human system cannot tolerate a foreign protein and therefore the protein must be destroyed. It is true, to be sure, that at every meal we take in food containing foreign proteins. But these proteins must be digested before they replace our own protein destroyed daily by life processes. The digestive juices in the stomach and intestines break down the complicated foreign protein molecule to its simplest elements—amino acids. During this breakdown process, intermediate substances are formed which are toxic. But they do us no damage because they are fully converted to the safe amino acids before they leave the digestive system.

When a foreign protein is injected under the skin or into a vein, however, the protective action of the gastrointestinal canal is by-passed. The cells of the organism are capable of producing digestive substances (such as fermentlike antibodies) which break down the protein. But the toxic intermediate products that are created during this process are in position to attack the body directly, and so these poisons produce sickness, that is, serum sickness. We postulated, therefore, that the interaction between the antibodies and the foreign protein was the cause of the sickness.

At the time of the first injection of horse serum into a patient, no such antibodies are present; they must be created. This process takes time, which accounts for the incubation period. After the patient has recovered from serum sickness, the antibodies are still present, and they remain in the circulation for about four months. If the patient gets a second injection during this period, there is no waiting for antibodies to be produced; they are already on hand and attack the foreign protein immediately. Within a few minutes to a few hours the toxic intermediates appear in the blood and the patient begins to show symptoms of the serum disease. Suppose, on the other hand, that the second injection is given after a lapse of four months. By that time the antibodies have disappeared. Nevertheless, the cells appear to remember how to produce them, and this time the production of antibodies is much faster than after the first injection. Consequently the attack on the protein is accelerated and the patient's reaction also is accelerated. He shows the symptoms of serum sickness in four to six days instead of eight to twelve. These studies led us to an important corollary conclusion: if a person shows an immediate or accelerated reaction to a serum injection, one is justified in assuming that



SERUM SICKNESS sometimes occurs when patient is injected with diphtheria serum. The sickness is caused by a foreign protein in the blood of horses which have been injected with diphtheria germs to produce the serum. In the first drawing the foreign proteins have entered the body of the patient. In second drawing proteins are broken down by digestive substances into toxic products which cause the symptoms of sickness. In the third drawing these toxic intermediates have been further broken down into various harmless amino acids.

very likely he has previously been treated with horse serum.

CAN the allergy theory be applied also to the other group of diseases we considered—measles. typhoid, smallpox, smallpox vaccination? It can indeed. As we observed, when germs of these diseases invade the body, antibodies are formed to fight them. After the germs have been mastered, the antibodies continue to circulate in the blood stream for a time. If a second invasion by the same germs occurs, the antibodies kill them immediately, before they have time to multiply. Since very little endotoxin is set free, the individual has no symptoms. He is, in fact, immune to the disease. He is immune because his reaction has been altered and takes place immediately. In other words, his immunity is based upon allergy.

As in serum sickness, the antibodies in these diseases disappear in time; but they reappear more quickly in response to repeated attacks of the disease and consequently the patient has at least partial immunity. He has "shaken off the infection with very mild symptoms."

Here, then, is the principle on which medical immunization is based. To forestall a severe infection, we inoculate ourselves with a mild form of the disease by injecting a small amount of toxin, of a modified toxin called toxoid or of attenuated germs. This mobilizes an army of antibodies ready to attack any natural invasion by the same germs. Vaccination against smallpox, injections against diphtheria, tetanus (lockjaw), whooping cough and yellow fever, and BCG vaccination against tuberculosis are examples of such immunization. Their effect is to create a beneficial allergy.

Thus allergy is an essential element in man's protection against serious infections. It is also important in diagnosis. Pirquet's fundamental studies in allergy led him, for example, to the discovery of the tuberculin test. A positive result in the Pirquet test indicates the existence of a tubercular infection. By this discovery, Pirquet became the father of all skin testing. There are now a number of skin tests used in the diagnosis of various diseases.

But we must consider the unpleasant and harmful phases of allergy. They constitute only a small part of all allergy, but they do cause great misery, and in extreme cases may even endanger life. The allergies that trouble people are known as hyperallergic or anaphylactic reactions.

In our study of serum sickness, Pirquet and I found that the elimination or shortening of the incubation period was not the only result of allergy. After repeated injections, the serum disease became more intensive than in the first attack. A child became hypersensitive to the toxic substances created by the interaction between horse serum and its antibody. Occasionally, especially when serum was injected intravenously, the serum sickness was so severe that the patient went into shock and showed symptoms of asthma. Then he broke out in a violent eruption of hives. Usually the patient recovered, but in a few extreme cases he died.

At this stage of the study occurred the phenomenon so common in science—almost simultaneous discoveries in widely separated parts of the world by several groups of scientists who happened to be studying the same sort of problem at the same time. While we were investigating allergy in Vienna, the great American bacteriologist Theobald Smith was experimenting along the same lines with guinea pigs. He injected them with horse serum containing diphtheria antitoxin. To his surprise, the guinea pigs, which tolerated the first injection without ill result, suddenly died when they were given a second injection two weeks later. Their symptoms resembled asthmatic shock. At about the same time the famous French physiologist Charles Richet made a similar discovery. In a floating laboratory provided by the Prince of Monaco, he was studying a potent poison derived from a sea anemone. He injected tiny amounts of the poison in dogs. After one injection, the dogs were allowed to recover completely. They also survived a second injection given two weeks after the first. But a dog that got a second injection after an interval of three weeks died suddenly in shock. Apparently the dog had become hypersensitive. Richet called this hypersensitiveness "anaphylaxis"—from the Greek *ana*, meaning the reverse of, and *phylaxis*, protection—to denote the fact that the dog had lost a protection which it formerly possessed.

RICHET'S dog and Smith's guinea pigs quite clearly had succumbed to similar types of attack. This class of syndrome is not to be confused with a human being's repeated inoculation with disease germs, which does not produce so damaging an effect. Anaphylaxis is always serious and sometimes fatal. Evidently we were dealing here with a kind of phenomenon entirely different from a germ attack.

The hypersensitive reactions of the animals resembled asthmatic attacks in human beings. This finding focused attention on the asthma syndrome. It was found that asthma and hay-fever patients were frequently extremely sensitive to horse-serum injections. This prompted the idea that such patients should be studied from the angle of hypersensitiveness to other protein substances. Since Pirquet had already used skin-testing to determine the presence of tuberculosis, and I had used it to determine susceptibility to diphtheria, we chose this method to determine to what substances hyperallergic patients were sensitive.

It was known that some persons were sensitive to certain foods such as fish, eggs, berries and so on, and that the inhalation of pollens, especially of ragweed, could produce attacks of asthma, sneezing, swelling of the face and other symptoms. The difficulty was that this sensitivity was always strictly specific to a particular substance, and it was often difficult to identify the offending substance. The skin-test method proved to be a handy way to find the offender. Scratch tests and intracutaneous tests were performed with extracts of foodstuffs, pollen of grasses and hundreds of other substances. When a person was sensitive to a given substance, that fact was disclosed by the appearance of a wheal around the scratch or intracutaneous injection. It was found that there is almost no foodstuff which will not produce a positive skin reaction in some hypersensitive patient. From many tests we learned which substances most frequently give rise to symptoms. Those that seem to be especially obnoxious are house dust, feathers and animal emanations, particularly from cats, dogs and horses. These substances are capable of producing a great variety of unpleasant symptoms, from sneezing and coughing to outright asthmatic attacks. Some of them are: itching, eruptions of hives and other rashes, a running nose, nausea, vomiting, colics and diarrhea, migraine and other intense headaches and a multitude of similar neurological symptoms.

The allergy-producing materials are not confined to natural substances. Many materials used in industry may produce hyperallergic symptoms, often by mere contact. Chemicals (especially dyes), insecticides, cleansers, soap, and, to the distress of the ladies, such cosmetics as nail polish, lipstick and face powder may cause skin irritations. (Fortunately nonallergic cosmetics are available.) Drugs also may have hyperallergic effects. Some of the new drugs, including penicillin, streptomycin and the sulfas, have been known to cause trouble in hyperallergic patients. As a rule the drug's beneficial effect outweighs any discomfort it may cause, but in some patients its side effects may be so distressing that repeated use of the drug is inadvisable.

Protein hypersensitiveness is a heavy burden to many people. A hay fever patient, obviously, is miserable during the pollen season. Before the present treatment with injections was discovered, the patient had two alternatives: to suffer through the season or to betake himself to a place that was free of pollen. In Europe, the Island of Helgoland is such a hay fever patient's paradise; in the United States, Bethlehem in New Hampshire's White Mountains is a similarly famous haven. But nowadays a patient may be relieved without fleeing. An attempt is made to discover the specific pollen to which he is susceptible. With that knowledge he can be desensitized by means of injections of an extract of the pollen. A similar treatment with extracts is used to reduce sensitivity to house dust, poison ivy and so on.

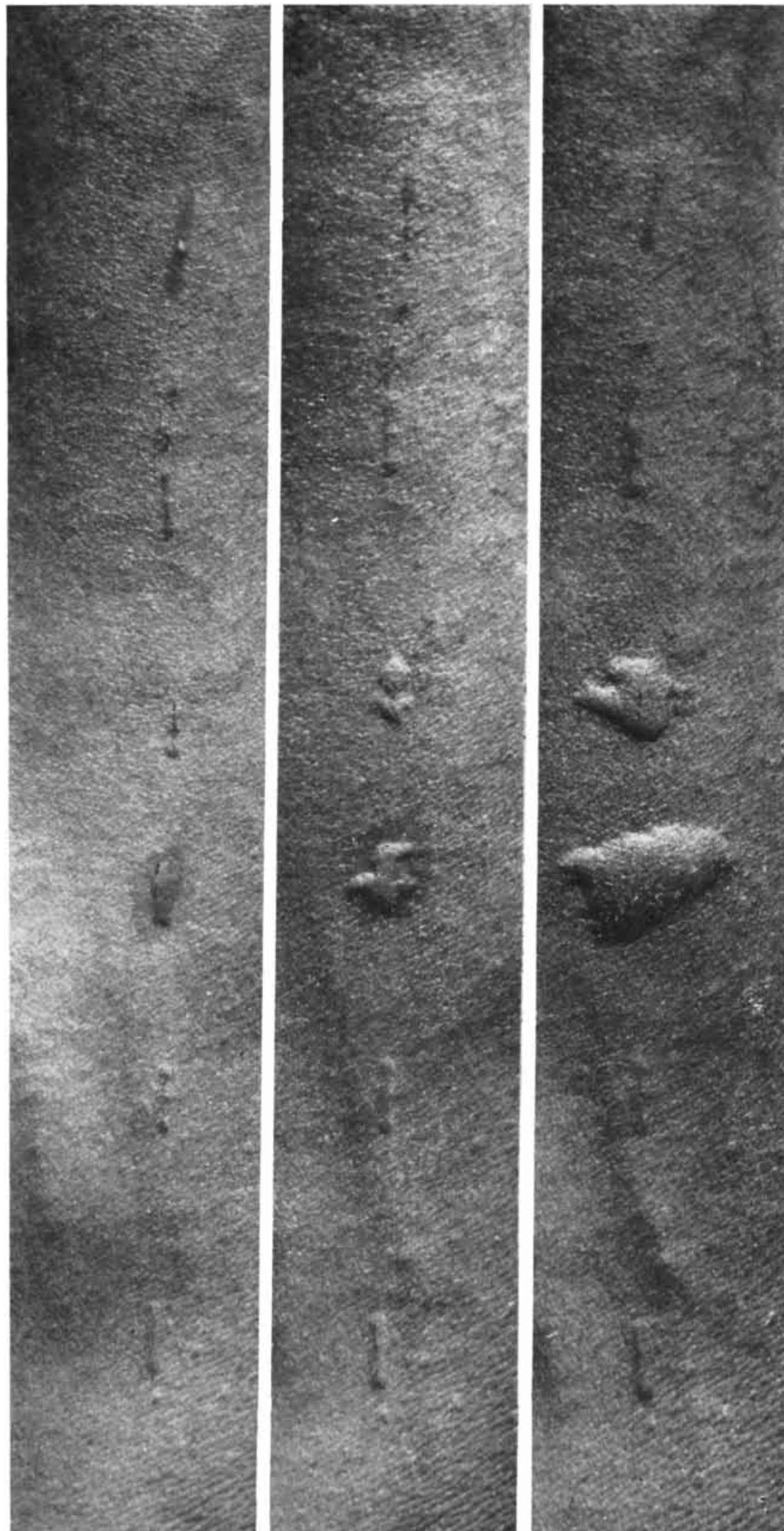
ALLERGIC reactions to foodstuffs are easier to handle. All one needs to do is to identify the offending food and then eliminate it from the diet. This may be a nuisance, but one can learn to live without eating oysters, for example, or fish, chocolate, nuts or strawberries. It is sometimes hard to keep children from food which they adore. But it has been my experience that older children are often better than adults in accepting their diet or other privations. A child deprived of the privilege of playing with dogs or cats, or riding ponies, or going to the rodeo, circus or zoo, is unhappy for a time but many children realize that it is beneficial for them to forego such pleasures.

Happily, as far as children are concerned, we can promise in many cases that their hypersensitiveness will diminish in time; eventually they become able to do all the things that other children do. One interesting discovery is that a given patient's tolerance to offending substances is not the same at all times. During periods of robust health, a hypersensitive child's tolerance may be so improved that he can eat and do everything. Again it must be borne in mind that allergy is not a disease, but only a different reactivity. A hay fever patient is healthy outside of the hay fever season, and even during the season there is nothing wrong with him if he is in a locality free from pollen.

Recently a great deal has been written about the role that histamine in the body is supposed to play in the causation of hyperallergic reactions, and about antihistamine drugs. But the theory is a very debatable one and I shall not attempt to deal with it here.

In sum, then, it cannot be too strongly emphasized that the uncomfortable symptoms conjured up in the layman's mind by the term allergy are but a small part of a larger whole. The conspicuously annoying effects of these allergies project them so disagreeably and intensely into our daily lives that the much more comprehensive and beneficial implications of allergy are generally overlooked. Actually allergy is a great boon to mankind. Instead of focusing our displeasure upon the discomforts caused by hyperallergic reactions, we should be grateful for the immunity we gain from this marvelous process. Were it not for allergy, the germs would kill us all. As medicine progresses, it should become possible to find effective treatments for the disagreeable phases. The time will come when no one will doubt that nature has indeed been kind to have given us the blessing of allergy.

Bela Schick, originator of the Schick test for immunity to diphtheria, is consulting pediatrician at New York's Mt. Sinai Hospital.



TEST FOR ALLERGY, made by scratching patient's arm with common allergens, produces miniature allergic reaction. First picture shows scratches immediately after they were made. The second, after one minute, shows wheals about scratches made with pollen extract of grasses (*top*) and ragweed. Third, after five minutes, shows patient is most sensitive to ragweed.

SCIENCE AND THE

U. S. Joins WHO

AFTER a year of hesitation, the U.S. has become a member of the World Health Organization. Ratification of the WHO charter was voted by the Senate last July. Similar action by the House was held up, however, until early last month by the House Rules Committee, which had declined to give the ratification resolution a place on the House calendar. The ratification was signed by the President June 14, making the U.S.—last of the Big Five nations to act—WHO's 42nd member.

As finally voted by Congress, the ratification resolution contains four House-imposed limitations on American participation in WHO. First, the U.S. financial contribution is limited to $1,920.000 a year. Second, the U.S. member of WHO's executive board must be an M.D. with at least three years of active practice. Third, U.S. representatives in WHO are to be investigated for loyalty by the FBI. Fourth, the resolution contains a broad reservation with respect to U.S. acceptance of specific WHO proposals.

Ratification came just in time to permit the U.S. to send a regular delegation to the First World Health Assembly, which met in Geneva June 24 for the formal launching of WHO. Over 500 delegates and technical experts from some 70 member and non-member countries were present as WHO took over from the Interim WHO Commission established two years ago by the United Nations. The Assembly mapped programs for fighting tuberculosis, malaria and venereal disease, and for promoting maternal and child health on a global scale.

Science Foundation Fails

AMONG the measures that fell by the wayside as the 80th Congress adjourned was the National Science Foundation bill. After the Senate had passed an amended version of the compromise Foundation bill on May 5, action was begun in the House Interstate and Foreign Commerce Committee on the original version of the compromise bill. As the result of a hearing June 1, the Committee reported out a bill which was also amended in several particulars. There were still differences between the House and Senate versions and a conference to reconcile the two would have been necessary. The Rules Committee did not assign it a place on the House voting calendar. Since the 80th Congress is now over, the Senate vote goes for naught; the bill is now dead and will have to be reintroduced in both branches of the 81st Congress.

Two other bills affecting science were passed, however, just before the last-minute draft and ERP battles. The first, signed by the President June 16, creates a National Heart Institute, similar to the National Cancer Institute, within the U.S. Public Health Service to carry on research in cardiovascular-renal diseases. But no funds for the Heart Institute were appropriated. The other measure sets up a National Institute for Dental Research in the Public Health Service.

$11 Billion in Chemicals

DURING the past quarter-century the chemical-process industries have displaced steel as the nation's largest industry. In the first of a new series of annual surveys, *Industrial and Engineering Chemistry* reports that the 1947 output of chemicals and allied products had a value of $11 billion—more than one and a half times the $7.1 billion gross product of the steel industry.

Twenty-five years ago the annual output of chemicals and related products such as paints and drugs was only $3 billion. The rise since then stems almost wholly from technological and scientific advances, because many of the most important chemical products of 1947 did not exist or were merely laboratory curiosities in 1923. Synthetic yarns, synthetic rubbers, several new classes of plastics, insecticides, the sulfa drugs, penicillin, streptomycin and other new products have brought a 30-fold increase in the production of organic chemicals. A five-fold increase in the output of basic inorganic chemicals has also taken place, due partly to the rise of the organics (for which inorganic chemicals are required as raw materials) and partly to the emergence of new synthetic fertilizers. The chemical industry's growth will continue for some time, since it has expanded its research facilities along with its production. As a consequence there are more new chemical developments on the horizon today than ever before.

German Documents

FOR the second year in succession, the Senate has come to the rescue of the Office of Technical Services, the Government agency charged with analyzing and publishing captured German scientific and technical documents. Four years ago OTS was established by the Department of Commerce to provide technical assistance to small business during postwar reconversion. When hundreds of tons of captured German technical reports began arriving in the U.S., the task of processing them and making their contents available to interested American laboratories and manufacturers was added to OTS' functions. Both this year and last, however, the House of Representatives failed to appropriate funds for OTS. Only Senate appropriations have kept the agency in existence. OTS will continue for another 12 months, but its appropriation is only $200,000. Since it has been directed to wind up its work within the year, OTS will be able to do little more than list the titles in the 2,500 trunks of German papers remaining to be opened.

Cape Cod Mecca

THIS season Woods Hole, Mass., is back to its peacetime norm as a traditional summer capital of American science. On a southern extension of Cape Cod opposite historic Martha's Vineyard, Woods Hole is the home of two world-famous institutions, the Marine Biological Laboratory and the Woods Hole Oceanographic Institution. The Marine Biological Laboratory is host in July and August to scientists who come from nearly every state and from abroad to work on a wide variety of general biological problems, many of which are most conveniently studied in marine animals. This summer the Laboratory has nearly 500 researchers in residence. The Oceanographic Institution, the field of which is the physics and chemistry of the ocean, also is having a busy season.

During the war the Marine Biological Laboratory was shut down. The Oceanographic Institution operated full blast, but worked exclusively on problems of warfare at sea, such as underwater acoustics. Although the Institution still holds Navy contracts, the last naval officer has left. With 385 scientists in residence, it has resumed the study of heat exchange between the sea and the air and other basic oceanographic problems.

Senior Societies

THE most esteemed honor offered to an American scientist, aside from award of a Nobel prize, is election to the National Academy of Sciences or the American Philosophical Society. The Academy, founded during the Civil War by an act of Congress (but privately supported) to advise the Federal government on military-scientific problems, has 401 members drawn from the physical and biological sciences and psychology. The Philosophical Society, which dates back to colonial times, has approximately the same membership but fewer scientific members, since arts, letters and the social sciences also are represented.

At their spring meetings, the Academy elected 30 new members and the Philosophical Society 14. Among them was Gerty T. Cori, Washington University of St. Louis biochemist, who was elected to both—the fourth woman scientist to receive this dual recognition. Dr. Cori joins her husband, with whom she shared a 1947 Nobel prize for their studies in carbohydrate metabolism, in the two societies. Another elected to the Academy was Glenn T. Seaborg, discoverer of plutonium. The Philosophical Society's elections included Robert Fox Bacher, physicist member of the U.S. Atomic Energy Commission.

Hybrid Corn

EARLY this spring, the UN Food and Agriculture Organization shipped $300 worth of hybrid corn seed to 17 European and Middle Eastern countries. With this, FAO hopes to bring a new order of farming to Europe and the Middle East, for hybrid corn has increased American corn yields by more than 20 per cent in a decade and a half.

Corn has never been a popular crop outside the New World. However, experimental plantings of hybrid corn in Italy last year—the first outside the U.S.—surprised Italian farmers. Yields ranged from 32 to 117 per cent higher than the inferior varieties used most often overseas. FAO believes that hybrid corn will overcome the Old World farmer's lack of interest in corn and make a significant contribution to the world food supply by multiplying the acreage devoted to one of the most efficient food crops known.

'ERP' for Science

THREE years after the end of the war, scientific workers abroad—who include many of the world's outstanding talents—still labor under frustrating handicaps. Aside from the question of their health and personal well-being, their equipment is obsolete or worn out, or was lost during the fighting. Most of the apparatus-makers who supplied them, moreover, are either out of business or are engaged in urgent tasks of reconstruction. In many countries, the only possible source for thousands of items of laboratory supplies and equipment is the U.S.—but the countries concerned have no dollars.

Two schemes for dealing with the situation are slowly being developed. The nearer of the two to materialization is an arrangement worked out by a group of American apparatus-makers who last year formed a U.S. Scientific Export Association. Sometime this summer the Association is to receive a $2.500.000 credit from the Export-Import Bank to finance apparatus exports to countries short of dollars. Shipments will probably begin next year to countries that make necessary supplementary agreements with the Export-Import Bank. The second scheme, to provide $3 to $4 million in dollar credits for purchase of American equipment by European institutions, is a UNESCO project. UNESCO's first financing proposals were rejected by the major nations, but more acceptable suggestions are expected to come from a current UNESCO meeting in Paris. If both the American and the UNESCO plans materialize, some $6 million will become available for re-equipping research centers abroad—by no means a large sum, but a useful adjunct to other efforts.

Max Planck Society

ONE of the first acts of the Allied Control Council in Germany was dissolution of the Kaiser Wilhelm Institute, the central agency through which German scientific work was coordinated and which played an important part in German military research. German scientists wondered what was to become of the 50 research agencies that were affiliated with the Institute. A partial answer has come from the ancient university town of Göttingen in the British zone. Under the presidency of Otto Hahn, discoverer of uranium fission, 11 German Nobelists living in the bizonal area have formed the Max Planck Society for the Advancement of Science to take the place of the Kaiser Wilhelm Institute. Until private and industrial funds become available, the Society expects to obtain funds for research from the bizonal government.

Two former affiliates of the Kaiser Wilhelm Institute, the Kaiser Wilhelm Institute for Coal Research at Heidelberg and the Paul Ehrlich Institute for Vaccines at Frankfurt, have joined the Max Planck Society. Nothing has been heard, however, from institutes in the French or Soviet zones, nor have any in the British zone as yet completed affiliation.

Meetings in August

AMERICAN Institute of Electrical Engineers. Pacific general meeting. Spokane, Wash., August 24-27.

American Chemical Society. Eastern session. Washington, D. C., August 30-September 4.

PHYSICS AND MUSIC

The agreeable sound of simple melodies and Beethoven symphonies is guided by physical rules, plus a little physiology and psychology. The understanding of these principles can enhance musical creation and enjoyment

by Frederick A. Saunders

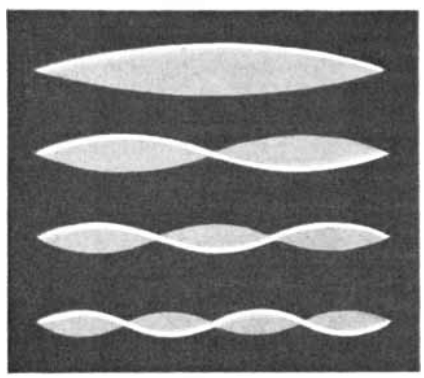
ANYONE who looks upon a great bridge arching across a wide river is thrilled by its beauty, and aware at the same time that a great deal of measuring, testing and calculating must have gone into its planning to make the structure safe. A bridge is an obvious combination of art and science. Not so obvious is the physical architecture of great music. One who listens to a symphony at an orchestral concert may know that the composer drew on his inspiration to fill pages with symbols, and that the conductor and his musicians interpret these to help bring to life again what was in the composer's mind. The listener is intellectually and emotionally moved by the sequence of sounds coming to him from many different sorts of instruments. But what has this bewilderingly complex example of art to do with science?

The answer is simple enough. Music is based on harmony, and the laws of harmony rest on physics, together with a little psychology and physiology. The simplest and most pleasant intervals of music have always existed among the harmonics of pipes and strings. From them grew the study of harmony, and they have formed the basis of many noble melodies. A classic example is the opening melody of Beethoven's *Eroica* symphony, whose first part consists of the simplest possible intervals flowing one after the other. Such simple combinations do something to our ears which is fundamentally pleasant and satisfying. Some musical instruments were well developed long before the subject of musical acoustics was born. Today the physics of music helps to guide improvements in musical instruments, in the construction of buildings with good acoustics, in the reproduction of music for immense audiences, and in many other ways.

To examine the physical basis of music we begin by considering the nature of sound. Sound is a word used in at least two senses: (1) the sensation produced in the brain by messages from the ear, and (2) the physical events outside the ear.

SYMPHONY is a vast blend of frequencies from many instruments. At left: Leopold Stokowski conducts rehearsal of New York Philharmonic.

The context usually makes it plain which meaning is intended. Thus we avoid long arguments over whether a sound can exist if there is no one present to hear it. Sound has its origin in a vibrating body, and the vibration may be *simple* or *complex*. The motion of the pendulum of a clock represents a simple vibration, one which is not rapid enough to be audible. To be heard as a musical tone, a vibration must have a frequency of at least 25 cycles per second. A pure tone is represented by a smooth



HARMONIC series is defined in various vibrations of a string. Harmonizing frequencies are two, three, four or more times simplest vibration (*top*).

curve in which distances to the right stand for time, and distances up and down correspond to the displacement of the vibrating body from its position of rest. A vibration of this sort is often called simple periodic motion because it repeats itself regularly with a constant period of time for each repetition. But pure musical tones are rare; the tones that are produced by musical instruments are almost always complex.

Complex vibrations can always be regarded as made up of a combination of simple vibrations of different frequencies. Their forms are very varied, as shown in the illustration on page 38. Sometime when you are out walking and have nothing better to do, try swinging your arms at different rates. The simplest case is easy: right arm going at twice the rate of the left. It is not quite so simple to make the right arm alone combine both of these motions, and it is still harder to combine rates whose ratio is one to three, two to three, and so on. One gives up before long; yet any violin string can do this easily without becoming confused. It can combine as many as 20 different rates at the same time into one complex vibration, which is caused in this case by the complicated motion of the string under the bow. These frequencies are simply related; their values are proportional to the integers 1, 2, 3, 4 and so on. They form a harmonic series. The vibration with the lowest frequency, corresponding to the number 1, is called the fundamental; the sound with double this frequency is the first harmonic, and the higher harmonics are calculated in like manner.

I. Harmonic Analyzers

The scientific study of musical instruments depends partly upon the resolution of complex tones into their harmonic elements, a process called harmonic analysis. It is often of practical importance to determine what components are present in a tone and how strong each one is. One old method of analyzing a musical tone is to study its wave form, as pictured by means of a microphone, an amplifier, and a cathode-ray oscilloscope (*see cover*). But the wave is frequently very complicated, and its analysis by mathematical methods into the simple waves of which it is built is very slow and tedious. In recent years instruments have been developed which analyze complex tones automatically, yielding rapid and accurate results.

Some of these harmonic analyzers make use of the physical effect called resonance, which is a response produced in one body from the vibration of another body. It is easily demonstrated on a piano. In piano strings the harmonics are strong. If you press gently on the key an octave below middle C, so as to free the string but not to strike it, and then strike the middle C key sharply, you will hear a continuing middle C tone coming from the lower string. The experiment succeeds only if the strings are in tune. The middle C frequency (about 260 cycles per second) is

FREQUENCY RANGE of some musical instruments and other producers of sound is tabulated in chart adapted from book *The Psychology of Music*, by C. E. Seashore. Frequencies, noted in scale at the bottom of page, are plotted horizontally. Range of scale is 40 to 20,000 cycles, as compared with the human ear's approximate range of 25 to 30,000 cycles. The thin line within each light horizontal bar indicates actual range of frequencies produced by each method. Circles on each line indicate effective range estimated by a group of expert musicians. Vertical lines at the right end of each frequency line indicate range of associated noise. The instruments in black panel are, from top to bottom, tympani, snare drum, cello, piano, bass tuba, French horn, bassoon, clarinet, male speech, female speech and jingling keys. In blue panel are cymbals, violin, trumpet, flute and clapping hands.

equal to that of the first harmonic of the lower string; hence the lower one can respond.

By a variation of the experiment, one can play a chord on a single string. Hold the lower string open as before, but now give a strong impulse to three keys at once—middle C, the C above and the G between. After the upper strings have been quieted, all three tones will be heard coming from the lower string alone, which is resonating to three frequencies at once. This works as well the other way around: hold the same three upper keys open with the right hand and give the lower C a sharp blow. The three upper tones will be heard, coming from the three untouched strings. Or again, try singing a tone into a piano with the loud pedal pressed down. (This frees the strings to vibrate in resonance with any tone with which they agree in frequency.) When you stop singing, you will hear a faint mixture of tones issuing from the piano.

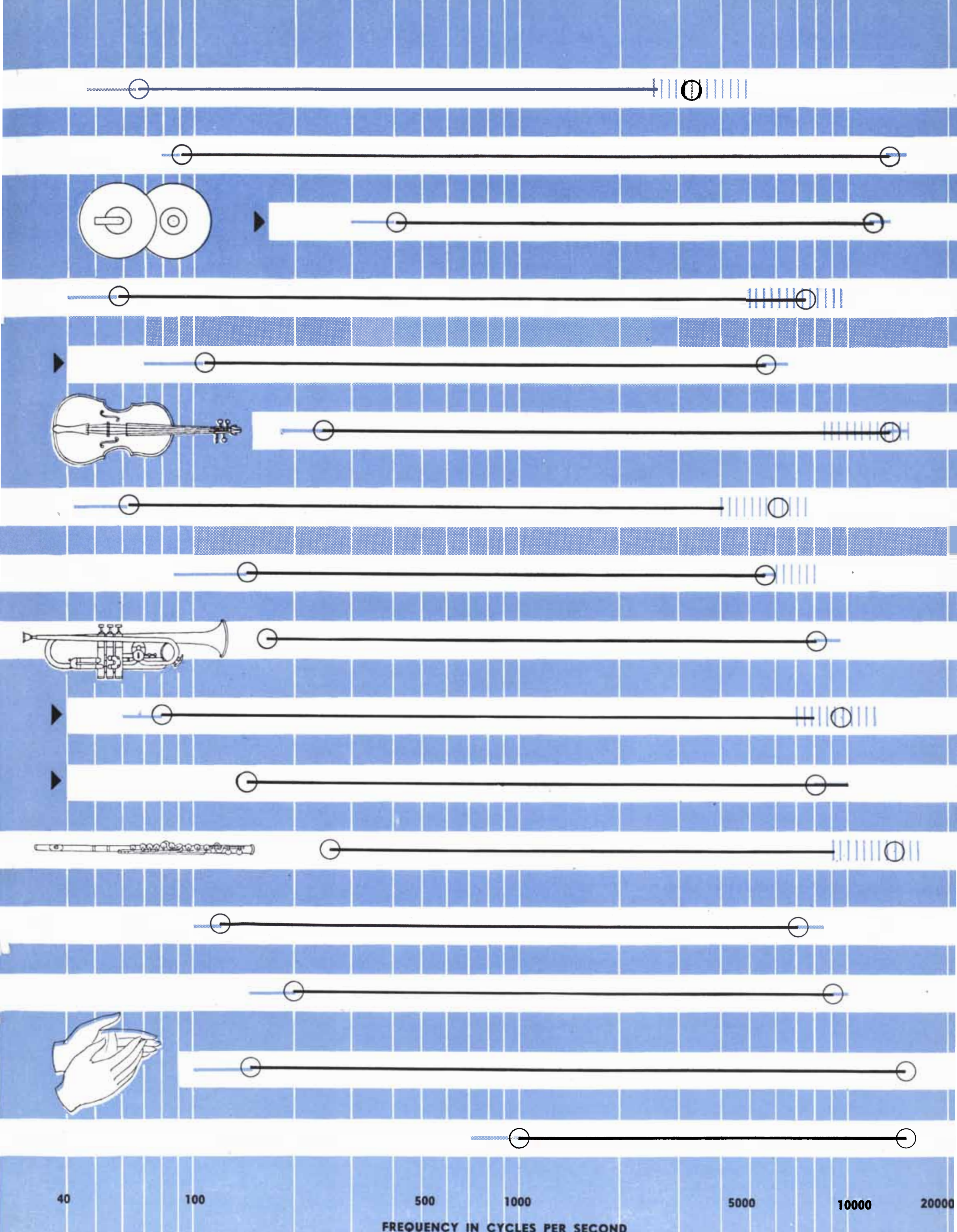
If we had some kind of attachment to the strings by means of which the response of each could be recorded, we should have one type of harmonic analyzer, but not a very good one. It would be unable to respond properly to frequencies lying between those of the strings. A more useful type of analyzer would be a single string whose pitch we could change slowly and steadily throughout the whole range of the musical scale. This could be fitted with an attachment which would record the string's responses, whenever they occurred, to the tone being analyzed. Such a device would be like the tuning apparatus in a radio receiver, which picks up radio waves on each frequency over which they are being broadcast. The device would miss nothing, but it would not be capable of making analyses instantaneously. The same sort of plan, carried out electrically, gives more rapid results. With suitable equipment it is possible to obtain within a few seconds a complete photographic analysis of a sustained tone, yielding numerical values for the strength and frequency of all harmonics present in the frequency range from 60 to 10,000 cycles per second. This method has been applied to the study of the tones of many instruments.

A remarkable frequency analyzer recently developed by R. K. Potter of the Bell Telephone Laboratories gives a continuous analysis of speech; its result is appropriately called "visible speech." One speaks into a microphone and the oscillations of his speech are then passed through 12 electrical filters, each of which allows only a narrow range of frequency to pass. When amplified. each filtered set of oscillations lights a tiny "grain-of-wheat" lamp; there are 12 lamps, arranged vertically. The fundamental tone of the speech lights one lamp, the first harmonic another farther up, and so on. The lamps that light in response to the speaker indicate the frequencies present in his speech. To reproduce his speech pattern, the light from the lamps falls on a horizontal moving belt made of phosphorescent material, so arranged that each lighted lamp traces a separate luminous line on the belt. The result is a characteristic pattern for each vowel and consonant, defined by lines of varying frequency and duration. The accompanying illustration demonstrates how a phrase looks to the eye. A trained observer can read words and phrases at sight, and a person who has been deaf from birth may thus learn to read speech. He can also correct imperfections in his own speech by matching the patterns he produces against standard ones. This visible speech is exciting to watch, and it is likely to be of great help to the deaf.

II. The Violin

Now let us turn to the consideration of musical instruments, a subject in which harmonic analysis has been very useful. We may agree at the start that nothing deserves the name of musical instrument unless it can make a loud sound. Our greatest musical artists must fill large concert halls, and for this they need loud voices, violins, pianos or other instruments. Some musical instruments require a method of amplifying the vibrations created by the player to produce powerful tones. Consider the violin as an example.

A wire mounted on a bent iron rod, with no body or plate to shake, gives almost no sound when it is excited by bow or finger. The wire is too narrow to push the air about sufficiently to create a strong sound wave. Such a performance is analogous to trying to push a


40
100
500
1000
5000
10000
20000
FREQUENCY IN CYCLES PER SECOND

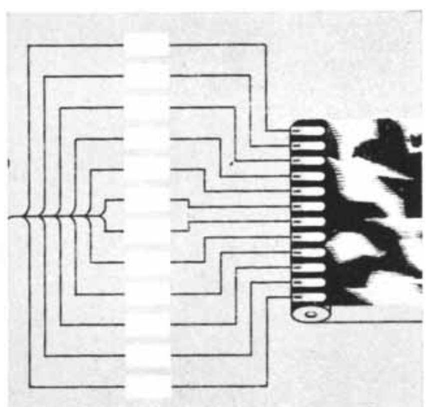
canoe through the water with a round stick as a paddle. If you stretch a piece of strong twine between two hands and pluck it with a free finger, it makes very little sound. But if a part of the twine near one end is pressed on the edge of a thin board, you have a crude stringed instrument, giving a much louder sound, which now comes from the board. The sound of a violin is emitted not from the strings or the bow but from its light wooden body. The contact between the strings and the body of a violin is through the wooden bridge, which is cleverly cut to filter the sound transmitted and remove some unpleasant squeaks. To produce loud sounds, the violin body must satisfy three conditions. It must be strong, light enough to be easily shaken, and big enough to push a lot of air around when it moves. The sounding board of a piano must fulfill exactly the same conditions.

As everyone knows, stiff objects vibrate much better than limp ones; we all have observed, for instance, how noisy a job it is to wrap a parcel in stiff paper, whereas if a handkerchief is substituted for the paper there is almost no sound. Large areas of stiff paper tend to move together as one piece, and thus push on the air sufficiently to start vigorous sound waves. In a violin, the wood must be light, so that the vibrations of the strings can move it, and strong enough to sustain the tension of the strings, which adds up to about 50 pounds. The kinds of wood most used are close-grained Norway spruce for the top plate, and maple for the back.

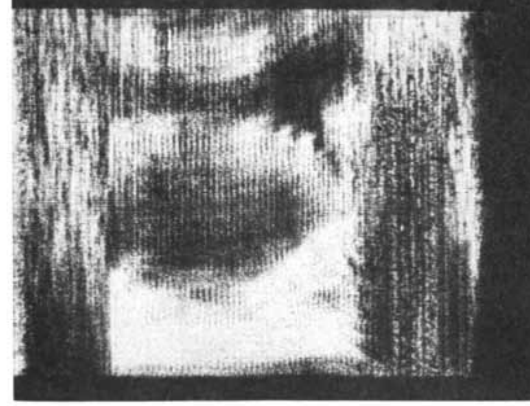
The body of a violin should respond equally to all frequencies of vibration within its range. The fact that it fails to do this is seldom noticed. The reason for the defect will be clear if we first consider the beautiful method devised by the German acoustical physicist Ernst Chladni (at about 1800) which discloses the natural modes of vibration of plates. By sprinkling sand on a flat metal plate and drawing a rosined bow across its edge, one can get a musical tone, and some of the sand is seen to move from certain areas and some to rest along quiet "nodal" lines. The accompanying illustrations show various figures produced on violin-shaped metal plates which were fixed at both ends and at a point corresponding to the violin sound post. In each figure there are several patterns, and each pattern is associated with a tone of a particular frequency. These tones are not in a harmonic series; in fact they are usually discordant with one another. A high tone forms a pattern of many small areas; a low tone produces a few larger ones. Every violin has its own natural modes of vibration, scattered over the musical scale, and eight or ten of them may be especially strong. When a violinist produces a tone coinciding with a strong natural frequency of his instrument the violin responds loudly, but if he makes one in the range between two such frequencies, the response is poor. This unevenness in response occurs in the playing of the best artists on the best violins, but it is seldom noticed since no artist is expected to maintain an even loudness.

The number of harmonics produced, and their strength, determine the "tone color" or timbre of a sustained tone from a violin. Whenever one of the harmonics comes near one of the natural vibrations of the plates, it is increased in loudness, and the tone is changed in tone color. This happens often, because there are several natural vibrations and many harmonics in each tone. Thus the tone color varies throughout the range of the violin. No one tone color is characteristic of any violin—much less of violins of any particular age or from any one country.

As a machine for producing sound a violin is very inefficient. Most of the work done by the player in rubbing the bow against the strings is lost as heat in the wood. The Chladni patterns show another reason for inefficiency. Two adjacent areas in a plate must be moving in opposite directions when the plate vibrates, rocking back and forth with the separating nodal line at rest between them. Thus at the same instant the air is compressed by one area and expanded by the other. The net effect on the air is greatly reduced, since the contributions of the two areas nearly cancel each other. Moreover, the front and back surfaces of any plate may work against each other: while one surface compresses the air, the back of the same area starts an opposite expansion. If the two waves can meet at the edge of the plate they will partly destroy each other. This action weakens the low tones particularly, not only in violins but in pianos and loud-speakers. To prevent this effect in loud-speakers, the vibrating area is commonly set into a "baffle" which, by enlarging the surface, inhibits the meeting of the front and back waves. Larger vibrating surfaces can emit low tones better. This is why the violoncello and double bass are made progressively bigger, and why the large sounding board in a concert grand piano helps to improve its deep bass tones.



ANALYZER made by Bell Laboratories separates sound frequencies with 12 filters. Each regulates a tiny light. Lights make image on screen.



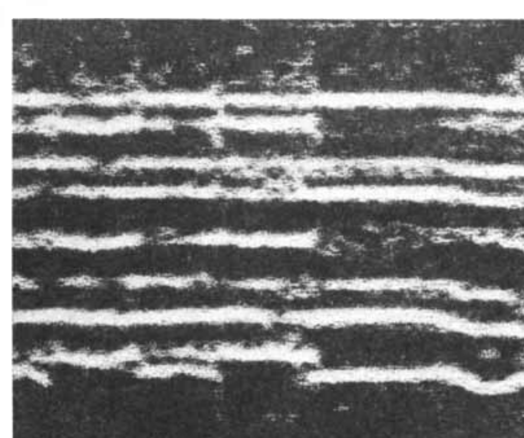
RECORD produced by "visible speech" apparatus depicted at left

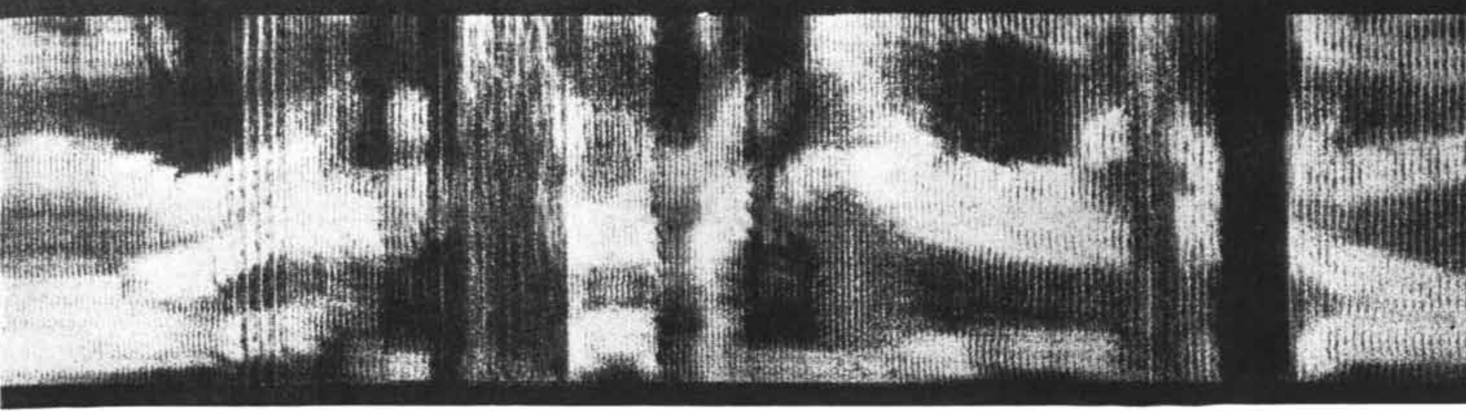
Not all of the tone emitted by a violin is produced by vibration of its plates. We must also credit the air inside the box with an important contribution. This air can vibrate in and out of the *f*-holes with a frequency which lies in the middle of the lowest octave. The tone there would be mean and ugly without the added vibration of the innner air, as one can discover by plugging the *f*-holes lightly with cotton. When the air inside the box is vibrating at or near its natural frequency, its resonance is strong. This can be demonstrated by setting a candle in front of one of the holes, with the instrument held vertical. When the right note is bowed, the flame dances wildly; for all others it remains quiet. (The effect is most marked in a cello.) Air resonance improves the tone just where improvement is most needed; that is, over a few semitones where the small size of the violin prevents the body from emitting the tones strongly. The maximum effect is near C sharp on the G string in violins, and near A or B on the G string in violas and cellos.

III. Old *v.* New Instruments

Now what makes a superlative violin?

VIOLIN MUSIC recorded by visible speech apparatus shows a horizontal





may be temporary image on a phosphorescent screen or, as in the illustration above, a pattern on a paper strip. **This pattern, which may be read by a trained observer, represents phrase "Four score and seven years ago . . ."**

This question is endlessly debated, but it cannot be settled by arguments. The most accurate and careful measurements in a laboratory with modern equipment are required, and a start has already been made. The impression made by a violin on a listener is due to many features: the quality or "tone color" of sustained tones, the ease with which the tones begin, the rate of decay of the sound, the loudness in different parts of the range. These items are often lumped together under the word "tone"; here we must separate them carefully. The tone color of sustained tones is probably the least important of the lot. The loudness in different ranges of pitch may be the most vital consideration in the judgment of a violin. A bad violin is weak in the low tones and too strong in the squeaky top frequencies.

Old violins are almost always thought to be better than new ones, and European better than American. This opinion may come in part from psychological causes —our admiration of old civilizations, the influence of tradition and so on—but part of it certainly comes from the beauty of workmanship characteristic of the best old instruments, and from their rarity. It is as difficult for most violinists to find any defect in a Stradivarius as it is easy for them to criticize the best-made American violin. In recent years careful experiments have been made with excellent modern apparatus, seeking to measure all the mechanical features mentioned in the preceding paragraph. A great variation in values was found among 12 Strads, many other old violins and a few dozen new ones, but the average values failed to show any consistent difference between old and new. This is not to say that there are no differences, but that the results were the same within the limits of error in the measurements, using very sensitive methods. These bold statements are supported by many "blindfold" audience tests, as well as by variations in professional opinions as to the merits of certain famous violins.

Violins seem to become lighter and better when played for a century or two. The effect of age on instruments which are not played appears to be small. Changes in the physical character of a violin can come about through vibration and also from contact with players. After a period of use a violin usually weighs more because it has absorbed water vapor from the air around the player. This makes the wood expand across the grain; when not in use it dries out again and contracts. These changes may alter both the physical and chemical properties of the wood. Some day it may be possible to attain the effects of years by a quick treatment of the wood; promising work along this line is now in progress.

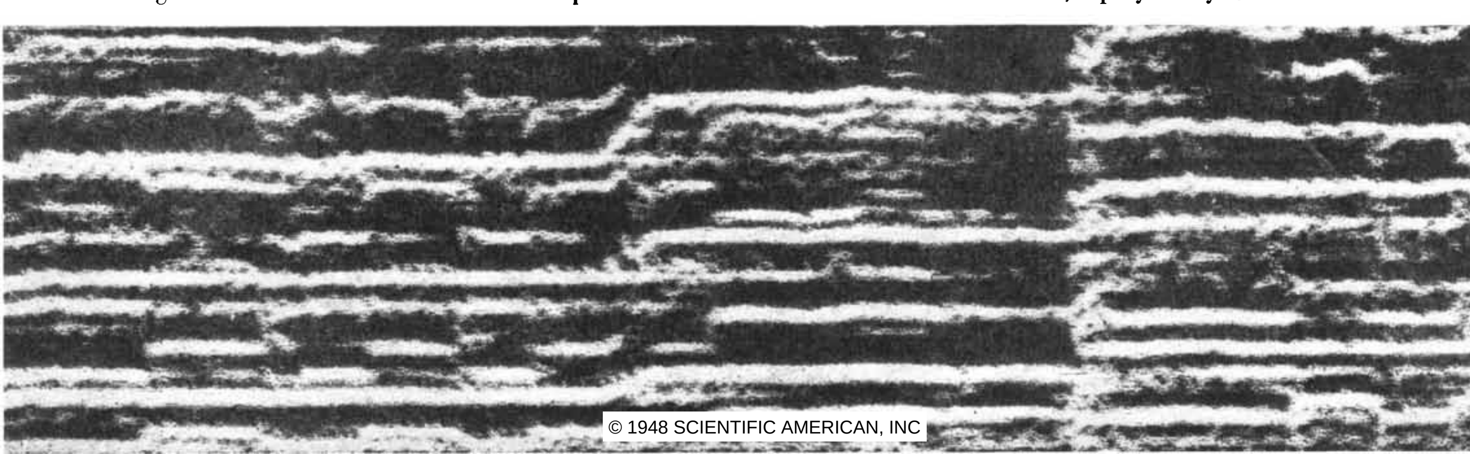
There are methods of mapping out the natural vibrations of a violin by exciting it electrically and measuring its response at every frequency. This yields a curve, called the response curve, by means of which violins can be compared. The inequalities in response at various frequencies are remarkable, in both old and new instruments. All good violins should in the future have a certified response curve furnished with them when they are offered for sale.

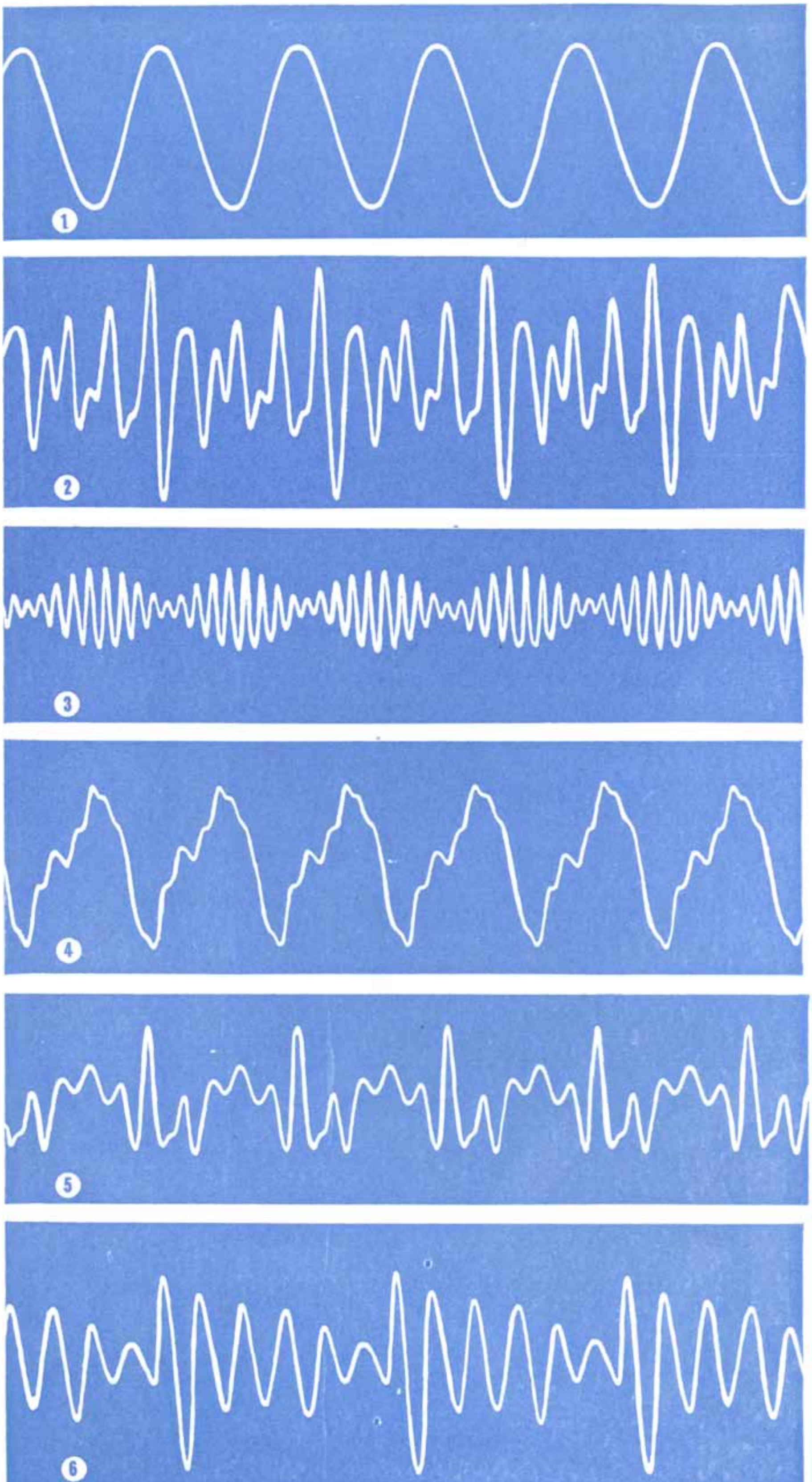
IV. The Piano

Some of the statements which I have made about the violin apply equally to the piano. The piano's sounding board acts like the violin body. While the violin has not changed in the last century, the piano has seen constant improvements in the sounding board, the strings, the hammers and the key action. So loud has the instrument become that the vibrations now shake the floor and are sometimes transmitted through the solid structure of a building to unexpected distances. In apartment houses peace may sometimes be preserved with the neighbors by placing rubber pads between the piano legs and the floor.

New problems arose with the invention of the piano's key and hammer mechanism. The hammer must be light but strong, in order to act quickly and give powerful blows to the strings. The pads must be soft to avoid the production of strong high harmonics that a hard hammer creates. (One can almost convert a piano into a harpsichord by using a teaspoon for a hammer.) When a player hits a key on the piano, the action gives the hammer a throw; at the moment when the hammer strikes a string it is not connected with the key, but is flying freely. It is as if the player were throwing soft balls at the strings from a distance. Once the hammer is on its free way, the player can do nothing more to it. His only control is

band for each harmonic produced by the instrument. Large number of bands illustrates complex nature of **musical sounds. Record shows passage from Glazounov's "Concerto in A Minor," played by Jascha Heifetz.**





COMPLEX WAVE FORMS of musical sounds are the result of combining several simple forms. The forms above are (1) the simple tone of a tuning fork, (2) pure chord produced by four tuning forks struck together, (3) "beat" tone of two tuning forks with almost the same frequency. Characteristic instrumental forms were made by (4) violin, (5) oboe, (6) French horn.

through the initial speed he imparts to the hammer. Thus it is a fact that for a given hammer speed the tone is exactly the same whether the key is pressed by the finger of a great artist or by the tip of an umbrella. Any skeptic to whom this statement is repulsive should open up a piano and watch the motion of a hammer. Piano "touch" is of course a mixture of effects: besides hammer speed, which affects loudness and tone color, it depends on the sequence of tones, the length of time each key is held, the management of the pedals, the phrasing and so on. Of these the last three are perhaps the most important.

There are two subjects in musical acoustics, incidentally, which often arouse furious arguments. One is piano touch. The other is the alleged characteristic flavor of music in different keys. Pupils are often taught that D major is a martial key. Today military marches are played on a piano whose D is 294 cycles per second. A musician in Mozart's time would have had a D of about 278 cycles per second (our C sharp), since the pitch has risen about a semitone in this interval. If two performances of the same music in different pitches can produce the same impression, then the flavor of the key must come from its name and not from its pitch.

V. Wind Instruments

The wind instruments operate on a very different plan from the strings, and as sound-producers they are much more efficient. A stringed instrument loses considerable energy in transmitting its vibrations from the plate to the air; in a wind instrument the sound is emitted directly by vibrations of the air inside the pipe. Hence an instrument like the oboe or clarinet in the orchestra stands out against the string section, and two or three of them are considered sufficient to balance a much larger group of violins.

The sound waves in wind instruments are generated in a variety of ways: by thin streams of air issuing from slots (the organ) or from the player's lips (flute); by the vibrations of single reeds of cane (clarinet family), of double reeds of cane (oboe family), of metal (organ), or of the player's lips (cornet, horn). Except in the case of a metal reed, which has to be tuned to its pipe, the mechanism that excites a wind instrument has no very definite natural frequency but will accommodate itself to the rate of the vibration of the air in the pipe. This rate is determined by the time it takes an exciting air impulse, traveling with the speed of sound (about 1,100 feet a second), to go down the pipe and back. In instruments which have side holes, this wave is reflected not from the end of the pipe but from the first hole that is open. By this means the player controls the effective length of the pipe and the frequency or pitch of the sound produced. Shortening the pipe by opening successive holes makes it possible to produce the notes of the musical scale; the higher tones are obtained as harmonics of these fundamental vibrations. The sound of the flute comes from two holes, the one at the mouthpiece and the first open one lower down; the vibrating air dances in and out of these two holes simultaneously. The holes still lower down emit practically no sound. The same principles apply to the oboe or clarinet except that there is no hole in the mouthpiece. The lowest tone is the only one whose sound issues from the end of the instrument.

In the brass instruments. the length of the tube is governed either by a sliding piece (slide trombone) or by insertion of additional lengths of pipe by means of valves operated with the fingers. At each length a large series of harmonics can be blown, and with several lengths available all the notes of the scale can be played, many of them in more than one way. The fundamental tones are not often used.

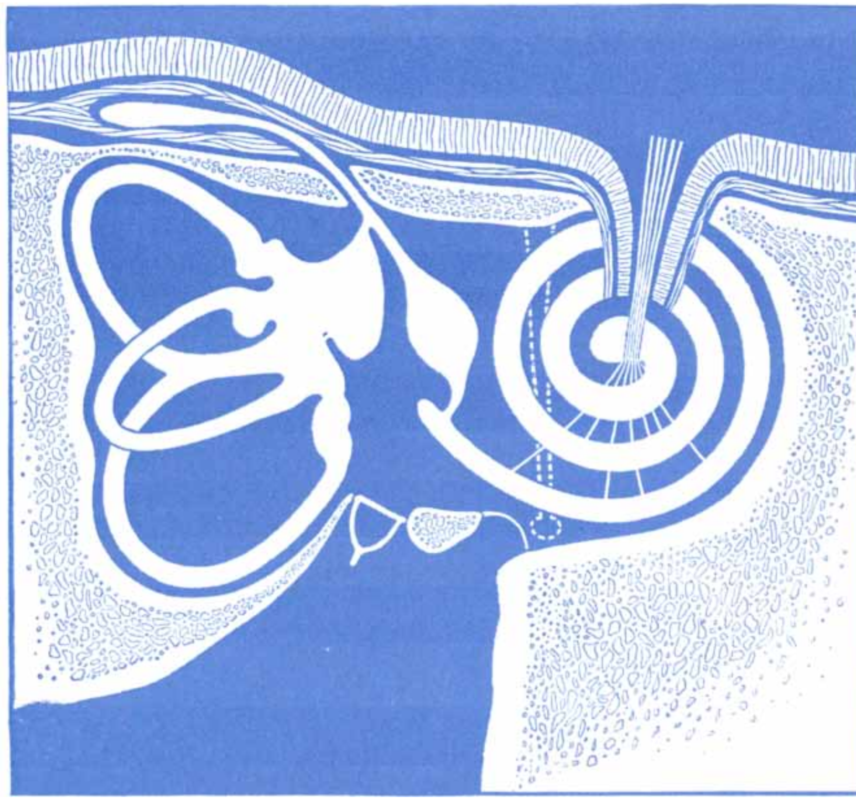
The tone colors of wind instruments are not as variable as those of violins; hence the player's opportunities for virtuosity are more limited. On the organ, the only wind instrument that has separate pipes for each pitch, the organist can build up tone colors by combining pipes of the same pitch but different colors. In the brass instruments, a player produces a marked change in tone color when he puts his fist or some other object in the "bell" from which the sound comes. This muting of the tone corresponds to what happens when one loads the bridge of a violin with an extra weight.

VI. The Singing Voice

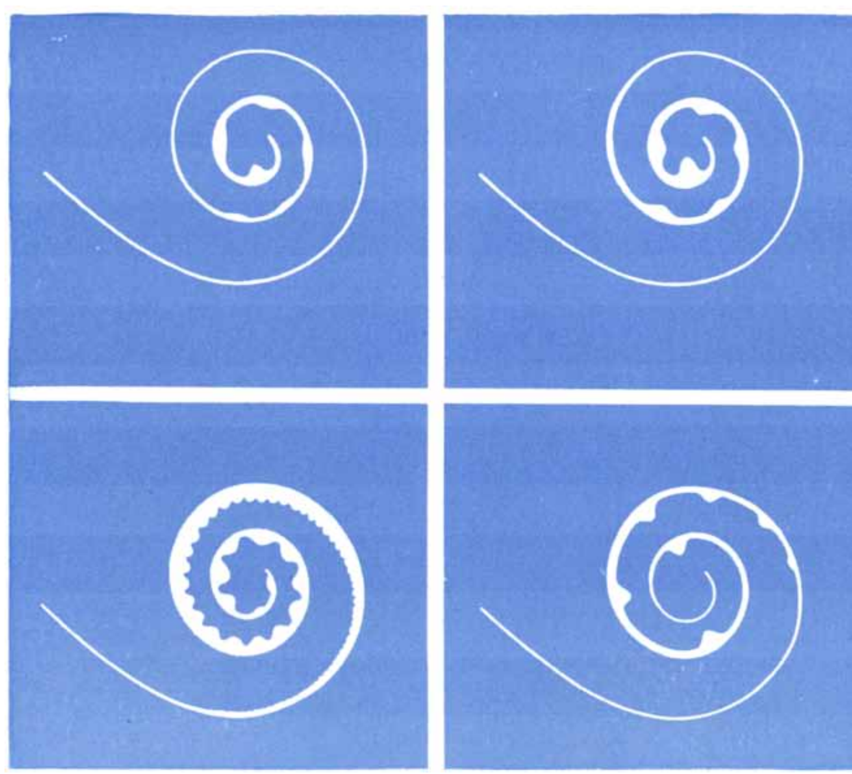
But none of these instruments has the variety of tone color available to a singer. The voice is the most versatile and expressive of all musical instruments.

The vocal cords vibrate somewhat as do the lips of a cornet player, that is, as a double reed. They produce a range of fundamental frequencies which is determined by the muscular tension that can be put on them and by their effective mass and length. The action of the cords has recently been photographed with a motion-picture camera, showing that they have a complicated, sinuous back-and-forth motion. Such a motion would be expected to generate a complex sound wave; voice sounds are indeed found to be rich in harmonics.

The throat and mouth space through which the sound passes on its way out can take the form of one chamber or be divided almost in two by the back of the tongue. A singer also varies the size of the mouth opening. These alterations enable the chamber to resonate to a variety of frequencies, some low as fundamentals, some high as harmonics. In singing, we presumably tune the chamber to resonate with the vocal cords at their fundamental



INNER EAR, here shown in highly diagrammatic drawing, is detector of sound. Spiral organ at right is the cochlea. From it run branches of the auditory nerve (*upper right*). These branches are attached to the basilar membrane, stretched across the cochlea's inside diameter along its full length. When sound vibrates membrane, nerve impulses are sent to the brain.



BASILAR MEMBRANE responds to various frequencies at various points along its length. Peaks on spiral diagrams show relative response. Two drawings at top show "false harmonics" of ear's response to a pure tone of increasing loudness. Two drawings below show membrane's accurate response to many harmonics of steamboat whistle (*left*) and note of a bugle (*right*).

or some harmonic. In general the pitch of the voice varies with the tension and length of the cords. its quality depends on the shape and size of the chamber, its loudness is determined by the amount of air pressure supplied by the lungs. The versatility of the voice comes from the ease and quickness with which all these changes can be made.

Singing teachers use certain special terms to describe all the processes involved in tone production. Although these terms have quite definite meanings to the teachers, to others such descriptions as "head tones," "chest register," and "tone placement" mean very little, and that little is probably misleading. One would suppose. for example. that the head and chest must vibrate somewhat at all times. and that the tone must always originate in the same place. One may also object to crediting the bony cavities in the head and the absorbent lung-space with helping to produce loud sounds, since these areas are powerless to contribute anything appreciable. It is to be hoped that before long there will be further experimental studies that will disclose the real behavior of the whole vocal apparatus, and that then such language can be used as will be understood by all.

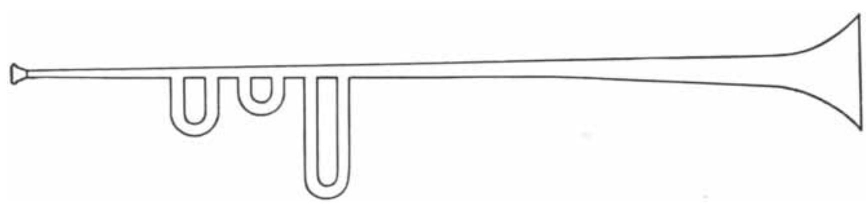
VII. Musical Scales

There is one special study in which mathematics and music go hand in hand. This is in the construction of musical scales. People with unmusical ears sing up and down the range of pitches without hitting the same spot twice; but music cannot be built on this plan. The piano must have a pattern on its keyboard, and a fixed frequency for each key, as the flute has fixed positions for its side holes. The pattern of the keyboard repeats itself in each octave. An octave is measured by the first interval in the harmonic series. Two tones an octave apart have a frequency ratio of 2 to 1; they produce in our ears a simple motion and a pleasant impression. To produce a similarly pleasing effect within the octave, its intervals also should be simple. with ratios like the ones found in the harmonic series, such as the musical fifth (ratio 3 to 2) and the fourth (4 to 3). Thus the scale is built up on the plan of having as many pairs of tones as possible which please us when sounded together. At the same time the musician demands freedom to shift keys without running into any trouble with different sorts of intervals.

The final result is a scale of 12 notes with semitone intervals all exactly alike. and just filling an octave. The mathematician tells us that if we multiply the frequency of any starting note by the 12th root of two (or 1.05946), we obtain the frequency of the next higher note, and if we continue this process. after 12 multiplications we arrive at the beginning of the next octave. This scale does not give us perfect musical intervals inside the octave, but there seems to be no way in which we can get a better one to fit all the conditions stated. The purist objects: he has a wonderful ear and he says it hurts to hear these intervals the least bit off. So the mathematician writes another paper on a perfect—but unusable—scale.

Recently the physicist and the psychologist have joined in the discussion. A new measuring device has been invented by O. L. Railsback. which he calls the chromatic stroboscope. With this he can measure the frequency of any tone while it is sounding, with a precision greater than we may ever need. It has been used to check the tuning of pianos. The results show that expert tuners agree among themselves but they tune the low notes too low and the high ones too high to fit the scale. They do this because it actually sounds better. and the explanation of this odd fact is that the harmonics of a piano string are themselves out of tune, and are sharper than they should be. The 14th harmonic occurs about where the 15th belongs. The scale that results is no longer the exact scale of "equal temperament." which we have just considered, but a "spread" one whose octave ratio is slightly greater than two to one, while its fifths are almost true. All these years we have been using two scales without knowing it. To make matters worse, it has been shown that. in contrast to the piano. the harmonics of pipes and of bowed strings are not out of tune; so that the organ is presumably tuned in equal temperament. The violin is always tuned to perfect fifths. yet nobody minds when it is played with a piano tuned to a different scale. These strange differences seem to have escaped the notice even of our friend the purist.

Recently musical psychologists of the University of Iowa, under the leadership of Dr. C. E. Seashore, have measured the performance of a number of first-class professional singers and violinists, and found that they do not use the scale of equal temperament nor any other scale exactly. We must all be less sensitive to the refinements of tuning than was supposed. The scale (or scales) we now use is quite good enough for such ears as the best of us possess.



BRASS INSTRUMENT is stretched out to illustrate function of valves. Manipulating valves adds extra segments to effective length of pipe. This changes the rate of vibration of air in pipe and frequencies of its tones.

VIII. The Listening Ear

The ear, in fact, is a surprising organ; it does not always tell the strict truth. S. S. Stevens of Harvard University has shown that the pitch of a pure tone varies with its loudness. Low tones may drop a whole tone on the musical scale, while very high tones go the other way. If, while listening to a loud tone whose pitch is off. you cover your ears, the pitch goes back to where it belongs. Fortunately, since this effect is observed to an appreciable degree only for pure tones, it is of little importance in listening to most music, because the tones are complex. Moreover, at the pitch where the ear is most sensitive (2,000 cycles per second), the effect disappears.

The ear may even manufacture sounds that do not exist. Harvey Fletcher and his group at the Bell Telephone Laboratories have found that as the loudness of a pure tone increases. the ear begins to hear a change of tone color, seemingly caused by harmonics which appear in the tone in increasing number and strength. The tone increases in shrillness and harshness until it sounds like the blast of a cornet in one's ear. Yet an oscilloscope picture of the wave form of the sound shows no trace of these harmonics.

These ghostly harmonics arise somehow in the ear itself. The sensitive basilar membrane. where sound is detected by a series of nerve endings, has been proved to respond to different frequencies at different positions along its length. The membrane is spiral-shaped, and Fletcher pictures its "auditory patterns" by means of a set of spiral diagrams showing where disturbances occur in response to sounds of different pitch. In the case of a soft, pure tone, the membrane is disturbed only at the place appropriate to the frequency. But as the same tone grows louder, new disturbances mysteriously appear at the points where the harmonics of this tone would be recorded. The source of the false harmonics is probably traceable to a natural imperfection in the action of the mechanism of the middle ear.

A practical consequence of this quirk is that any tone, pure or complex, increases greatly in harshness as it becomes louder. Thus even a good radio gives a bad tone when turned up too loud; the ear is to be blamed, not the radio set. A violin has a harsher tone to the ear of the player than to a listener some distance away. A violin whose sound was amplified electrically to fill a large hall would sound quite unnatural.

IX. Room Acoustics

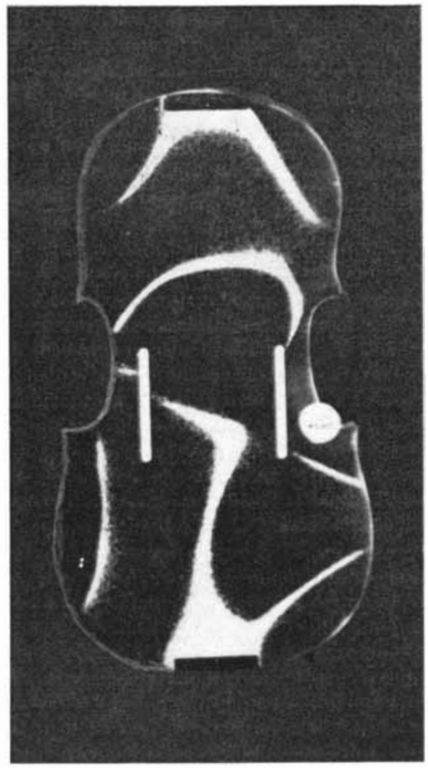
Science has made a very considerable contribution to music in connection with the acoustics of halls. To make clear the nature of this contribution we must consider some of the facts about sound in rooms. If the source of sound in a room is suddenly stopped, the sound lasts a little while; it dies down as it is absorbed or escapes through openings. The duration of this sound is long if the room is large or if the sound was a loud one; it is shortened if many absorbing substances are present. The absorptivity of a material is great if it is full of fine pores in which the regular vibrations that constitute sound are made irregular and thus turned into heat.

The best absorptive material is a closely packed audience. But porous plates of various sorts are available for covering walls or ceilings to cut down reflection of sound and increase absorption, in case the audience is not large enough. A bare room with hard walls reflects excellently, and this has two effects: the sound is made louder (just as white walls make a room lighter), and it is prolonged. Speech becomes hard to understand, because successive syllables overlap. Music usually benefits more by reflection than speech does: it has fewer short "syllables." and the reflections can make it loud enough to be heard well even in the rear seats of a very large hall.

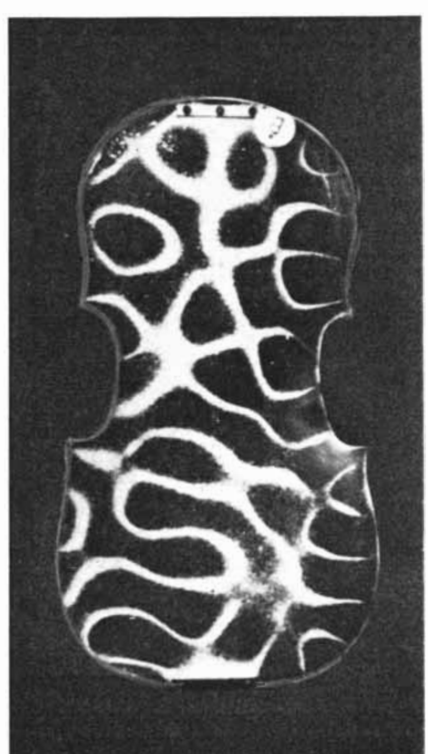
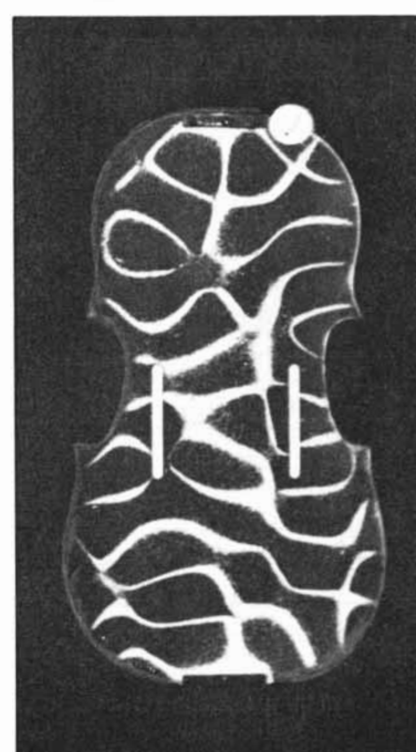
Wallace Sabine of Harvard was the first to work out the proper way of correcting the acoustics of noisy halls by increasing their absorptivity. He founded architectural acoustics, which is fast becoming an exact science. It is now a simple matter to provide for good acoustics in a hall before it is built, and a bad hall can usually be made tolerable by treatment at any time.

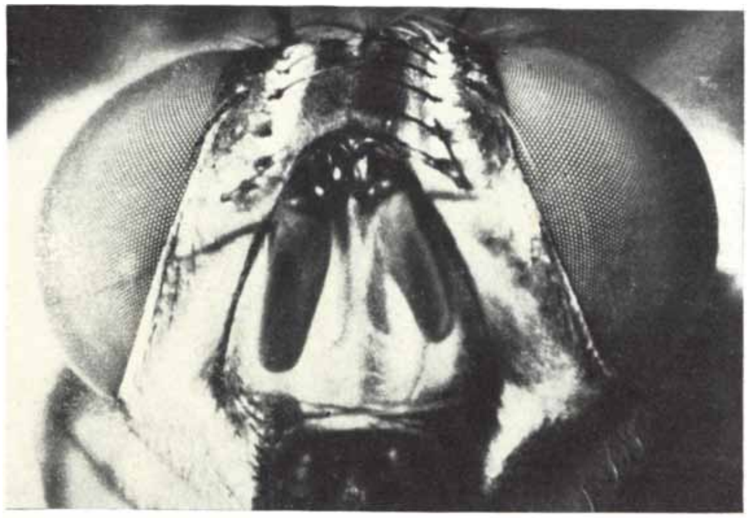
One musical application of acoustics concerns the marked effect which the character of a room may have on the tone color and the loudness of a voice or other musical instrument. Most absorptive materials absorb more of the high tones than the low ones. When you select a piano in a bare showroom, it is likely to have a "brilliant" tone, meaning that it is strong in high frequencies. But if you place the same piano in a living room full of stuffed furniture, cushions and thick carpets, you may find its tone dull and weak. The high frequencies are still present, but they are quickly absorbed, and so you do not get the reinforcement of these tones that occurred in the showroom. A violin's tone color and power likewise depend on the sort of room in which it is played. On the other hand, a singer whose shrill high tones are hard to bear in an ordinary room should bring along a truckload of cushions, the presence of which would have the effect of greatly increasing the listeners' pleasure.

Frederick A. Saunders is emeritus professor of physics at Harvard University.




CHLADNI PLATES indicate the vibration of the body of a violin. These patterns were produced by covering a violin-shaped brass plate with sand and drawing a violin bow across its edge. When the bow caused the plate to vibrate, the sand concentrated along quiet nodes between the vibrating areas. Bowing the plate at various points, indicated by round white marker, produces different frequencies of vibration and different patterns. Low tones produce a pattern of a few large areas; high tones a pattern of many small areas. Violin bodies have a few such natural modes of vibration which tend to strengthen certain tones sounded by the strings. Poor violin bodies accentuate squeaky top notes. This sand-and-plate method of analysis was devised 150 years ago by the German acoustical physicist Ernst Chladni.



COMPOUND EYES (*left and right*) of the housefly are bulging domes of many tiny lenses. Behind each lens extends a separate shaft to fly's light-sensitive organ.

INSECT VISION

The compound eye of this vast living order, the practical solution to a difficult optical problem, reproduces a world of coarse images

by Lorus J. and Margery J. Milne

ALTHOUGH man has managed to achieve a working relationship with most animals. it is doubtful that he will ever get along smoothly with the insects. Even if other differences are ignored, men and insects are poles apart in their vision. Not only strategically but biologically they are incapable of seeing eye to eye. Human eyes and insect eyes are built on plans so radically unlike that man has only a dim notion of how the world looks to a mosquito.

We know pretty well what a whale sees. Or a mouse, an elephant, a bat, a cat. They see approximately as we do. The eagle from its aerie, the snake in the grass, the turtle on the lily pad and the minnow darting below have various vantage points but very similar eyes. We can even guess with some certainty how the sea looks to a squid. All of these animals have visual organs much like our own, with an almost spherical eyeball containing a pigmented iris around a pupil. Light passing through the pupil is focused by a doubly convex lens on a sensitive retina. The image on the retina is as precise as that on light-sensitive film in a camera, and it is formed in much the same way.

An insect's eye is radically different in design. It has to be because of its small size. Eyes of the camera type produce poorer and poorer pictures when they are reduced below certain minimum dimensions, for the pupil then becomes so minute that no recognizable image can be formed by light passing through it. The smallest camera-type eye is that of the tiny shrew; the eye of this inch-long creature is only a twenty-fifth of an inch in diameter. This is actually too small to do the animal much good—the shrew is almost blind. Camera eyes less than an eighth of an inch in diameter are poor visual organs, found only in animals that depend on them very little. This principle is well known to photographers. Seldom can the iris diaphragm on even a good camera lens be closed to leave an opening less than a tenth of an inch in diameter. Sometimes users of small cameras wonder why their lenses will not stop down farther to match bright subject matter. This is the answer: resolution suffers by further pinholing.

Only an insignificant number of the 800,000 insect species are big enough to carry a camera-type eye that would work well. The smallest insects that see are about a hundredth of an inch long. Eyes of insect dimensions need a new principle, and the design they have developed is known as the compound eye. This design is universal in insects; even the largest of them, which are between six and seven inches long and could see with camera eyes, have compound eyes like their fellows.

The compound eye does away altogether with true images. In their stead, the insect's visual organ makes use of a mosaic of information on the relative brightness of various parts of the surrounding scene. The eye itself is composed of a small or large number of identical units, arranged side by side in close formation like seeds in a sycamore ball. Sometimes this arrangement is described as resembling the filled cells of a honeycomb. The comparison is not exact, for the bees make their cells with parallel walls, and the units of the compound eye are long cones. Only by being so can they fit together like the sycamore seeds to give a convex surface to the group. And this convex surface is one of the most important features of the insect eye.

In a sycamore ball each seed has an axis of symmetry—an imaginary lengthwise line that radiates outward from the center of the ball. The units of the compound eye (called ommatidia) also have axes of symmetry that fan out. These axes are the lines of sight for the individual ommatidia, and each aims at a separate part of the environment that surrounds the insect.

Although the compound eye does not rely on images as does the camera type, each ommatidium has its individual lens. These lenses are very transparent and *could* produce an image deep in the eye in the region of the light-sensitive cells. But between the lens and the receiving end of the system is interposed a pigment diaphragm with a minute central aperture. Unless the light passes through this tiny hole it cannot reach the retinal cells that alone can send a message to the brain. Only light rays from a definite region on or near the axis of the ommatidium are led through the aperture by the converging action of the lens. At the same time the pinhole blurs the image to some shade of gray, light or dark, something the sense cells are able to measure as values of brightness. And since each ommatidium of a compound eye faces in a slightly different direction from any other (like the sycamore seeds), its responsibility is restricted to one particular portion of the surrounding space. The barely overlapping fuzzy images of the ommatidia, all added together, represent to the insect the world it lives in.

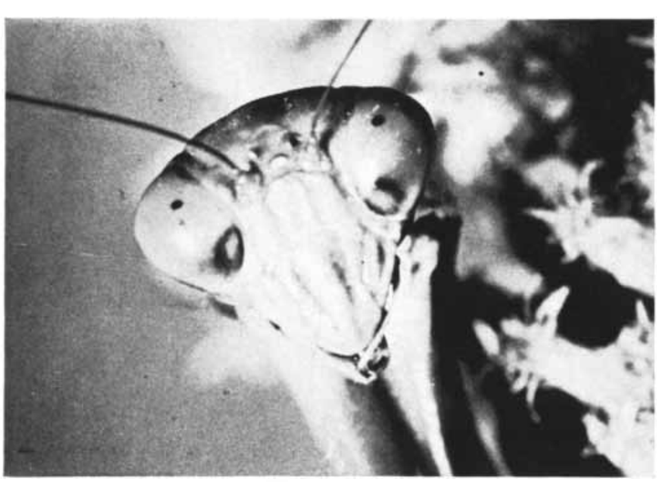
THIS detailless type of image is not necessarily bad or good. It is more familiar to us than many realize. Halftone illustrations in books and newspapers are somewhat similar. since the illusion of a photograph is built up from jet-black ink on white paper through the varying sizes of a close and regular pattern of fine dots. The printer has no gray inks with which to render shades of tone. He employs a trick "screen" to produce dots of different sizes, but all of equal blackness. He assumes rightly that readers will not look for extra detail in the halftone by examining his product with a lens. Actually the detail is not there. Magnification reveals only the pattern. The excellence of the reproduction (and illusion) depends on the number of dots per inch—on the fineness of the screen. Similarly the mosaic picture characteristic of insect vision depends for detail on the size of the ommatidia. The smaller and more closely packed they are, the more restricted is the field of view of each unit, and the finer the detail the creature can recognize in its environment. Insects like the dragonfly have immense numbers of minute ommatidia packed into a great bulging compound eye that covers most of the head, allowing them the acuity of vision needed for darting after gnats and mosquitoes. By comparison a grasshopper's vision is very crude, its ommatidia coarse and relatively few.

Even a small dragonfly has far better vision than one of the lesser mammals such as a mouse. Furthermore, the insect eye plan allows almost equally good seeing forward, up, down, to the sides and far astern—all at the same time and without shifting the head. To accomplish this it is necessary only to have the compound eye include more ommatidia, so that the extras can cover additional parts of the surrounding scene. Few have bettered the dragonfly in this, for its right eye extends to the top of its head to meet the left eye on the mid-line. In fact, almost the whole head is occupied with visual units. Space is left only for the neck and a small region in front and below where the antennae and mouth parts are located.

Because of the bulbous form of the dragonfly's eyes, there are ommatidia in both the right and left eyes that stare straight ahead of the insect. Others slightly toward the mid-line converge to overlap fields at various distances in advance of the creature. The same is true slightly to the side, above and below. Thus the dragonfly has true binocular vision, and with it comes the highly useful ability to gauge distance and depth. On this the insect depends in chasing down its active, dodging victims. Whether the prospective prey zooms or dives, the dragonfly does not lose sight of it. The pattern representing the victim merely shifts to other ommatidia in the binocular field. Only to the rear, where its own muscular body obstructs the view, is a dragonfly blind. Small boys know that a butterfly net swept *after* a dragonfly is more likely to capture it than one from front or side, where the insect sees a warning flash of movement.

Binocular vision and depth perception are part of the essential equipment of insects that hunt living animals by sight. They are features of the praying mantis, horsefly, tsetse fly, water strider, back swimmer, tiger beetle and hunting wasp. Vegetarian insects do not require this sort of vision. Their food does not run away. Thus lateral placement of the less well-developed eyes of the grasshopper allows more space inside the insect's head for its chewing muscles and their attachments. Chewing is most important to a plant eater, since it must munch through prodigious quantities of greenery to gain an appreciable amount of nourishment.

An insect evinces the greatest response to movement and to actions close by. The shifting of any object causes a pattern of light or dark to move over the mosaic of ommatidia. The closer the object, the more ommatidia will be affected. And the more ommatidia that telegraph news of contrasts in brightness to the insect's brain, the more the animal responds. For this reason a large dark disk moving in front of a white background is not nearly as effective in disturbing the possessor of a compound eye as an equal area broken up into coarse spots like a checkerboard. Yet this increase in "contrast contour" has its



IN DAYTIME praying mantis has bright green eyes. Dark spot toward the top of each eye is "false pupil," marking lenses that point directly toward the observer.

AT NIGHT green pigment in mantis' eye migrates, leaving eye chocolate brown. Eye then gathers more light. Mantis is one of a few species with this adaptive power.

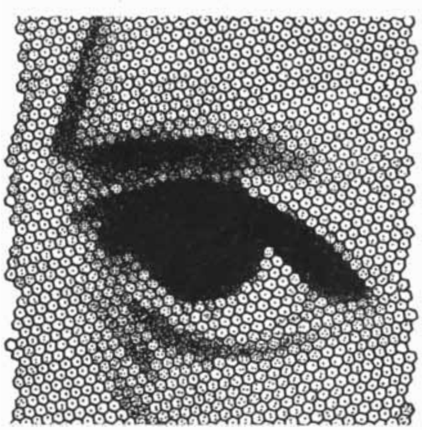
limits, for a very fine pattern is not seen at all. The most stimulating is one that has spots matching in dimensions the field of view of a single ommatidium at a given distance. Hence a coarse pattern is effective from a greater distance, a finer one nearby. It is a matter of angle—and this feature varies from one kind of insect to another. In the housefly, for example, the most stimulating pattern has spots three degrees across. These are the smallest that the ommatidia will recognize as distinct. The three degrees is a measure of the fly's visual acuity. The honeybee distinguishes patterns one degree in size. This is still only one-sixtieth as good a performance as that of a human eye with normal "20/20 vision."

OUR own vision, so much richer in detail, may be seriously upset by refractive errors. Thus a nearsighted person cannot focus an image of distant objects unless aided by spectacle lenses of the divergent type. Near objects, on the other hand, are not only distinct but actually magnified considerably, so that a myopic individual sees more detail at close range than does a normal person. A compound eye, because of its low visual acuity, behaves somewhat like a nearsighted human eye. An object close to an insect affects many ommatidia and vision is relatively distinct. But as the object moves farther away, fewer and fewer of the eye units are directed toward it. Details disappear rapidly and soon so few ommatidia are concerned that the object has negligible effect. The deterioration in the mosaic image is at least 60 times as rapid as that in a normal human eye. This means that we can recognize an insect 60 times as far away as it can see its relative with comparable distinctness. Sixty feet versus one foot is the same order of difference as that between a seriously nearsighted person and someone with normal vision. Neither myope nor insect can see the moon distinctly. For the compound eye, the half degree subtended by the full moon (or the sun) may not fill even a single ommatidium with light. The brilliance produced by sun or moon on flowers and landscape may stimulate the insect, but the celestial bodies themselves cannot.

The relationship between size of object and its interest for an insect can be demonstrated with a butterfly in a dark room with black walls. If a bare electric bulb is turned on, the butterfly will flit toward it. Even if the insect's wings are clipped together to prevent flight, the butterfly will creep in the direction of the bulb. But if a sheet of white paper is held close to the insect on the side opposite the bulb, the butterfly will turn around and walk toward the paper. The bulb is far brighter, but the paper it illuminates has a larger area that stimulates more ommatidia. This is the insect's guide.

To many insects, a flower or group of blossoms is an attractive pattern. Actually, there were no flowers as we know them on this earth until insects appeared. Then plants developed means for making use of bees and other bugs to carry pollen and ensure setting of fruit—a method less wasteful than casting immense quantities of pollen into the wind to be blown to a waiting unfertilized ovary. Yet to attract an insect requires first something to see (the petals), then something to present a reward (the nectar or pollen). Anyone doubting the importance of the visual stimulus can prove the point by pulling the petals from a branch of apple flowers. The nectaries are still there. So is the pollen. But the bees will do no more than hover over the petalless blossoms. Never do they alight and collect the reward they so eagerly seek.

HALFTONE engraving, here enlarged, creates effect of shading with one ink and dots of various sizes.



MOSAIC IMAGE of insect eye operates on similar principle. Each lens system detects single tone of scene.

The apple tree presents another demonstration of what an insect sees. On a perfectly still day, honeybees come to the apple blossoms indiscriminately. But if there are two trees with unequal exposure to a breeze, the tree that sways gently and flutters its flowers is far more populous with bees than the tree that stands calmly in the sheltering lee of some building. If the wind shifts so that both trees are disturbed equally, the insects redistribute their attention. To a bee cruising overhead, the quiet tree appears as a pinkish-white area that moves slowly across its visual mosaic in accordance with the insect's flight. Fluttering flowers, on the other hand, stimulate and restimulate ommatidia in a manner that is independent of the insect's own motion. They draw attention to themselves and flag the insect down. So does a wildly swatting man trying to drive away an angry hornet. Stay still and you will almost disappear!

EVEN the rapid waving of petals in a high wind does not present a movement too fast for the insect's eye to follow. Experimenters have held bees in front of screens on which were projected alternating stripes of dark and light. If the pattern was shifted to the left, the bee followed the motion with its antennae—extending the left antenna straight to the side, the right antenna dead ahead. So long as the pattern stripes were one degree across (for maximum use of the bee's visual acuity) and the contrast in brightness was high, the insect continued to recognize the direction of movement when the stripes flickered at the rate of 50 to 60 per minute. This is as good performance as can be expected of a human eye. Those who have experienced the uneven illumination of lamps run on electric power generated at Niagara Falls know that their fluttering, at the rate of 50 flickers per minute, is only barely perceptible.

The flickering of an ordinary electric bulb would not be apparent to a honeybee, however. The difference between the dim and bright phases offers insufficient contrast. Similarly in the shifting pattern experiment, the full measure of flicker recognition is obtained only with very light and very dark stripings. If the contrast is reduced, so is the highest recognizable rate of flicker. By studying insect behavior in this way it has been possible to show that the compound visual mechanism requires a contrast at least 20 times as great as is necessary to gain recognition in the camera-type eye. This tells us that for the insect the tonal range from black to white contains about a twentieth as many shades of gray as the human eye can identify distinctly.

Related to this deficiency of grays in the vision of insects is their response to darkness. The range of brightness between a sun-drenched beach and a shadowed woodland under a starlit, moonless sky is about a billion to one. Human eyes can adapt themselves throughout this tremendous spread. But an insect that is active only in daytime believes that night is at hand if the illumination drops suddenly to a hundredth of the sunshine level. The insect may go to sleep promptly, as many brave souls know who have captured a bumblebee in hands cupped together around the buzzing insect when it backed from a flower. Try it! Don't be alarmed when the captive shrills a warning as it creeps around the closed surface of your palms. The sudden darkness overcomes its concern, and it quiets down with astonishing speed. Several seconds of direct sunlight are required to awaken the sleeping bee again. During the twilight of solar eclipses almost the whole insect population goes to sleep. The ability of the compound eye to adapt to the dark is relatively poor. Even when allowed an hour to grow accustomed to the dark, the compound eye needs a thousandth of full illumination to see, whereas the human eye needs only a billionth. For this reason, if no other, daytime insects do not awaken with the birds, but stay quiet on their sleeping sites until the sun has cleared the horizon and filled the shadowed spots with light.

Many insects, of course, are abroad at night. But they depend more on odors than on vision in finding their way about. Most night-flowering plants that rely for pollination upon sphinx moths, owlets and other insects are highly odoriferous (like the honeysuckle, evening primrose and nightshade) or have very large white blossoms (like the Jimson weed). Many of the nocturnal insects have become adapted to the darkness in another way: their eyes lack the pigment diaphragm that limits the light for day-flying kinds. Thus they have sacrificed the only mechanism available to the compound eye for achieving high acuity of vision, but they have gained an advantage. Without the pigment interference, light entering a number of adjacent ommatidia lenses can be refracted and fall on the same sense cells. The image that results is fuzzier, but it gains in brightness. Some insects that are active in twilight hours actually shift their eye pigments to suit the circumstances. The praying mantis' eyes, except for the black false pupils, are pale green by day, matching its body. By night the same eyes are chocolate brown—so dark that the false pupils scarcely show. Pigment from deep in the eye has been shifted to the surface to allow the ommatidia to act "one for all and all for one"—not each to itself as in the daytime condition.

The compound eye recognizes colors in its surroundings. Indeed, the insect can see where we cannot, in the ultraviolet part of the sun's spectrum. To the honeybee, at least, this ultraviolet region is a distinct "color" that the insect can distinguish from the portions of the spectrum visible to us—violet, blue, green, yellow, orange and red. The little fruit fly, *Drosophila*, the familiar experimental organism of modern heredity studies, is attracted very strongly to light of any wavelength from the short ultraviolet into the longer yellowish-orange. But as though by compensation, the honeybee, the fruit fly and most other insects are completely blind to red light. This, by the way, is another reason why dawn and sunset hours provide too little illumination for insects to be active. The longer passage of the sun's rays obliquely through the atmosphere filters out much of the blue end of the spectrum with which the insect sees. Some of the fireflies prove, however, that insect eyes have possibilities far into the long waves too. Pure spectral red light, flashed at the proper interval after a male on the prowl has emitted his signaling glow, is sufficiently close imitation of the green from a responding female to lure the swains in numbers to the experimenter.

Bees of various kinds show a remarkable "color constancy" in visiting flowers. Attempts have often been made to confuse them with squares of cardboard laid out in a random arrangement. Where most of the cardboards are gray of varying darknesses and the other cards are colors including some that match the flowers nearby, the bees fly to and hover over the matching cards. They pay no attention whatever to the grays or wrong colors. This evidence of color vision indicates that honeybees and bumblebees, at least, can distinguish yellow and green (together as one "color") from blue-green, from blue and violet, and from ultraviolet. These four regions of the spectrum are true colors to the insects, and they never confuse them with any shade of gray. But variations within these regions yield no response. Compare this behavior with the 17,250 gradations of hue that the well-trained human eye can distinguish!

The world through an insect's eyes, then, is a drab place in many ways. Yet these insects are part and parcel of the greatest group of competitors man has on this earth. If the insects' vision is inferior to man's, it is nonetheless adequate to their purpose. And if we are to control these dangerous rivals, we must investigate their totally different point of view.

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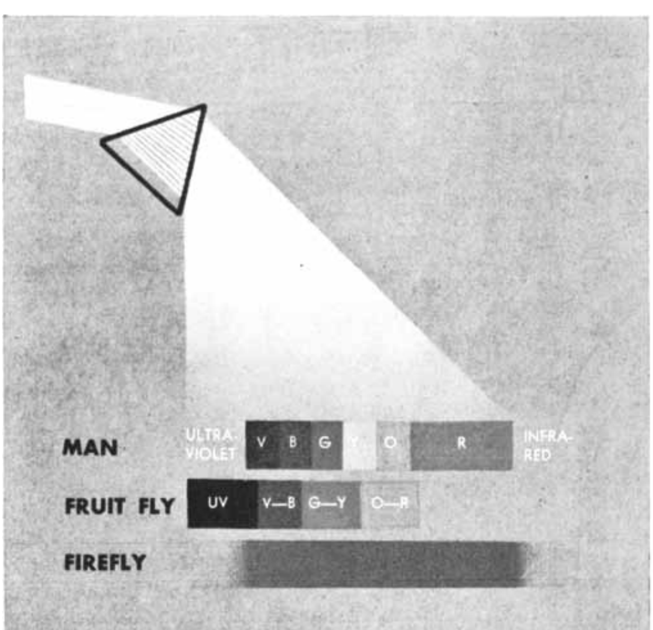
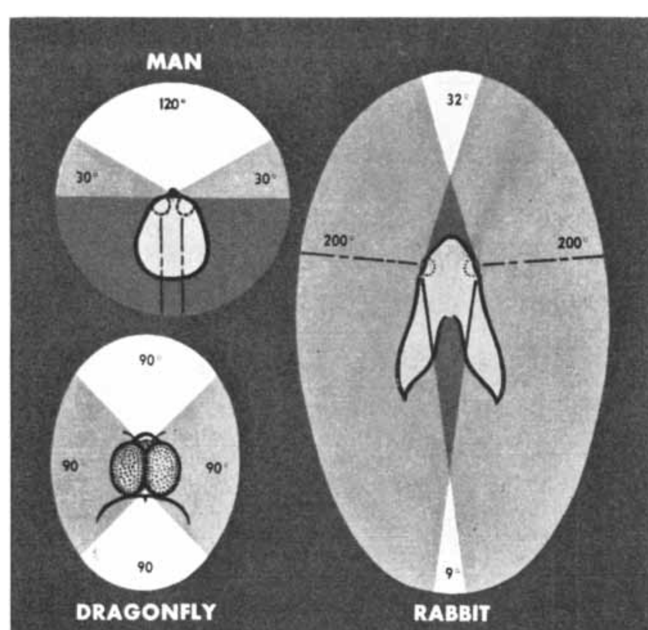
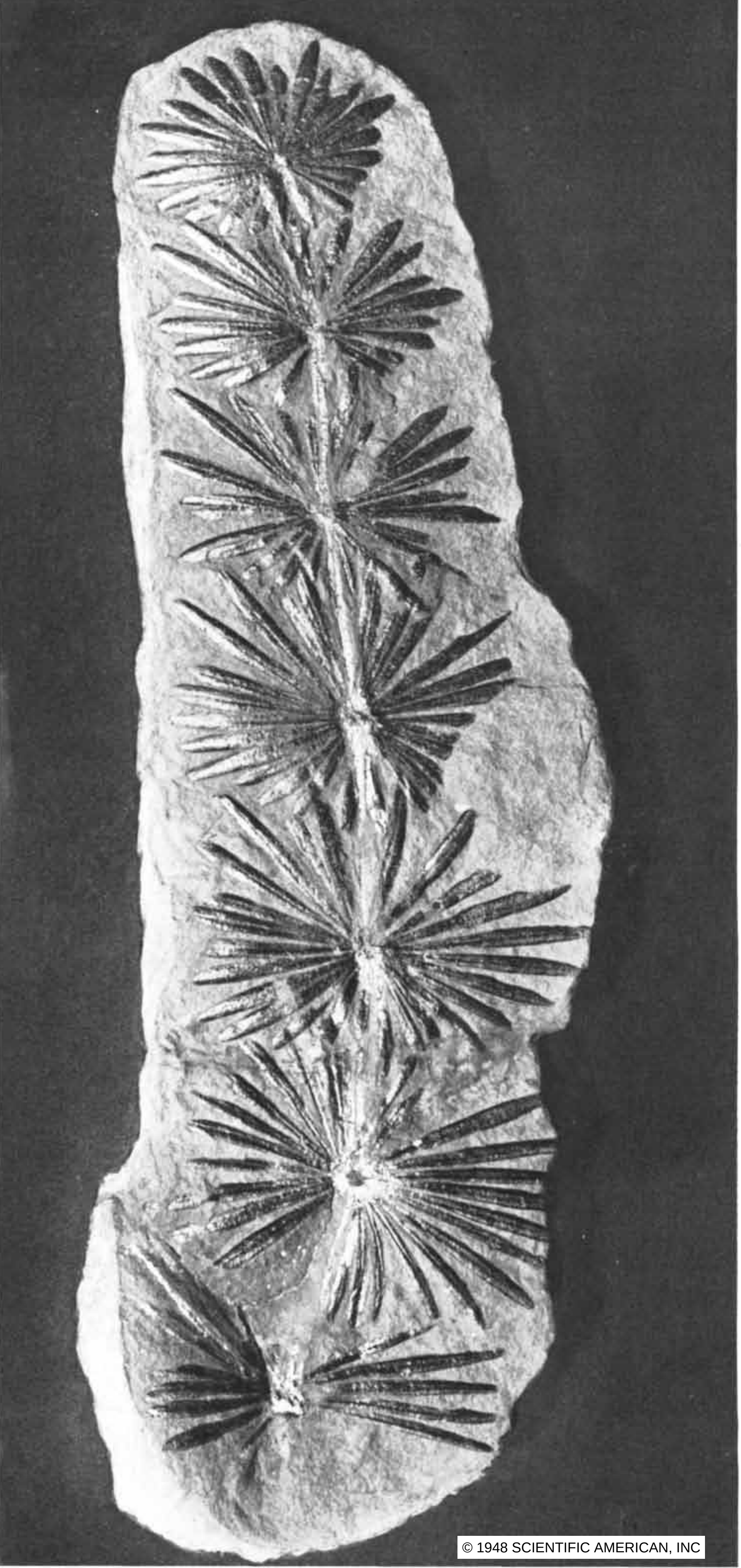


WAVELENGTHS detected by human eye run from violet to red. Fruit fly detects few colors in a shorter wave band. Firefly may have broadest spectrum of vision.



BINOCULAR field in man (*white area*) is broad, but dragonfly also has it astern, with monocular vision to both sides (*light gray*). Rabbit has big monocular field.



THE

COAL ranks with soil and water and air as a vital necessity of 20th-century man. Without it, he could scarcely plan his tomorrow, much less a more abundant future. It is the principal raw material of his technology; indeed, it is not too much to say that coal is man's chief ally in his scientific conquest of the physical world. Coal makes possible the smelting of iron and the making of steel; it builds man's tools, drives his machines, transports his goods, fertilizes his crops, preserves his foods, lights his cities, warms his houses, fights his wars and even cures many of his ills. There is almost no material product of our civilization, from bombs to medicines, that does not owe its existence directly or indirectly to coal. Let its mining be halted for only a few days, and almost immediately trains stop running, factories shut down, lights grow dim, food ceases to flow to market places and a fatal paralysis falls upon man and his civilization.

As the most important deposit which nature has stored in the earth, and as a fascinating natural phenomenon in its own right, this powerful black stuff has been studied for centuries by many specialists—geologists, chemists, botanists, paleobotanists. Yet of such infinite variety and complexity is coal that only recently has the modern method of science determined how it was made.

Strictly speaking, coal is a sedimentary rock, so classified by geologists because it has no fixed chemical formula. Like other rocks, it varies in chemical composition. No bed of coal is precisely like another, and even within the same bed the various parts may differ greatly in chemical structure. Coal is the most complex of all rocks; this is what makes possible its thousands of different uses.

This same complexity also is the cause of the historic argument about coal's origin. Many of the early investigators were led to strange conclusions. In 1546 the German mineralogist Agricola announced that coal was condensed petro-

GIANT RUSH *Calamites* left impression of its leaves in mud which was later metamorphosed into shale.

BEGINNINGS OF COAL

The remains of strange and beautiful plants have preserved solar energy of the geologic past for the uses of man

by Raymond E. Janssen

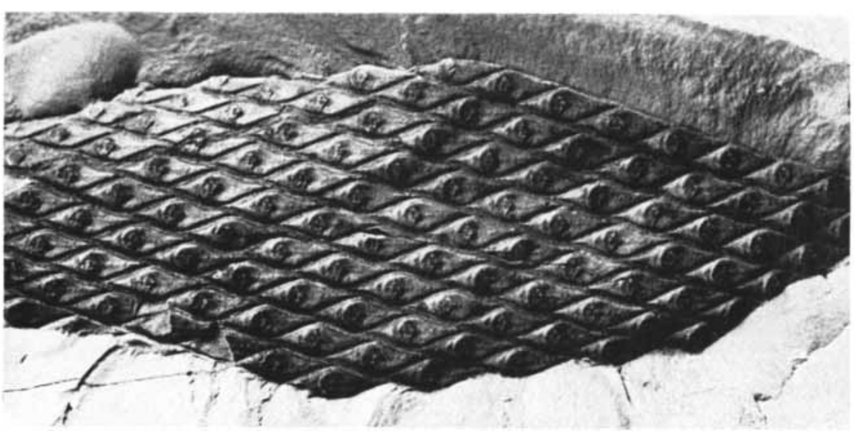
leum. The 18-century Irish mineralogist Richard Kirwan argued that coal originated from the decomposition of the oldest (Archeozoic) earth rocks. A half century later the German chemist Fuchs suggested that coal was formed simply by the precipitation of surplus carbon dioxide in the rocks. As late as 1903 reputable geologists denied that coal could possibly have had an organic origin.

The first to suggest the correct answer was another German named Klein, who in 1592 suspected that bituminous coal and lignite came from wood. In 1709 the German Johann Scheuchzer recognized scattered plant remains in coal—strong support for the theory of its vegetable origin. Still stronger evidence was discovered in 1833 by the English geologist William Hutton: by the use of the microscope he showed that coal contained an abundance of recognizable plant material including cellular structures like those of charcoal. He also observed that shales and sandstones immediately above and below coal beds often showed the fossil imprints of leaves, stems and seeds, spread out as though they were in a herbarium.

Today the plant origin of coal is established beyond debate, and we can reconstruct in exact detail not only the geological processes by which primeval forests were converted into coal but a rather complete picture of the plant life that covered the earth hundreds of millions of years ago. As we shall see, the conditions that created the coal deposits no longer exist to any appreciable extent. So far as man is concerned, nature has made its last important deposit in our bank of coal.

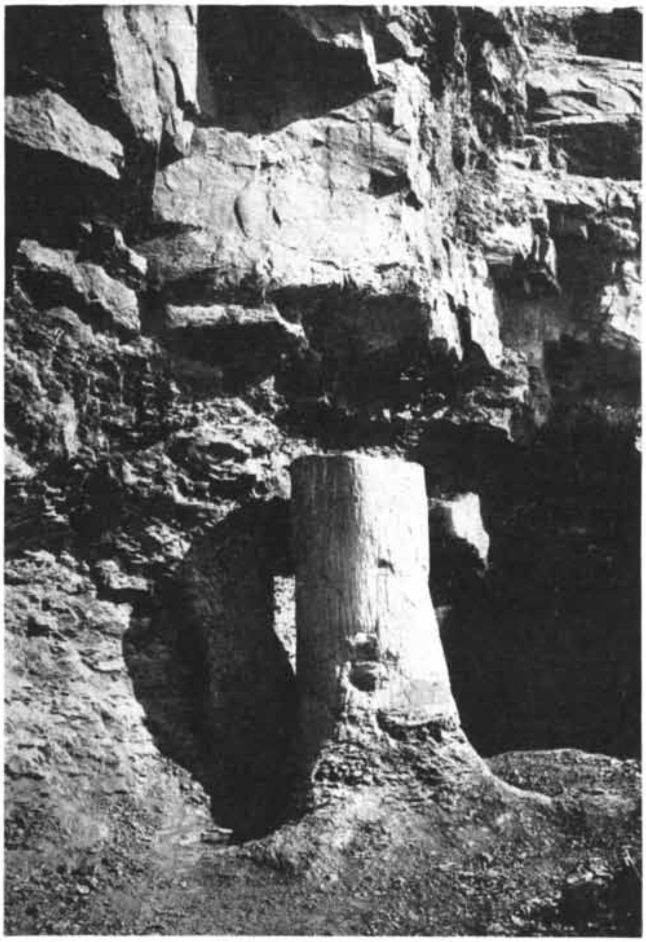
As every schoolboy now knows, coal was formed by the compression of buried masses of plants over periods of millions of years. One basic question that has concerned geologists is whether it was made from land plants or sea plants. The evidence at first strongly suggested that they were sea plants. Most coal beds are overlaid by strata of marine material. Moreover, great accumulations of marine algae, which might be the potential stuff of coal beds, are found along seashores and in huge masses in the open ocean. It was logical, therefore, to assume that coal beds had been deposited on the bottoms of seas. But during the past 50 years microscopic studies of fossilized plant tissues have proved that coal is composed of land plants. Fresh-water plants have rarely been found in it, and marine plants never.

Some have argued that the plants were transported from their original habitats by currents and redeposited in beds beneath the sea. But there are several evidences which indicate beyond doubt that all major beds were formed *in situ*, that is, in the places where the plants grew. The fact that thick beds of pure coal occur unmixed with sand, silt or other sediments is proof in itself that the plant material was not deposited in the sea. Had this been the case, the plant debris would have been interstratified with other sediments. This is the situation which prevails in the strata immediately above the coal beds proper, where isolated plant fossils are found embedded in the shales and sandstones. In order to account for thick beds of pure coal, we must look to present-day boglands where pure plant debris is accumulating in ever-increasing depths beneath the semi-stagnant swamp waters. Here it packs down into peat—the first step in coal-bed formation. Also, in many coal mines the fossil stumps of trees can be seen still standing where once they grew, with roots extending down into the coal bed, or even below the coal and into the shale beneath. These undershales were once the soils in which those trees were rooted. Such evidence can be taken as undeniable proof that the plants which formed the coal were not transported before they were deposited, but that they actually grew in the sites now occupied by the coal beds.

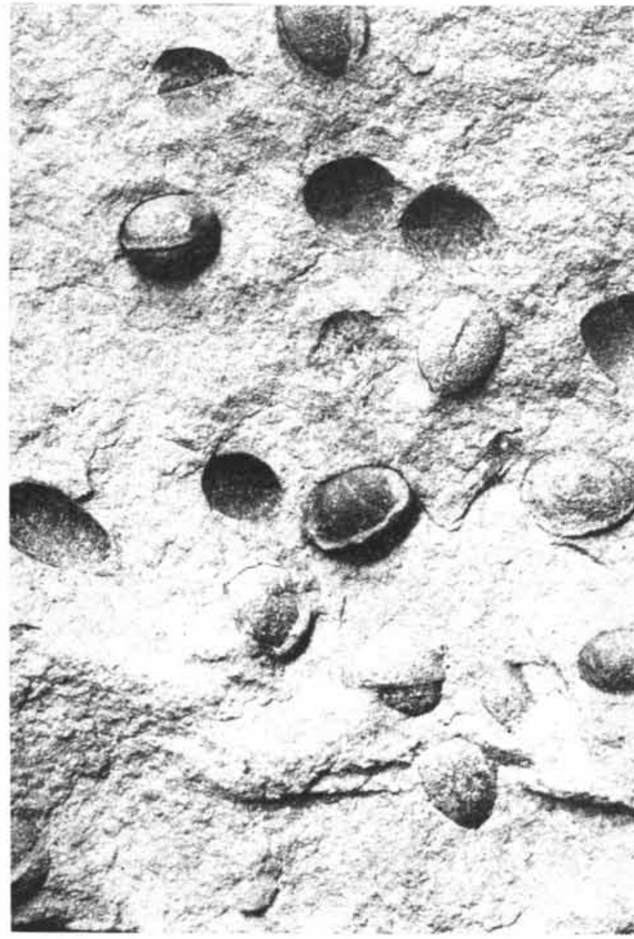


BARK of *Lepidodendron*, a common tree of the Pennsylvanian period, was covered with diamond-shaped scars. Large impressions of fossil plants do not appear in coal itself. They are left in rocks above and below coal beds.

Geological evidence shows that coal has formed in varying quantities ever since land plants began to flourish on the earth. The earliest recognizable fossils of land plants have been found in rocks of the Silurian age, deposited some 400 million years ago. But plants were not then plentiful enough to give rise to extensive coal beds; only one Silurian coal formation—a small deposit in Bohemia—has been found on our entire planet. In the Devonian period, which followed the Silurian, scattered forests began to appear; they formed a few thin coal beds. But most of our great beds derive from the two succeeding periods, the Mississippian and Pennsylvanian, approximately 250 million years ago. Then arose the first towering forests, and a wealth of vegetation that has given to these



STUMP of a fossil tree is preserved in a Nova Scotia coal field. Flora of the Pennsylvanian period almost covered the earth, even growing in what is now Antarctica.



FOSSIL NUTS of the seed fern *Neuropteris* are embedded in a slab of sandstone. Nuts, now borne only by trees, grew only on ferns in the Pennsylvanian period.

two periods the name "Carboniferous." The world's major high-grade coal deposits are found mostly in the strata of the Pennsylvanian period. And, singularly, although land plants have continued to flourish in great abundance ever since. the size of coal beds in the strata succeeding the Pennsylvanian has steadily dwindled.

The reason for this is geological. Consider, for example, the geological conditions and processes whereby coal was made in North America in the Pennsylvanian period. The region between the Appalachian and Rocky Mountains was then a vast inland sea. Into it, from the bordering lands, great rivers washed sediments of sand and soil. These sediments, built up by millions of years of erosion, gradually filled many parts of the sea basin and formed deltas that forced the sea to retreat. in much the same way as the delta of the Mississippi River is now encroaching upon the Gulf of Mexico. (Only a few million years ago an arm of the Gulf extended as far north as the Ohio River; it was filled in by the present Mississippi, whose delta actually begins not at New Orleans but at Cairo, Illinois!) The deltas of Pennsylvanian times were vast swamplands. far more extensive than any swamps in the world today. From their mucky soils sprang huge forests, like the bayou jungles that cover the Mississippi Delta today. Their trees grew and died and fell in thick organic masses into the boggy waters.

THEY did not decay, as dead plant material ordinarily does on dry land. In the presence of oxygen, dead plants normally oxidize to carbon dioxide and water, and their decayed remains mix with the soil as humus. But the swamp waters under which the Pennsylvanian trees were buried excluded oxygen and killed even anaerobic bacteria, so the dead organic matter, although partly decomposed, did not entirely rot away. Instead, it became a slimy colloidal mass, the substance now called peat. This peat was of various kinds, some brown and spongy, some black and compact, depending on the amount of decomposition that had taken place.

Over these mucky masses, the sea advanced and laid down new sediments. As the pressure piled up and the buried peat dried and hardened, it was pressed into lignite—low-grade coal. Under the further pressure of eons of deposits, the lignite became bituminous coal. It was under such great pressure by this time that one foot of bituminous coal represented 20 feet of original plant material. Eventually, under even more extreme pressures, part of the bituminous was compacted to anthracite coal. Such pressures develop only where rock strata are folded upward into great mountain ranges, which accounts for the fact that anthracite is found in folded strata alone and is much less abundant than bituminous.

Coal beds are seldom found singly. They almost always lie in great series of layers, separated by layers of other sedimentary rocks. How may one explain this pattern of seam piled on seam, as well as the peculiar fact that the layers between the coal beds are usually of marine origin? Again, geologists have found the answer in the rocks. As the deltas piled up on the sea basin, the basin itself was depressed. Sea bottoms are known to sink from time to time. As the basin sank under the increasing weight of sediments, the swamplands, which were only a few feet above sea level, fell below that level and the sea washed over them. The inundated forests were killed, with some trees

FRONDS of the true fern *Asterotheca miltoni* are imprinted in shale. Ferns ranging up to 70 feet in height were commonest and most diversified plants of period.

BROKEN TRUNK of the giant rush *Calamites suckowi* shows knothole where one of its branches broke off. This specimen was found in a West Virginia coal mine.

falling in the water, and others remaining upright.

NOW marine deposits covered and enclosed them. A new delta arose, and a new cycle began. The delta grew a forest, the forest fell and turned to peat, the compacted mass sank below the sea again and was covered again by new sediments. The cycle repeated itself again and again. In parts of West Virginia more than 100 different seams of coal have been found, one lying above the other, with sea debris in between. From these successive layers, one can read an accurate geographical, geological and botanical history of the Pennsylvanian period, covering 35 million years or more.

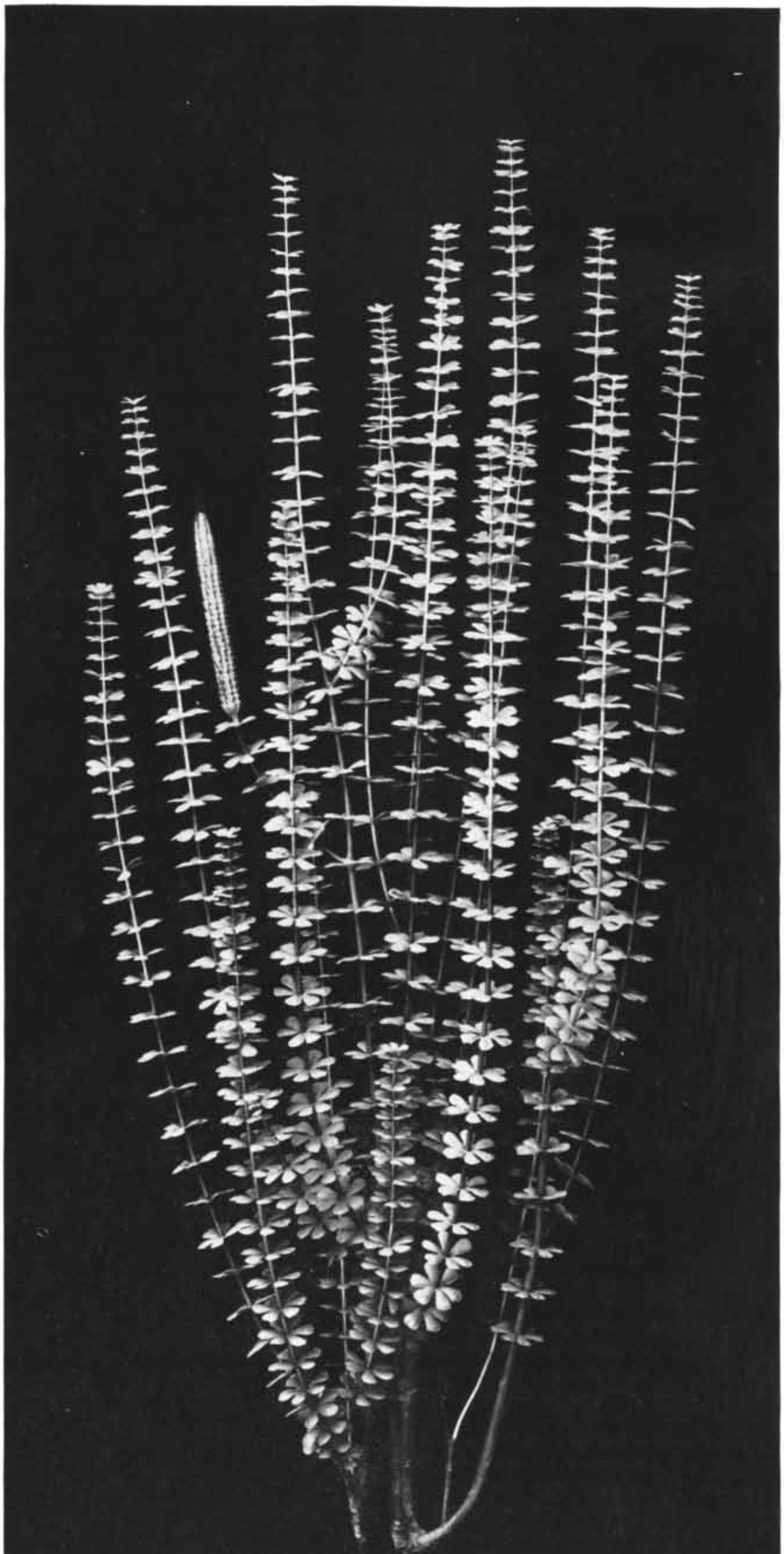
It is in the plant life of that ancient time that geologists are naturally most interested. From coal itself little can be learned, for in coal seams the plants have been so altered by extreme pressure that only their cell structures remain for study. But in the sediments immediately above the coal, that is to say, in the roof shale or slate of coal mines, geologists have found many fossils of complete plants, with stems, roots, seeds and leaves which were beautifully preserved, even down to their intricate veins and texture.

Thanks to the branch of geology known as paleobotany, which has developed greatly since the turn of the century, knowledge of the ancient plants which formed coal has become amazingly complete. Through painstaking and detailed study of countless fossil specimens taken from the world's coal mines, thousands of varieties of coal-age plants, now long extinct, have become known.

The Pennsylvanian plant world was vastly different from ours. There were then no forests of deciduous, broad-leaved trees, no grassy prairies, no flower-carpeted meadows. No pine trees clothed the mountain sides, no palms swayed in the breezes along the shores. These plants were not destined to appear on the earth until millions of years later. The coal swamps were covered instead with an immense, lush growth of plants more like our club mosses, horsetails and ferns. Although these plants were lower forms, botanically speaking, many of them were of gigantic size. The forests were dominated by stately pteridophytes (from the Greek *pteridos*, meaning fern, and *phyton*, plant), which attained the dimensions of large present-day trees. The undergrowth consisted mostly of ferns and other shrubby plants and vines with fernlike foliage.

The principal trees of the coal age were of the botanical order *Lycopodiales*, which then had a much greater variety of forms than it has today. The best-known present members of this order in the temperate zones are *Selaginella*, the club moss, and *Lycopodium*, the ground pine. In the coal age, the dominant Lycopodiales were two huge tree species—*Lepidodendron* and *Sigillaria*. Their most distinctive feature was a peculiar kind of scar on the trunk, representing the former attachment places of fallen leaves. Strangely enough, after the leaves had fallen these leaf scars continued to grow throughout the life of the trees, giving their bark a characteristic pattern quite unlike the rough bark of present-day trees. Hundreds of different scar patterns are known, and it is by such variations that the ancient tree fossils are classified.

The Lepidodendron trees had diamond-shaped, spirally arranged scars on their trunks and branches. The trees branched by twos, each branch dividing repeatedly into two smaller ones to the ultimate tips. At the tips were borne cones containing



RECONSTRUCTION of coal-age "weed" *Sphenophyllum* shows its circular leaf pattern and slender reproductive cone (*upper left*). Sphenophyllum seldom grew higher than two feet, carried its leaves in multiples of three.

the reproductive spores. When ripe, the cones were shed and two new branches began to grow from this point. These in turn bore a new series of cones and the cycle repeated itself. The Sigillaria trees, in sharp contrast, did not branch at all. Instead, they bore their leaves in a single spreading crown at the top of the trunk, much in the fashion of modern palm trees. Their cones were carried on small stems which emerged at irregular intervals along the trunk, like the pod-bearing structures of modern cacao trees. When they fell off they left oval scars resembling knotholes on the trunk.

THE Lepidodendron and Sigillaria leaves were long, grasslike spikes, sometimes as much as three feet in length but never more than half an inch wide. The trees attained heights of 100 feet or more, with trunk diameters of six feet or so at the base. They grew abundantly all over the earth in the coal age, and their stems and leaves were one of the chief constituents in the formation of coal. Cannel coal, which is a special variety of bituminous, is composed almost entirely of the massed spores of these trees.

The great swamplands of the coal age also teemed with gigantic rushes, called *Calamites*, which resembled the modern bamboo. Their enormous trunks were as much as two feet thick at the base and towered 50 feet or more. Jointed like the bamboo, the trunks bore lateral branches, in some species from every joint. Along the full length of every branch, at closely spaced intervals of an inch or two, were whorls of spatula-shaped leaves. Each whorl or cluster had 15 to 30 leaves. Coal miners often mistake these fossils for asters or daisies, for when pressed flat in the rocks the leaf-whorls suggest a flower. These gigantic rushes have left only one small modern descendant: the common roadside weed known variously as horsetail, scouring rush or jointed grass.

The most ubiquitous "weed" of the coal forests was *Sphenophyllum*—a small, slender-branched, herbaceous plant that seldom grew more than two feet high. Its branches sprouted many whorls of tiny triangular or wedge-shaped leaflets, clustered always in multiples of three, the average number in most species being six to twelve. At the branch tips, the weed, like the Calamites rushes, bore reproductive cones.

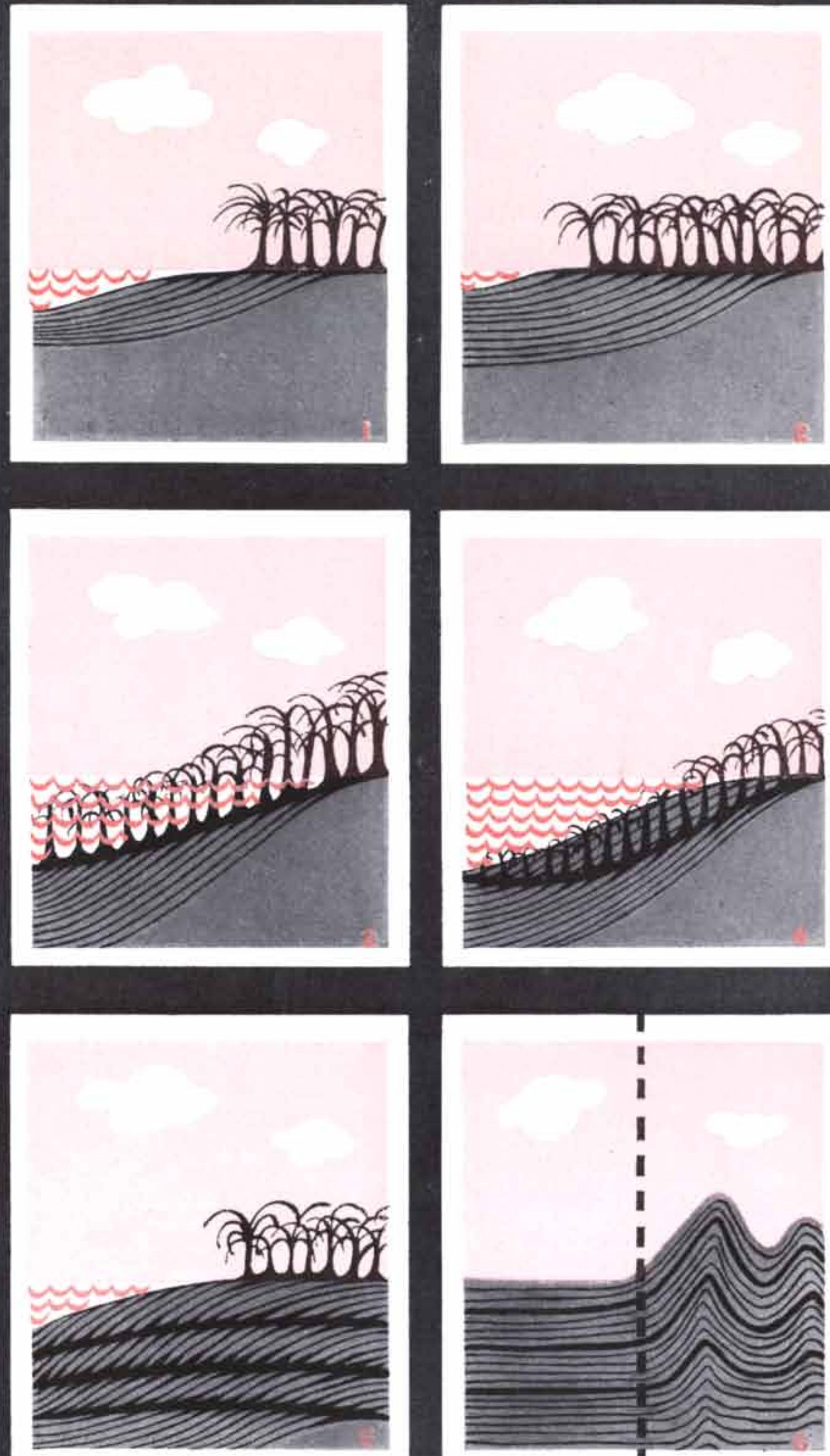
But by far the richest growth of the coal age was the fern plants—ferns in hundreds of varieties and in such profusion that the Pennsylvanian period is known as the Age of Ferns. No one can conceive of how opulently they grew until he has visited a coal mine and seen their delicate leafy imprints dotting the roofs of its passageways for mile upon wonderful mile. Their lacy outlines in black carbon stand out in bold relief against the gray background of the shales in which they are embedded. These ferns, all with the characteristic finely divided fronds of their kind, appear in shapes now no longer seen on earth, some as herbaceous forms, some as scramblers or vines that clothed the forest trees in lacy negligee, some as trees themselves, soaring to a height of 70 feet.

Strictly speaking, they were not all true ferns, although until very recently they were considered so. Microscopic examination of their stem structures has shown that, unlike modern ferns, which without exception reproduce by spores borne on the undersides of the leaflets, a majority of these ancient ferns bore nutlike seeds attached to the fronds. They have therefore been given the name *Cycadofilicales*, or seed ferns. How strange it is that nuts, which today grow only on trees, a quarter of a billion years ago were borne only on ferns! The seed ferns did not outlive the coal age and are now utterly extinct, but the true ferns have come down in unbroken succession through all the changes of the earth's geological history.

THE flora of the great coal age in general resemble the plants now found in the tropics more than they do those in other regions. Moreover, the trees of that period did not have growth rings in their trunks, which indicates that they developed under more or less uniform growing conditions, without great changes in the seasons. These plants are found in coal beds all over the earth, even in the Arctic and Antarctic regions. Does this mean that most of the world had a tropical climate in those days? Perhaps so, but there are some puzzling anomalies to explain. Even if the polar regions had been warm enough to tolerate tropical plants, their poverty of sunlight during half the year would hardly have permitted the lushness and sustained growth of vegetation required to form coal beds. Science may have to find an explanation other than tropical climate for the arctic coal beds. There is a suggestion of a possible answer in recent geological studies which indicate that the earth's great continental masses have shifted bodily in position since the coal strata were formed. If true, this suggests a much less stable earth than many geologists care to admit; but it would account for the presence of extensive coal beds in the Arctic and Antarctic. In any case, here is a challenging problem for study and solution.

The vast realm of plants that lies buried below the surface as coal is the foundation of our modern industrial world. Without the use of coal, medieval conditions would still prevail. Long after our reserves of oil, gas and other strategic mineral resources have been depleted, coal will still remain a most important resource.

Raymond E. Janssen is associate professor of geology at Marshall College in Huntington, W. Va.



MAKING OF COAL begins (1) with deposition of delta. Sea retreats (2) and forest grows on new land. Sea bottom sinks (3), submerging forest. Second delta is laid down over first (4). Process is repeated many times (5), peat hardening into coal. Entire region is then elevated (6). Most coal is bituminous and lower grades, but folding of strata (*right of dotted line*) produces anthracite.

THE PHILIPS AIR ENGINE

The renascence of a forgotten idea has presented our technology with a remarkable new prime mover. Its main advantages: efficiency and independence of special fuels

by Leonard Engel

PROWLING around an industrial fair at Munich in 1937, an engineer of Holland's famous Philips electrical firm discovered a curiosity. It was an old-fashioned Stirling air engine—a 19th-century invention which had been all but forgotten in the high-powered 20th. The engineer found the contraption rather interesting; he thought it might even solve a problem—supplying power for small radio transmitters in isolated areas—with which the Philips firm was at the time much concerned.

Philips' engineers began to analyze the machine. Soon they decided that it had more interesting possibilities than they had thought at first. Essentially it needed only redesigning with modern materials, they concluded, to become a remarkably efficient engine. They went immediately to work, and became so excited about their project that they continued it in secret throughout the German occupation of the Netherlands. Since the end of the war, development of their machine, which is now known as the Philips air engine, has proceeded rapidly. More than 25 laboratory and test models have been built at the Philips Physical Research Laboratory in Eindhoven and additional development work is under way in the U.S. and England. By now the air engine has evoked wide interest among engineers on both sides of the Atlantic. Some enthusiasts compare its renascence with the discovery of the steam engine and the internal combustion engine. Indeed, its performance so far indicates that for many purposes the air engine may be superior to both.

The air engine is an external combustion machine like the steam engine, with air instead of steam as the working medium. Air is alternately heated and cooled to drive a piston. The engine can be designed to run on almost anything that burns, including bituminous coal—an important consideration in these days of almost insatiable demand for high-grade fuels. Built of ordinary metals, and with very few moving parts, it is as compact as a gasoline engine but far quieter. And its efficiency (*i.e.*, the proportion of fuel energy converted into mechanical energy) may ultimately exceed 30 per cent. This figure is better than that attained by comparable gasoline engines at any time and better than that of a Diesel engine under any operating condition except full load.

The air engine has drawbacks that disqualify it for some jobs. But it is so simple and economical in operation that many engineers consider it in general a very satisfactory answer to technology's long quest for a quiet, efficient, trouble-free motor. They think it will soon rank as one of the major "prime movers." The Philips engineers are confident that within a few years they will turn out practical air engines for a variety of uses, with speeds of up to 3,000 revolutions per minute and power outputs of one to several hundred horsepower.

The importance of this development may be gauged by the fact that only four other basic engine types have evolved since the age of power began. It was in 1698 that the Englishman Thomas Savery built the first working steam engine, which James Watt and his contemporaries were to translate into a practical machine in the following century. The idea of the internal combustion engine was born in the fertile brain of the Dutch astronomer and telescope maker Christian Huygens, who in 1680 suggested a power plant run by gunpowder explosions. Huygens' scheme did not work out, but it started a train of thought that led in 1820 to the building by an Englishman named W. Cecil of a machine operated on an explosive mixture of hydrogen and air, and thence to the modern gasoline engine a half century later. The two other basic prime movers are more recent: the steam turbine (based on the same principle as a windmill, with steam substituted for wind as the motive power) was developed in the 1880s, and the gas turbine, which uses hot gases instead of steam, has been perfected in the last decade.

THE AIR ENGINE has been known in principle for nearly two centuries but, like many good ideas in science and technology, it has suffered a long lag in application. The Stirling engine was designed more than a century ago by a Church of Scotland minister named Robert Stirling and his brother James. Their machine even reached the stage of commercial production. It was clumsy and inefficient, however, and the Stirling engine lingered on into the 20th century only as a laboratory motor and as a toy.

The air engine operates on the classical principle underlying all heat engines, which was formulated a century and a quarter ago by the brilliant young French engineer Sadi Carnot. Carnot's principle was roughly this: if a cold gas is compressed and heated and then allowed to expand again to its original pressure, the heat imparted to the gas can be converted to mechanical energy by permitting the gas to expand against a piston or through a turbine. The efficiency of this process depends not on the gas used but on the difference between the maximum and minimum temperatures. Thus it makes no difference in theory what gas is employed; air will do about as well as any.

In the air engine, air is cycled back and forth in a closed circuit within a cylinder. Heat is supplied by a burner fitted over one end of the cylinder. The cycle has four overlapping stages: 1) the air is compressed in a "cold space" at the cool end of the cylinder; 2) it is moved to a "hot space" at the other end and heated to high temperature; 3) it is expanded against a piston; 4) it is cooled and returned to the cold space, where it is recompressed. Then the cycle begins anew.

During the cycle, the pressure of the air varies by a ratio of something more than two to one. This is low in comparison with other engines and one might imagine that the air engine, while theoretically efficient, would actually develop little power. However, its power output can be raised to a level comparable with that of other engines by increasing the pressure of the air within the cylinder. In one Philips engine the minimum pressure is 22 atmospheres (308 pounds per square inch) and the maximum is 50 atmospheres (700 pounds per square inch).

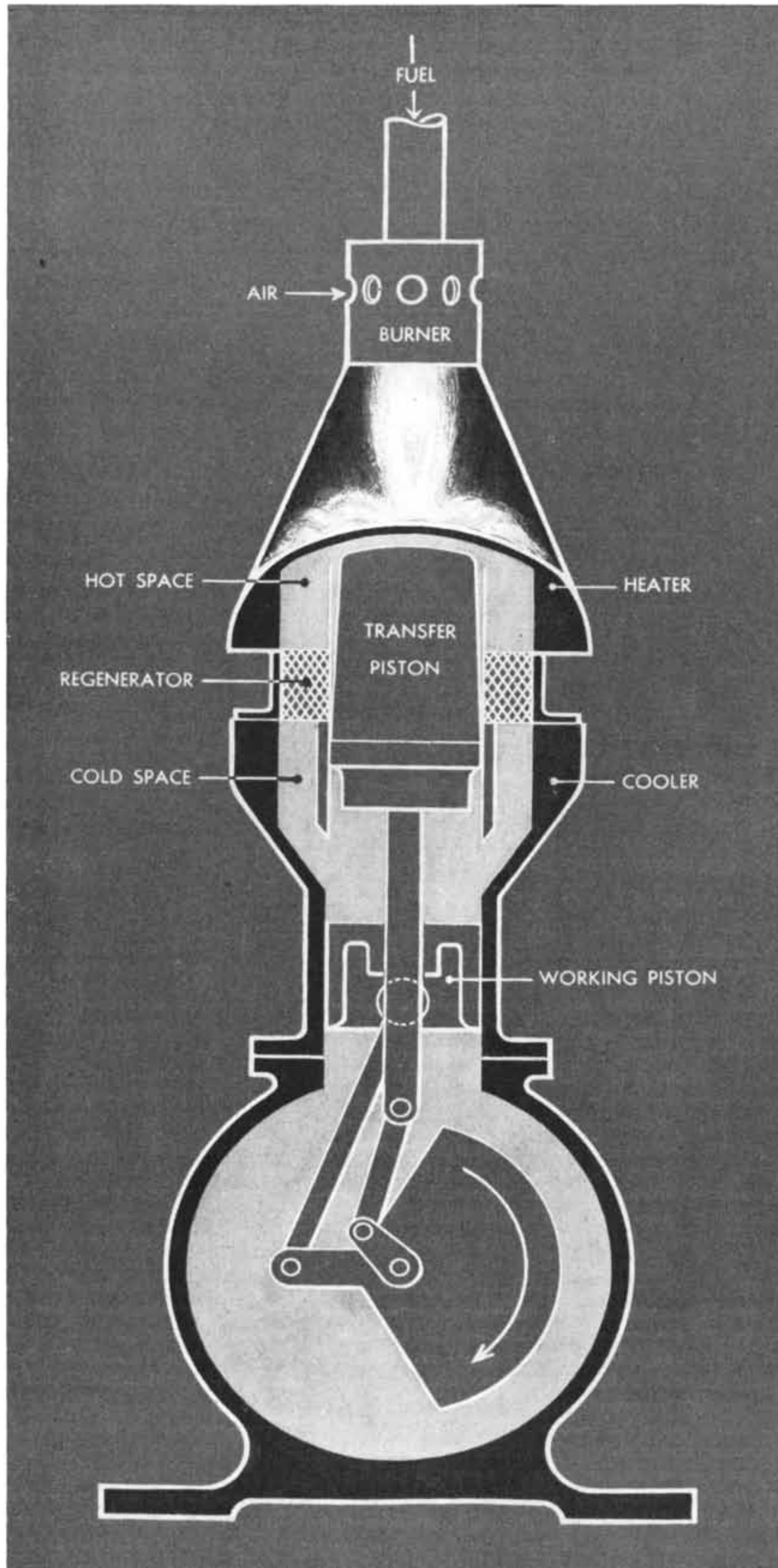
As in other heat engines, many different mechanical arrangements are possible. Philips has already developed four distinct types of air engine. One is a single-cylinder model illustrated at the right. Another has four cylinders arranged in a square. Still another, a four-cylinder V with a projected output of 300 horsepower, is under construction in Holland.

Common to all models is a critically important device known as the "regenerator," situated between the hot and cold ends of the cylinder. This device is a heat exchanger which absorbs unspent heat from the expanded air as it leaves the hot space and gives the heat back when the air returns. Thus the machine conserves heat and uses it again and again. Only one fourth of the heat imparted to the air during any one cycle is supplied by the burner; three quarters is unspent heat from previous cycles, transferred by the regenerator. Without regeneration fuel consumption would rise by a factor of four and the air engine would be impossibly uneconomical.

Regeneration is, of course, widely employed in other prime movers. Steam engines and steam turbines, for example, use waste heat to raise the temperature of incoming water, and in several types of gas turbine, the combustion air is preheated in a similar manner. Regeneration is also utilized in high-temperature chemical processes and in the blast furnace to heat air for the blast. It is an interesting fact that it was the Stirling brothers who invented the regenerator (or "economizer," as they called it). The Stirling engine also incorporated a surprising number of other modern engineering features.

THE chief improvements in the Philips engine are not in basic design but in materials. Yet all of these materials are readily available. There are no special high-temperature alloys such as are required for gas-turbine blades. The heater, which constitutes the "radiator" for conducting heat from the burner to the engine's charge of air, and other parts exposed to the hot air are fabricated from nonscaling stainless steel. The heater's fins are of aluminum bronze. Other parts, such as pistons and connecting rods, are of standard metals. Contemporary materials, however, are so much superior to those of the last century that even commonplace metals have effected extraordinary improvements in performance. The Stirling engine. which was limited to low temperatures and pressures, weighed 880 pounds per horsepower and had an overall efficiency of three per cent. The Philips machines, which develop peak pressures of 50 atmospheres and hot-space temperatures of 1.350 degrees F., weigh 10 to 20 pounds per horsepower, and production models can be made lighter still.

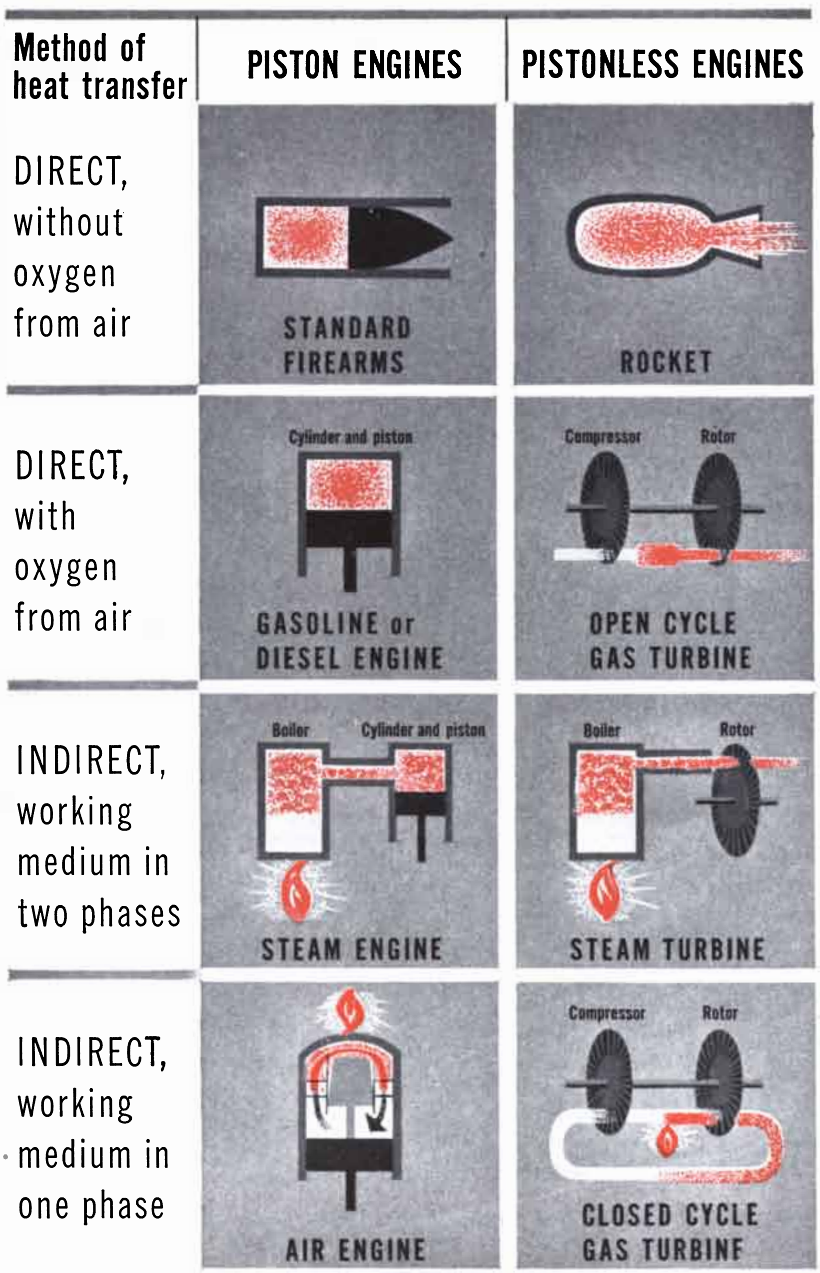
A particularly striking example of the gains brought by modern metals is afforded by the regenerator. In the Stirling engine, the regenerator consisted of a series of closely spaced thin iron plates. This arrangement had too little surface area for rapid heat transfer and the plates so impeded the flow of air that the regenerator was often left out. In the Philips engine, a coil of fine steel wire, crimped to expose more surface, takes the place of the iron plates. The wire coil is a heat-transfer agent of astonishing effectiveness. It heats the air flowing through it from 250 degrees F. to 1,100



THE AIR ENGINE has an unusual but simple principle of operation. Heat is applied outside the engine by burner (*top*). Air in "hot space" is heated, pushing working piston downward to rotate crankshaft (*bottom*). Working piston merely helps displace air. Cycle of operation is depicted on page 55.

A CLASSIFICATION OF HEAT ENGINES

The air engine has a unique place among the devices designed to obtain mechanical energy from heat. In this chart the heat engines have been considerably simplified to show their fundamental principles of operation. The application of heat is indicated by red areas. In many heat engines efficiency is cut down because much heat is wasted. Outstanding exceptions are the air engine and the closed cycle gas turbine, which conserve heat by recycling working medium. The two should prove complementary. The air engine is most efficient at low horsepower, the closed cycle turbine at high horsepower.

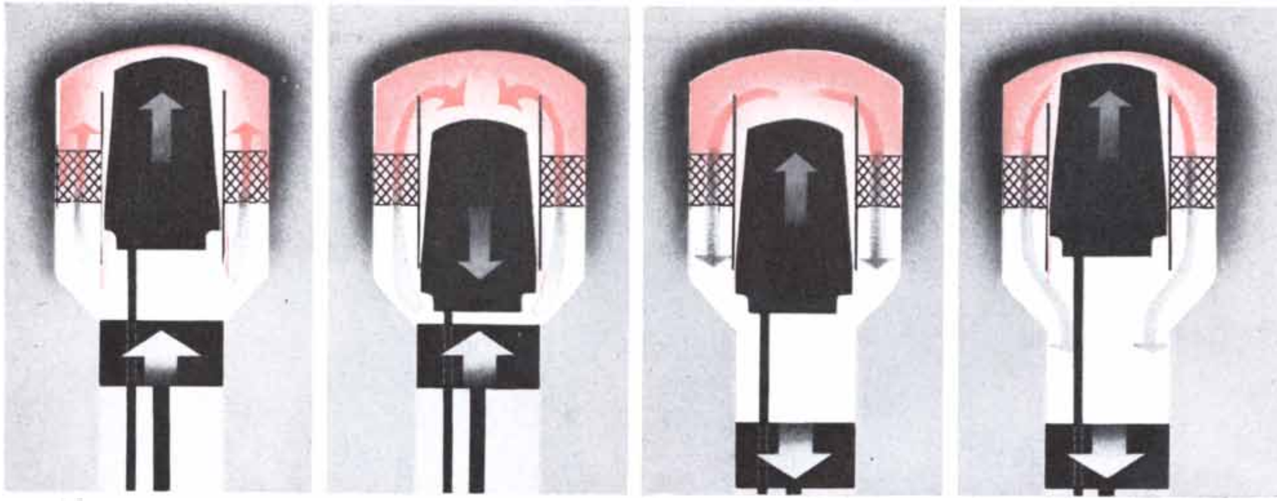


degrees and then cools it again to 250 degrees—and it accomplishes this no less than 3,000 times a minute.

The single-cylinder Philips engine utilizes a transfer piston, an especially ingenious feature of the Stirling engine. In single-cylinder air engines, it is necessary to have two pistons: one to move air from the cold space to the hot, and the other to move it back. Theoretically, both of these pistons would have to operate under pressure, since the first piston would serve to compress the cold air and the second would take up the expansion of the heated air. Such an arrangement, however, would introduce large friction losses, for the pistons must be fitted tightly to prevent the leakage of air. Two pistons working under pressure in a single cylinder would be impractical. The problem is dealt with by making one of the pistons merely a transfer piston, *i.e.*, one which displaces the charge of air from one space to the other, and by using the second piston for both pressure strokes. How this works is shown in the diagram at the top of page 55.

ONE OF THE major attractions of the air engine is that it is inherently simpler and longer-wearing than comparable internal combustion engines. It can be designed so that all wearing parts are at the cold end of the cylinder. By means of an air cooler supplementing the regenerator, the cold end can be kept below the temperature of boiling water. Thus wear due to heat is reduced to a minimum. A second advantage is that, in contrast with the explosive gas expansion in an internal combustion engine, the heated air expands with relative slowness, resulting not only in less wear but in quieter operation. Third, the combustion being external, there is no deposition of carbon on the working parts. Fourth, the air engine has no valves. In most reciprocating engines, valves are required because the cylinders must be opened once during each cycle. In the internal combustion engine, cylinders are opened to receive air and fuel and dispose of the products of combustion; in the steam engine, to receive the charge of steam from the boiler and, after it is spent, exhaust it to the condenser. The air-engine cylinder, on the other hand, needs no valves because it is a completely enclosed system that requires no intake of air or fuel, and the movement of air within the system is entirely controlled by the pistons.

Multiple-cylinder air engines of large horsepowers can be constructed by assembling single-cylinder engines. However, Philips has worked out an even simpler arrangement that eliminates the transfer piston. In this, there are as many air systems as there are cylinders, but each system consists of the top half of one cylinder as hot space and the bottom half of the next cylinder as cold space; the



SINGLE-CYLINDER air engine requires two pistons. In first drawing working piston (*bottom*) pushes air up into hot space (*red area*). Air is partly heated by passing through wire regenerator coil at the sides. Transfer piston (*top*) then moves down, pushing more cold air into hot space. In third drawing heat expands air, pushing working piston downward. Cycle is completed when transfer piston removes remaining air from hot space.

flow of air, via heater, regenerator and cooler, is between one cylinder and another, not between the top and bottom of each cylinder. When the pistons are made to work in the proper order, the expansion in the top of a cylinder coincides with a cold compression and cold transfer in the bottom half of the same cylinder (though the latter is actually the cold stage of the next air system). Each piston serves simultaneously as working piston and compression-and-transfer piston. The engine therefore has only one piston for each cylinder, which seems as simple a design as is possible in a reciprocating engine.

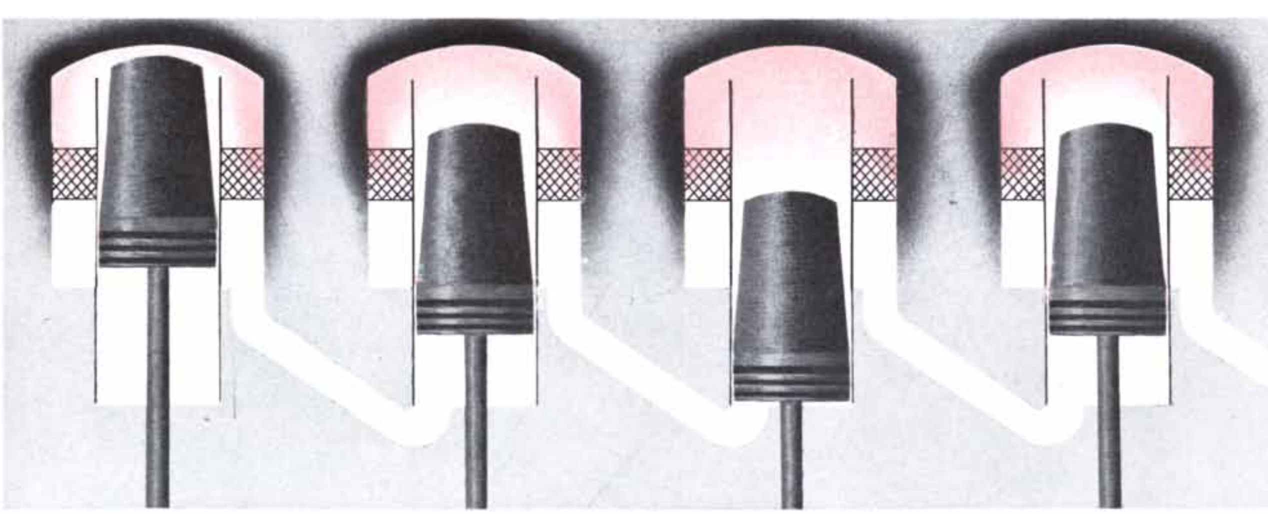
Of the air engine's disadvantages, the most important is the fact that it does not start instantly. Like other external combustion engines, it must be warmed up. This may bar the air engine from many automotive applications. But in some—in farm machinery, for instance—slow starting is not enough of a handicap to nullify the air engine's other advantages. In other fields, such as small power-producing plants, refrigeration plants and small motor ships and boats, where instant starting has no special value, the air engine's ability to operate on low-grade fuels with a minimum of maintenance and repair should prove decisive.

The air engine's independence of liquid fuels gives it a great advantage over internal combustion engines and over most versions of the new gas turbine. Gas turbines usually require liquid fuels because the turbine wheel is spun by combustion gases. An effort has been made to adapt some gas turbines to powdered coal, but no practical success has yet been attained.

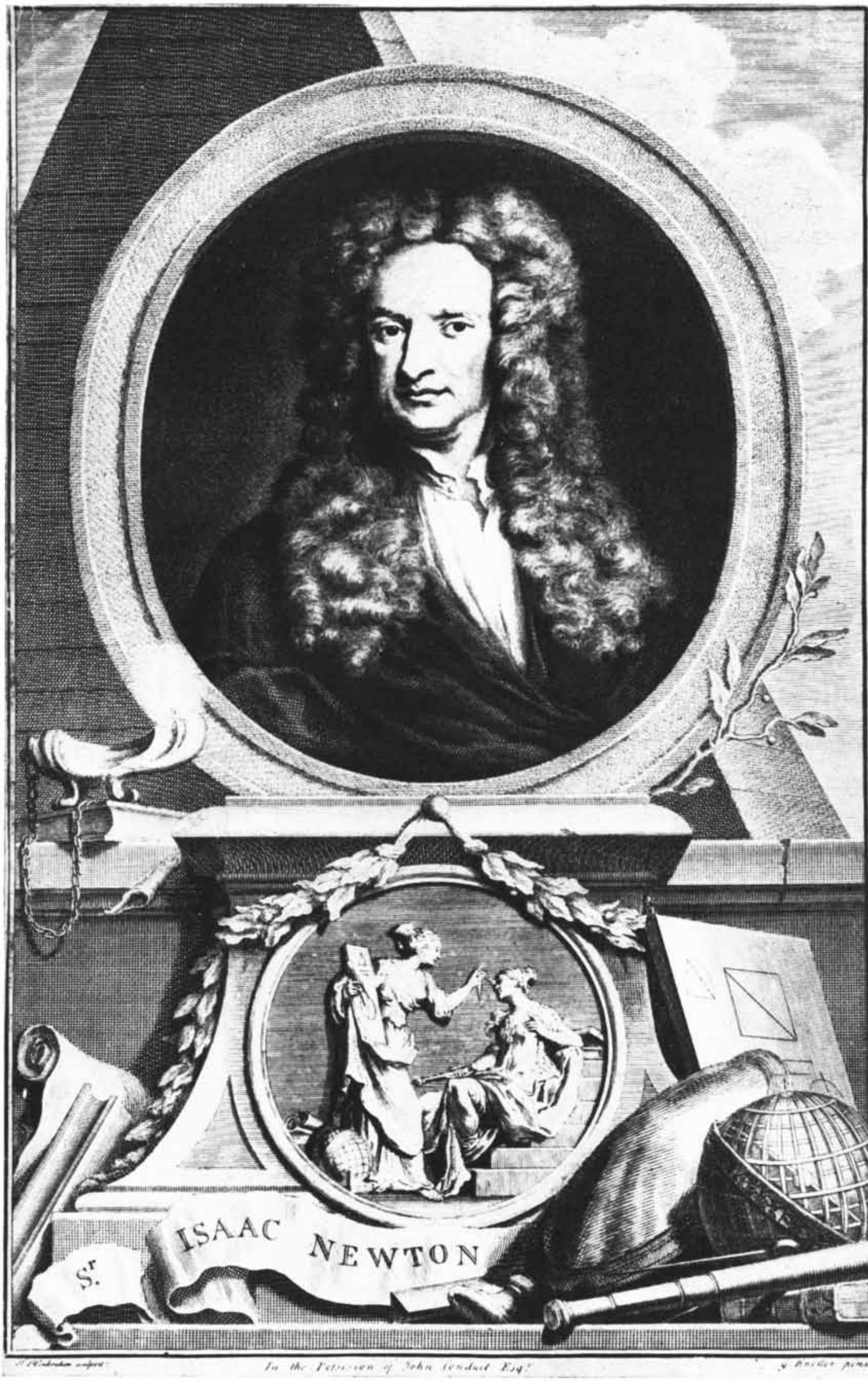
Another kind of air engine now under test is the Swiss Ackeret-Keller turbine, an external combustion engine which has a cycle exactly like that of the air engine except that a turbine replaces the piston. Air passes successively through a compressor, a regenerator, an "air boiler," the turbine, and finally through the regenerator and a cooler back to the starting point. The Ackeret-Keller turbine operates on any fuel and promises a thermal efficiency higher than that of the steam turbine.

Thus it appears that in the near future air engines may be available throughout the whole span of the horsepower spectrum: Ackeret-Keller air turbines in the high horsepowers where turbines are preferable, and Philips air engines at low and medium horsepowers where reciprocating engines are the most efficient prime movers.

Leonard Engel is a writer of articles on scientific and other topics.



MULTI-CYLINDER engine requires only one piston in each cylinder instead of two. Each piston becomes a combined working piston and transfer piston. Cylinders are connected so that bottom of each piston pushes air into the hot space of the next cylinder. The top of each piston is pushed down by expanding air in the hot space. All pistons are connected in this manner, but here connection of piston at far left has been omitted.



THE AGING NEWTON was "the recipient of honors and good fortune of every description. He . . . became a counselor to young scientists, grew rich and philanthropic and was knighted by Queen Anne. . . ." The portrait from which this contemporary engraving was made was painted by Sir Godfrey Kneller, the noted artist.

BOOKS

A fine collection of essays about Isaac Newton, both the man and his accomplishments, on the occasion of his tercentenary

by James R. Newman

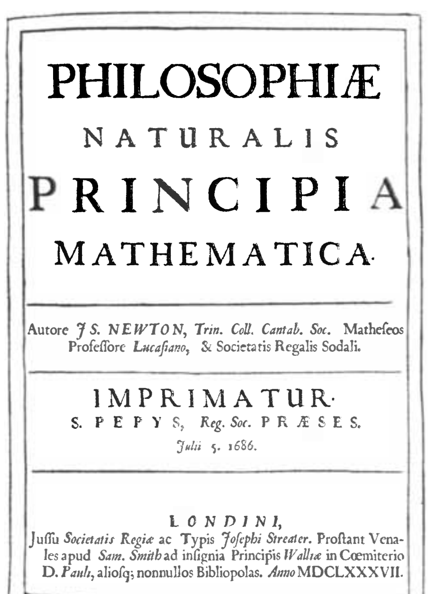
ON Christmas day, 1642, in the year when Galileo died, there was born in the Manor House of Woolsthorpe-by-Colsterworth a male infant, so tiny that, as his mother told him in later years, he might have been put into a quart mug, so frail that he had to wear "a bolster around his neck to support his head." This unfortunate creature was, the parish register reads, "Isaac, sonne of Isaac and Hanna Newton." There is no record that wise men honored the occasion, yet the child was father to a man who altered the thought and habit of the world.

The English Royal Society, over which Isaac Newton presided for almost a quarter century, planned to celebrate the tercentenary of his birth in 1942. (Strangely, this was to be the first international event in Newton's honor since one that took place during his life, when he was elected a foreign associate of the French Academy of Sciences.) Postponed because of the war, the celebration was finally held at London and Cambridge in July of 1946. With representatives of 35 nations attending, it was an international gathering such as had rarely been convoked even before passports, iron curtains and the congealing effects of security persuaded many a traveler to stay home.

A number of the lectures delivered on the occasion have been collected by the Cambridge University Press in a new book called "Newton's Tercentenary Celebration." This slender, handsomely printed volume is a worthy record of the celebration and a credit to the Press. Among its contributors are Sir Robert Robinson, president of the Royal Society; E. N. da C. Andrade; H. W. Turnbull, and such eminent non-British scientists as Niels Bohr of Denmark and S. I. Vavilov of the U.S.S.R. The tributes here offered to Newton's memory concern various aspects of his work and deal also with the man himself. In every sense it is a fine book with as much meaning for the plain, thoughtful man as for the scientist.

I found of especial interest the introductory lecture by Professor Andrade, a lucid survey of Newton's vast achievements, and the brilliant paper "Newton the Man," prepared by Lord Keynes but delivered, because of his death, by his brother Geoffrey Keynes. Andrade's lecture, without giving new facts, tells Newton's story more gracefully and convincingly than this reviewer has heard it told before; the fragment by Lord Keynes (it was never completed), a fresh appraisal based on unpublished manuscripts and personal papers in his possession, is enriched by the imagination and color which Keynes brought to much of his writing.

It is possible to construct a brief biography from these essays. Newton had a happy, normal childhood with little to foreshadow the flowering of his genius. At 18, having done "well enough at school and badly enough as a farmer," he was sent to Cambridge, where he came under the influence of the mathematician Isaac Barrow. It was Barrow who trained Newton, early recognized his powers and, eight years later, voluntarily relinquished his chair in mathematics to his pupil—surely a rare phenomenon in academic life.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostant Venales apud *Sam. Smith* ad insignia Principis *Walliæ* in Cœmiterio D. *Pauli*, aliosq; nonnullos Bibliopolas. *Anno* MDCLXXXVII.

TITLE PAGE of Newton's great *Principia* also bears name of Pepys, then president of the Royal Society.

By the time he became a "senior sophister" in 1664, Newton had begun to show a deep interest in mathematics and natural philosophy. Still, his university years were not all grind. His expense account shows—besides such items as "magnet, 0-16-0" and "the hist. of the Royal Society, 0-7-0"—more frivolous entries: "at the tavern twice, 0-3-6," "at the tavern several other times, 1-0-0" and even "lost at cards twice, 0-15-0."

In 1665 Newton was back at Woolsthorpe, having been forced by the plague to leave Cambridge. There, in two years of benign solitude, he "laid the foundations of his work in the three great fields with which his name is forever associated—the calculus, the nature of white light, and universal gravitation." It was an incredible achievement. Yet there is little to show how Newton's mind evolved these discoveries other than a few words in a memorandum that he wrote when he was 73: "All this was in the two plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since."

It would be a mistake, of course, to infer that these brilliant conceptions came to Newton's mind suddenly and that nothing in the intellectual life of the time had opened the way for them. The calculus, as he proposed it, was a "correlation of what he [had] learned from Descartes, Wallis and Barrow, combined with his original methods of infinite series and their reversion." It was a wonderful creation but not without forebears. His mechanics of the universe, set forth in the great *Principia*, was the culmination, as he recognized and stated, of the work begun by Copernicus and richly enlarged by Tycho Brahe, Kepler and Galileo. The famous discoveries presented in his *Opticks* were built on only meager foundations laid by earlier scientists. But altogether the preceding period was not so dark nor Newton's illumination so unexpected as is sometimes supposed. Great ideas emerge from the common cauldron of intellectual activity and are rarely cooked up in private kettles from original recipes.

THE book has some interesting observations on the celebrated tale of the falling apple, which, like the account of Galileo's experiments with heavy bodies dropped from the tower of Pisa, has not had a kind reception from modern historians of science. Andrade credits Stukeley's report of a conversation in which the aged Newton said that while he was "thinking of what pull could hold the moon in its path, the fall of the apple put it into his head that it might be the same gravitational pull, suitably diminished by distance, as acted on the apple." This account is more plausible than the one which implies that the mere fall of an apple first suggested the universal principle of gravitation. Falling apples, after all, are commonplace and one might wonder why they did not suggest gravitation to some earlier scientist.

Newton had both a "horror of controversy" and the related habit of postponing for years publication or even informal disclosure of his results. His mathematical inventions of both the generalized binomial theorem and of the calculus he gave to Barrow in 1669 when he started to lecture at Cambridge, but the manuscript was not published until 1711. This postponement was partly responsible for Newton's famous controversy with Leibnitz over the invention of the calculus.

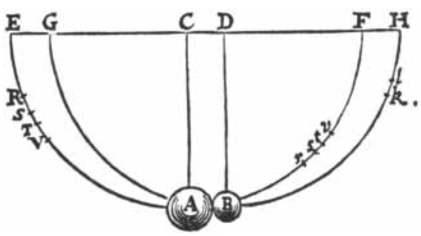


ILLUSTRATION from the *Principia* depicts behavior of moving bodies accelerated in the same direction.

In 1671 Newton sent Oldenburg, secretary of the Royal Society, an account of his experiments with light: "being in my judgement the oddest, if not the most considerable detection, which hath hitherto been made in the operation of nature." Again, the book itself did not appear until the next century.

THE circumstances surrounding the writing and publication of the *Principia* are elements in the case study of a great man's neuroses. It was characteristic of Newton's temperament to labor in volcanic fits and starts and to alternate his efforts between science, theology and the occult. In 1675, when he was urged to express himself on the subject of planetary motions, it happened, as he said, that he had developed a "great distaste for science." Indeed, one may doubt whether he would have assembled his conclusions and completed his system had he not been, as he wrote, "spurred, cajoled and importuned" by his admirers and his detractors. The grand unifying principle of gravitation occurred to him, as I have mentioned, in his meditations at Woolsthorpe. During the ensuing years he had repeatedly returned to the problem of explaining the motions of the physical universe, but for various reasons he had not forced his mind to the summit. His disinclination to pursue the matter beyond writing a little book, *De Motu Corporum*, is expressed in a letter to Robert Hooke in 1679. "But yet my affection to philosophy [*i.e.*, science] being worn out so that I am almost as little concerned about it as one tradesman uses to be about another man's trade or a countryman about learning, I must acknowledge myself averse from spending the time in writing about it which I think I can spend otherwise more to my own content and to the good of others: and I hope neither you nor anybody else will blame for this averseness."

It was not for this averseness that Newton was blamed. Instead, Hooke, having independently concluded that the motion of the planets could be explained on the basis of an inverse square law of attraction, was furious when the *Principia* appeared with his name not even mentioned in the preface. Newton, vexed beyond bounds by Hooke's contentiousness, threatened, as Andrade says, "to suppress the third book of the *Principia* which is the crown of the work and contains the celestial mechanics." It was the occasion for Newton's famous lament: "Philosophy is such an impertinently litigous lady, that a man had as good be engaged in lawsuits, as to have to do with her."

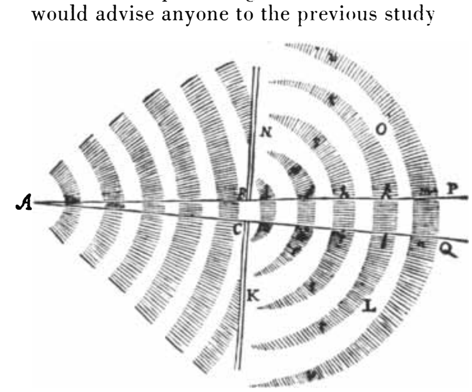
Despite the bitter controversy, there emerged unscathed what remains to modern times the supreme scientific creation, "preëminent," Laplace said, "above any other production of human genius." Nor has time altered this judgment. Einstein, referring to the *Principia*, has said that to Newton nature was "an open book, whose letters he could read without effort." The late Sir Arthur Eddington, answering those who with the coming of relativity would reduce Newton's status to that of an honored relic, wrote: "To suppose that Newton's great scientific reputation is tossing up and down on these latter-day revolutions is to confuse science with omniscience."

The first book of the *Principia* deduces the laws of simple orbits, those already set forth by Kepler, from the "vast generalization that every mass point attracts every other mass point" according to the law of inverse squares. (From this it follows directly that the path of each planet is an ellipse.) It gives also the complete laws of impact of two bodies. The second book treats of "motion in a resisting medium" and tackles the complex problems of the motion of fluids. Hear Newton's words ("like the third movement of a supreme symphony . . . with a recapitulation of previous themes and short statement of the new theme") as he opens the third book:

"In the preceding books I have laid down the principles of philosophy; principles not philosophical but mathematical. . . . These principles are, the laws and conditions of certain motions, and powers or forces, which chiefly have respect to philosophy. But lest they should have appeared of themselves dry and barren, I have illustrated them here and there, with some philosophical scholiums, giving an account of such things . . . as the density and resistance of bodies, spaces void of all bodies, and the motion of light and sounds. It remains, that from the same principles, I now demonstrate the frame of the System of the World."

In the third book, as outlined by Andrade in a formidable list, are established the motions of the planets; the masses of the sun and of the planets which have satellites (a feat which Adam Smith considered to be "above the reach of human reason and experience"); the density of the earth, estimated at "between five and six times that of water" (the accepted figure today is 5.5); the conical motion of the earth's axis (the precession of the equinoxes); the foundation for the theory of tides; the orbits of the comets; the irregularities of the moon's motion due to the pull of the sun; and "the flattened figure of the earth."

The *Principia* is a difficult work, written in a style of "glacial remoteness," without concession to the reader, in the aloof manner of "a high priest." This fact was recognized by Newton. "Upon this subject," he wrote, "I had, indeed, composed the third book in a popular method, that it might be read by many, but afterwards, considering that such as had not sufficiently entered into the principles could not easily discern the strength of the consequences, nor lay aside the prejudices to which they had been many years accustomed, therefore, to prevent the disputes which might be raised upon such accounts, I chose to reduce the substance of this Book into the form of Propositions (in the mathematical way), which should be read by those only who had first made themselves masters of the principles established in the preceding Books: not that I would advise anyone to the previous study of every Proposition of those Books; for they abound with such as might cost too much time, even to readers of good mathematical learning . . ."



WAVE BEHAVIOR similar to that which causes diffraction is explained in cut for passage in the *Principia*.

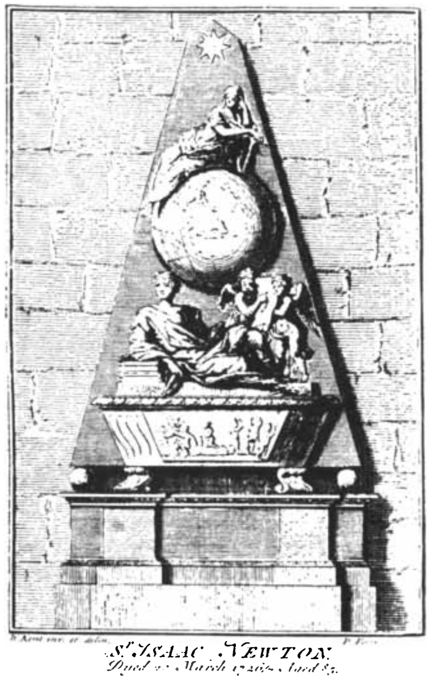
WILLIAM WHEWELL, the 19th-century Master of Trinity, expressed well Newton's incomparable talent in the use of geometric methods. "As we read the *Principia*," he wrote, "we feel as when we are in an ancient armoury where the weapons are of gigantic size; and as we look at them we marvel what manner of man he was who could use as a weapon what we can scarcely lift as a burden."

With the completion of the *Principia* Newton's consuming interest in science was spent. Political and other distractions now claimed him. As an M.P. for Cambridge there is, to be sure, no evidence that he made a splash. (There is an anecdote, perhaps apocryphal, to the effect that his only recorded utterance in Parliament was to ask that a functionary close a window which was causing a draft.) But after he had fallen into a period of "melancholy" and prolonged sleeplessness. when he lost, as he said, "the former consistency" of his mind, he recuperated fully to take on the post of Warden, and later, Master of the Mint. Though a lucrative post, this was not a sinecure, and he found his time occupied in the details of developing a new coinage system.

More than 30 years remained to him during which he was the recipient of honors and good fortune of every description. He supervised new editions of his works, became a counselor and patron to young scientists, grew rich and philanthropic and was knighted by Queen Anne, an honor, Andrade says, that had never before been conferred for services to science. In the warmth of adulation he relaxed his reserve, if not to the point of affability at least to the extent of a ready graciousness and seignorial benevolence; he even reminisced more or less freely for the benefit of contemporary biographers and raconteurs. When Newton died in his 85th year, his body lay in state in the Jerusalem Chamber of Westminster Abbey and none less than the Lord High Chancellor, two dukes and three earls carried his pall. This, Andrade remarks, "meant something in those days."

This is a bare synopsis of Newton's life and work. What about the man himself, in appearance and temper? Newton was of medium height, "exceptionally well set," with abundant hair that turned gray at 30 and silver white in later years. Two portraits reproduced in this volume show him as a strikingly handsome man. In later life he grew a trifle heavy and pink-faced. "When he rode in his coach," says a contemporary, "one arm would be out of his coach on one side and the other on the other"; with his peruke off he was "a venerable sight."

His working and sleeping habits were irregular but this did not seem to impair his health, which, save for rare intervals, was excellent. While he wrote the *Principia*, being then in the mood both for his theoretical inquiries and for experiments in chemistry and alchemy, the fire in his "elaboratory" scarcely went out for six weeks at a time. Only superlatives serve to describe his thunderbolts of insight. A problem set by the eminent Bernoulli as a challenge to "the acutest mathematicians in the world" came to him one afternoon by post and he solved it before going to bed. In 1716, when Leibnitz presented a problem "for the purpose of feeling the pulse of the English analysts," it was also solved by Newton in a few hours. Repeatedly Newton, as Augustus De Morgan once wrote, seemed "to know more than he could possibly have any means of proving." Halley once asked Newton how he knew and whether he had proved a certain discovery about planetary motion



NEWTON'S TOMB is in England's Westminster Abbey. He died on March 20, 1727, at the ripe age of 85.

which Newton had just imparted to him. "Newton was taken aback—'Why, I've known it for years,' he replied. 'If you'll give me a few days, I'll certainly find you a proof of it'—and in due course he did." Asked how he made his discoveries, he once said, "By always thinking unto them" and again, "I keep the subject constantly before me and wait till the first dawnings open little by little into the full light."

Newton left behind a mass of unpublished papers: half a million words on alchemy; 1,300,000 words on theology; assorted and voluminous notes and letters. (Some of the material was in the Portsmouth collection acquired at auction by Lord Keynes.) No competent scholar has ever sifted the papers with care. A nervous bishop of the 18th century took one look at the theological manuscripts and put them aside "with horror"; others were equally disinclined to pry.

Even in his brief scrutiny of the unpublished material Keynes gathered insights more acute than those of earlier biographers. The conventional picture of Newton as the supreme rationalist, "one who taught us to think on the lines of cold and untinctured reason," is false. Newton was not, said Keynes, the first man in the age of reason. "He was the last of the magicians, the last of the Babylonians and Sumerians, the last great mind which looked out on the visible and intellectual world with the same eyes as those who began to build our intellectual inheritance rather less than 10,000 years ago." He was also a "profound neurotic." This went far beyond mere shyness, reserve, inwardness and distrust. He cared nothing for women; he found it difficult to give anything of himself, to part with anything he created. Pride of accomplishment and the desire for recognition, both normal, were countered in Newton by a morbid fear of criticism and the neurotic instinct not to reveal his thoughts. It seems clear, and for this we may be thankful, that Newton's inner life was richer by just so much as he was incapable of imparting to others; his meditations were serene and undisturbed because when engaged upon them, for however extended a period, the world around him ceased to exist. This may explain how he was able to perform the feat of keeping the elements of a problem in uninterrupted focus "until he had seen straight through it." As Keynes said, anyone who has tried to concentrate fully upon a problem knows that despite the most intense concentration "it will dissolve and escape."

THOUGH he was master of reason, Newton's deepest instincts were "occult, esoteric, semantic." He looked on the universe, says Keynes, as a riddle. He felt that if he thought long and hard and focused his attention on the clues left by God it would all become clear. He would read the "riddle of the Godhead" as he had read the riddle of heaven and earth. If this explanation suffices for the works for which he is remembered, it will suffice to explain the theological and Hermetic writings which constitute the bulk of his utterances and (since he kept them locked in strong boxes and never consented to disclose their revelations) probably the most precious part of his work.

"I do not know," said Newton shortly before his death, "what I may appear to the world; but to myself I seem to have been only like a boy, playing on the seashore, and diverting myself, in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me." Despite its orotund style, the comment was probably sincere. Newton was a mixture of scientist and mystic; a flux of contradictory inclinations and diverse powers; a spirit both shining and inscrutable; a mind, in Wordsworth's lines, forever "voyaging through strange seas of thought alone."

James R. Newman is an attorney, visiting lecturer at Yale Law School and by avocation a writer on scientific subjects.

THE AMATEUR

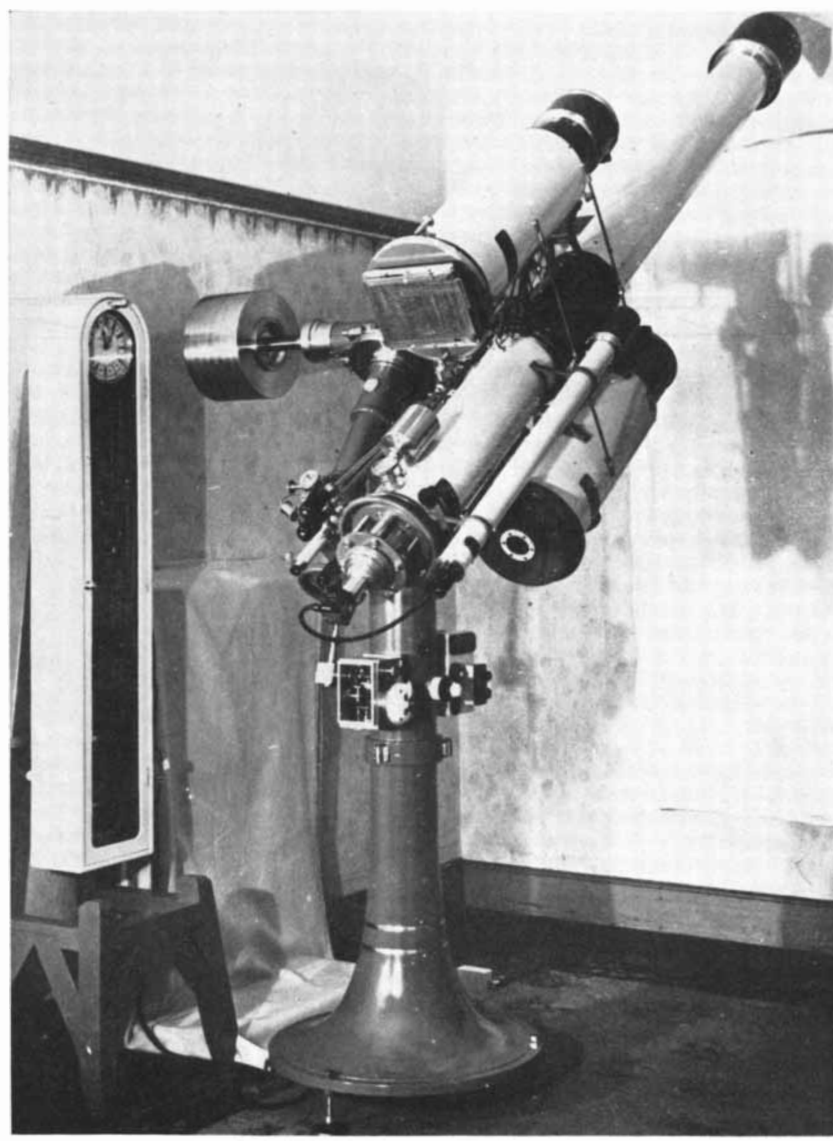
Conducted by Albert G. Ingalls

NOT in the 22 years since the book *Amateur Telescope Making* altered a little-known art into a nationwide hobby has this magazine learned of as finished an amateur's telescope as the one described this month. Since the telescope was made in Scotland this may be a good time to put aside that tiresome boast about "Yankee ingenuity."

If about 170 hours suffice to make a six-inch refractor that is serviceable and satisfactory, what accounts for the 17,000 hours of spare-time work that Robert Louis Waland, a Dumfries aircraft factory employee, gave to this telescope over a period of 11 years? Extras? The answer is yes—two attached star cameras, a drive that was an immense job in itself and a synchronome clock. But mainly it was high standards of design and exquisite workmanship throughout.

Waland began, as is recommended, by making a reflector. On the refractor shown here, which was his next, he was helped by Ellison and Dr. E. A. Baker of the Royal Observatory at Edinburgh and by *Amateur Telescope Making—Advanced.*

The lower part of Waland's telescope pedestal is made of aluminum cast in two



Waland's six-inch refracting telescope with star cameras

ASTRONOMER

parts. The upper part is of steel tubing. These parts and the mounting are blue-gray. The tube and cameras are cream. The upper camera has an $f/4.5$, five-inch photographic doublet lens. The lower one is a 5½-inch Schmidt.

On the right is a two-inch star finder and on the left a little 6× telescope for viewing the illuminated declination circle without leaving the eyepiece; Waland claims he is "lazy"! The eyepiece end has a penta-prism star diagonal and guiding head, hence does not revert the image. Why aren't there more of these?

The synchronome clock shown in the illustration controls an induction motor that runs the drive on the pedestal and this, the job Waland says he is most proud of, cannot here be described for lack of space. He barely mentioned the clock, a type accurate to one second a week, and was asked why. His reply: "It's just an ordinary synchronome I made." He also omitted to mention the optics and was queried: "Where did you buy them?" Reply: "What! And deprive myself of all that pleasure? All optics home-brewed including 11 eyepieces." Perhaps these two full-sized jobs looked minor against a 17,000-hour total.

By accident Dr. Erwin Finlay Freundlich, before Nazi days founder and director of the Einstein Institute ("Einstein Tower") and now at the University of St. Andrews, learned of Waland's telescope. The outcome: Waland is now instrument maker at St. Andrews and is building the University a 30-36-inch Schmidt-Cassegrainian telescope.

Wartime restrictions kept Waland from building an observatory from new materials. But now he has found some second-hand steel and can at last have a private observatory at his new home "Orlington," which is in Priestden Place, St. Andrews, Fife, Scotland.

The remaining description is primarily for telescope makers who wish to study closely the details of this advanced telescope. Waland writes:

"The axes are made from three-inch heavy seamless steel tubing. The design is such that the 1½-inch inner shafts carry no weight, except in the case of the counterweight. The 'bottleneck' is made from solid steel 3½ inches in diameter.

"The lower end of the polar axis has a handwheel for quick motion in right ascension and an hour circle for direct setting. This circle is free to rotate on the polar axis and is set by the hand knob at the top. The time shown by the indicator on the axis housing corresponds to the sidereal time at the moment. The telescope is then rotated on the polar axis until the lower indicator, which rotates with it (being attached to the inner shaft), shows the right ascension of the object.

"The worm-wheel drive is totally enclosed and runs in an oil bath. The second worm-wheel reduction connects to the clock by a driving shaft with universal joint at both ends. The worm wheel is not attached directly to the polar axis but is free to rotate on the latter.

"The polar axis is driven by the worm wheel by way of the right ascension clamp.

Lower end of the polar axis

which can be operated from the eyepiece end of the telescope in any position of observation. The gearing seen between the telescope tube and the declination circle transmits the power. The clamp takes the form of a V-shaped pulley attached to the worm wheel and surrounded completely by a V-ring (like a V-belt on a pulley). The ring is clamped by a screw. This screw is operated by two universal joints and a sliding, keyed shaft. This compensates for the slight lack of alignment and varying distance, which results from the operation of the right ascension slow-motion tangential lever. This lever is

The two axes from below

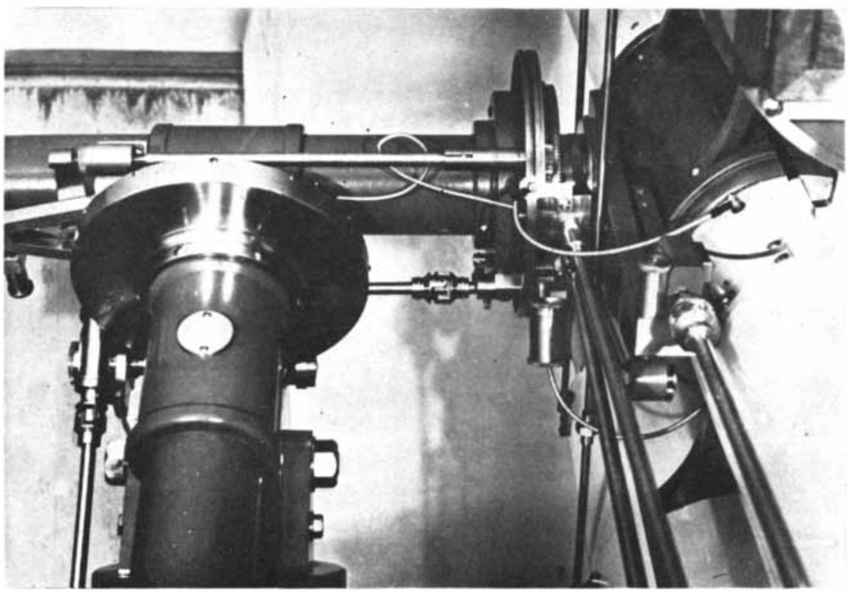
L-shaped and pivoted where the legs meet, and is also operated by a second set of gears beyond the declination circle. The movement is transmitted through the rod which can be seen running parallel to the declination axis. The end of this lever is seen above the worm housing. This screw motion applied by hand is opposed by a powerful spring operating on the other arm of the lever. This cuts out backlash and its evil effects. The same lever is attached to a V-shaped casting seen below which transmits the motion to the declination axis by way of the pivot point of the lever, using the clamp also as a pivot. This imparts a rotation to the polar axis and is quite independent of the clock drive."

THROUGHOUT much of the literature of telescope mirror-making the terms parabola and paraboloid are used interchangeably as if the two were synonymous. Of course nearly everybody understands what is meant, a paraboloid being the two-dimensional surface generated when the one-dimensional curve called a parabola is rotated about its axis. The escape from the alleged crime is that when a mirror is called a parabola its cross section is described.

inch. If the telescope is not on a mounting it can itself be moved a little. The chances are that the average observer does these things unconsciously, but it is instructive to realize what he is doing and why.

COULD a large flat be made by attaching several small flats to a rigid backing and adjusting them to a single plane? Readers who have asked this question will find interest in a report by Professor Arthur Howe Carpenter of La Grange, Ill.

"I made it work," he says. "When I corrected the secondary for my 20½-inch Cassegrainian telescope I needed a flat of the same diameter for use in figuring the secondary. Having three 10-inch flats on



The two axes from above. At right, the telescope tube

What more rightfully rubs the mathematician's whiskers backward is calling the paraboloid a curve. Being two-dimensional, it is a surface. In sum, then:

Parabola: one-dimensional, curve.

Paraboloid: two-dimensional, surface.

WALKDEN of London mentions a wrinkle for observing with his richest-field telescope. In an ordinary straight view where the telescope tube is fixed, as on a mounting, the central 20 degrees of the field may be good and the margins fairly good, until you swivel your eye to get a direct look at them with the central part of the retina. Then they seem strangely dim and also have poor definition.

What you have done, Walkden points out, is to move the crystalline lens of the eye sidewise from the Ramsden circle so only a crescent of the lens and the telescope mirror remain in use. This is because the Ramsden circle is so close to the size of the eye lens; you planned it that way when you designed the telescope.

The wrinkle is simply to compensate this partial eclipse by moving the whole head in the opposite direction an amount which will come to about a seventh of an

hand I silvered them and set them up—the three arranged in triangular fashion—on a heavy, solid backing made of two-by-fours bolted together. Each flat was given its own trio of push-pull adjusting screws. By adjusting first two and then all three flats I brought the star images into coincidence. This was a tedious job. I was helped by a very small defect in the pinhole and later when the secondary was figured I could see that same defect very perfectly with a good eyepiece. It looked exactly as it had by direct inspection with a pocket magnifier.

"Next the convex secondary was mounted in place and tested and corrected in the usual manner.

"Actually the three flats probably did not lie in precisely the same plane, but they did lie in parallel planes, which was as good."

In similar experiments Russell Porter once brought three small flats into a single plane by screw adjustment. "The screws," he says, "were not even delicate, just plain machine screws. By placing a large flat over the three smaller ones it took only a few minutes to contact them with the large one, same color over all three."

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful. The lists are not intended as bibliographies of source material for the articles. The references selected will provide supplementary information.

THE RECOVERY OF EUROPE

A SURVEY OF THE ECONOMIC SITUATION AND PROSPECTS OF EUROPE. Research and Planning Division, Economic Commission for Europe. United Nations Publications, 1948. Columbia University Press, agent.

NETWORKS OF WORLD TRADE. League of Nations, 1942.

REPORT OF THE COMMITTEE OF EUROPEAN ECONOMIC COÖPERATION. U. S. Department of State, 1948.

OUTLINE OF THE EUROPEAN RECOVERY PROGRAM. U. S. Department of State, 1948.

ANTIQUITY OF MODERN MAN

THE ANTIQUITY OF MAN. Sir Arthur Keith. Lippincott, 1938.

WHO WERE OUR ANCESTORS? Loren C. Eiseley in SCIENTIFIC AMERICAN, May, 1943.

MANKIND SO FAR. W. W. Howells. Doubleday, Doran, 1947.

MAN RISES TO PARNASSUS. Henry F. Osborn. Princeton University Press, 1927.

GALAXIES IN FLIGHT

BIRTH AND DEATH OF THE SUN, Chapter 12. George Gamow. Macmillan, 1941.

THE SOLAR SYSTEM AND ITS ORIGIN, Section I. Henry Norris Russell. Macmillan. 1935.

THE EXPANDING UNIVERSE. Sir Arthur Eddington. Macmillan, 1933.

THE REALM OF THE NEBULAE. Edwin Hubble. Yale University Press, 1936.

ALLERGY

WHAT'S YOUR ALLERGY? Lawrence Farmer and George Hexter. Random House, 1939.

ALLERGY IN THEORY AND PRACTICE. R. A. Cooke. Saunders, 1947.

BRENNEMAN'S PRACTICE OF PEDIATRICS, Vol. II, Allergic Diseases. Bela Schick and Murray Peshkin. Prior, 1945.

PHYSICS AND MUSIC

THE PHYSICS OF MUSIC. Alexander Wood. Methuen, 1947.

SOUND WAVES: THEIR SHAPE AND SPEED. D. C. Miller. Macmillan, 1937.

THE PSYCHOLOGY OF MUSIC. C. E. Seashore. McGraw-Hill, 1938.

THE ACOUSTICS OF MUSIC. W. T. Bartholomew. Prentice Hall, 1942.

VISIBLE SPEECH. R. K. Potter and others. Van Nostrand, 1948.

INSECT VISION

BUTTERFLY VISION. H. Eltringham in *Transactions, Entomological Society of London*, pages 1-49. 1919.

THE ORIENTATION OF ANIMALS. G. S. Fraenkel and D. L. Gunn. Clarendon Press, 1940.

THE OPTICS OF THE INSECT EYE. C. J. van der Horst in *Acta Zoologica*, Vol. 14, No. 1, pages 101-109, 1933.

INSECTS AND THE SPECTRUM. H. B. Weiss in *Journal of the New York Entomological Society*, Vol. 54, pages 17-30, 1946.

AN ANALYSIS OF THE VISUAL CAPACITY OF THE BEE'S EYE. E. Wolf in *Cold Spring Harbor Symposia on Quantitative Biology*, Vol. 3, pages 255-260, 1932.

THE BEGINNINGS OF COAL

THE NATURE AND ORIGIN OF COAL AND COAL SEAMS. A. Raistrick and C. E. Marshall. English Universities Press, 1939.

LEAVES AND STEMS FROM FOSSIL FORESTS. Raymond E. Janssen. Popular Science Series, Illinois State Museum. 1939.

PLANT LIFE THROUGH THE AGES. Albert Seward. Macmillan, 1931.

FORMATION OF COAL BEDS. J. J. Stevenson. New Era Printing Company, 1913.

PLANTS OF THE PAST. F. H. Knowlton. Princeton University Press, 1927.

THE PHILIPS AIR ENGINE

THE PHILIPS ENGINE. *The Engineer*, December 12 and 19, 1947.

THERMODYNAMICS APPLIED TO HEAT ENGINES. E. H. Lewitt. Pitman, 1943.

THE PHILIPS AIR ENGINE. H. De Brey and F. L. Van Weenen in *Automotive Industries*, December, 1947.

A TEXT BOOK OF GAS, OIL AND AIR ENGINES, Part III. Bryan Donkin. Griffin, 1911.

AIR ENGINES. H. Rinia and F. K. Du Pre in *Philips Technical Review*, May, 1946.

BOOKS

SIR ISAAC NEWTON'S MATHEMATICAL PRINCIPLES OF NATURAL PHILOSOPHY AND HIS SYSTEM OF THE WORLD. Translated by Andrew Motte; revised by Florian Cajori. University of California Press, 1934.

OPTICKS—OR A TREATISE OF THE REFLECTIONS, REFRACTIONS, INFLECTIONS AND COLOURS OF LIGHT. Isaac Newton. Reprinted from the Fourth Edition with an introduction by Albert Einstein. Bell, 1931.

ISAAC NEWTON. L. T. More. Scribners, 1934.

ISAAC NEWTON. J. W. N. Sullivan. Macmillan, 1938.

THE LIFE OF ISAAC NEWTON. David Brewster. Harper Brothers, 1843.

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