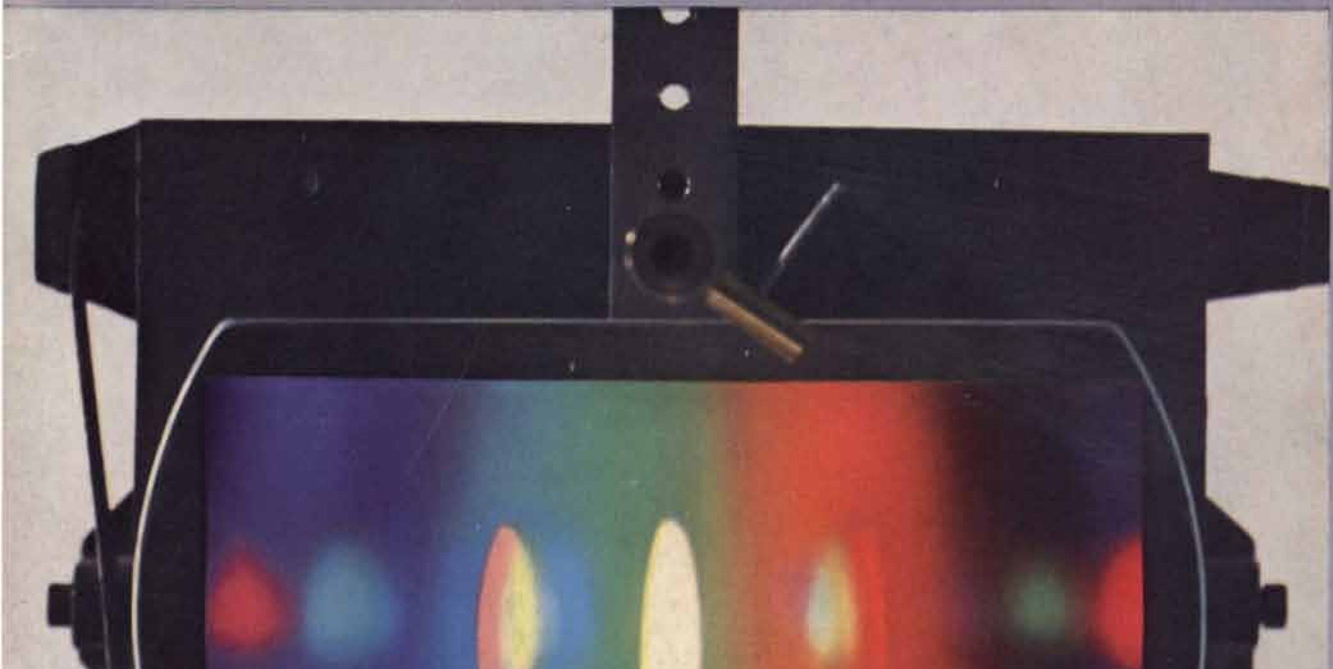
SCIENTIFIC AMERICAN



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June 1952

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Chinese jar, Ming dynasty.
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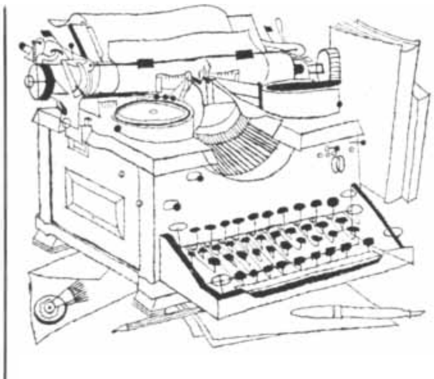

LETTERS

Sirs:

It is unfortunate that the really beautiful and vivid high-speed telephoto movies of birds in natural color taken by John H. Storer (author of "Bird Aerodynamics" in your April number), do not lend themselves to display through the medium of your magazine. The writer has personally derived considerable inspiration from viewing those movies on several occasions.

It is with respect to the function of the primary feathers that this letter is written. The writer believes that there is no real evidence available to prove the speculation of Storer that the primaries act as propellers. If the primaries were absolutely necessary to propulsion then certain classes of ornithopters would not be capable of flight, namely bats and insects. If we assume that the same physical laws that govern the flapping flight of insects and bats govern that of birds, we cannot conclude that primary feathers are necessary to provide the propulsive forces necessary for overcoming the drag of the bird. Absolute proof of whether primaries are necessary to bird flight could easily be obtained from an experiment in which these feathers are removed from a bird. If the bird cannot fly without these "propellers," Storer's theory is correct and another theory will be needed for bat and insect flight.

However, there is a theory that covers the flapping flight in general which shows that lift and propulsion can be obtained simultaneously on plain airfoils. Dr. Erik von Holst of the Wilhelmshaven Marine Biological Laboratories has shown experimentally that a flapping wing having a non-sinusoidal motion can provide both lift and propulsion even when perfectly flat plates are used as wings. (The insects prove this fact in nature.)

If the primaries are not needed as propellers, what is their function? In a paper "Performance Measurements of a Soaring Bird" in the *Aeronautical Engineering Review,* December, 1950, I offer some experimental evidence that the primaries act as a slotted diffuser tip capable of reducing the drag resulting from lift, the so-called induced drag. This theory on the function of the primaries is supported to some extent by the fact that high aspect-ratio sea birds have a pointed wing tip whereas the land soaring birds, which must land in trees, and therefore need short low-aspect-ratio wings, have slotted tips. The slotted tip makes up for the smaller aspect ratio.

The explanation of bird flight is not a simple one. It will require the efforts of many ardent students of nature such as Storer before we arrive at the true facts. Perhaps Storer by his article in your magazine will inspire other students (as he did me) to approach this intriguing problem.

AUGUST RASPET

Mississippi State College
State College, Miss.

Sirs:

In his interesting article on Logic Machines (*Scientific American,* March) Martin Gardner refers to Allan Marquand as "another British logician." In fact Marquand was at one time a Fellow of Johns Hopkins, and he built his logic machine at Princeton. The machine was made, he says, "from the wood of a red-cedar post which once formed part of the enclosure of Princeton's oldest homestead."

In *Dictionary of Philosophy and Psychology* we are informed that Marquand had designs made "by which the same operations could be accomplished by electro-magnets." It may well be that Marquand also anticipated the use of

Scientific American. June, 1952, Vol. 186, No. 6. Published monthly by Scientific American, Inc., 2 West 45th Street, New York 36, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York, N. Y., Post Office as second-class matter June 28, 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 2 West 45th Street, New York 36, 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 Manager, SCIENTIFIC AMERICAN, 2 West 45th Street, New York 36, N. Y.

Subscription correspondence should be addressed to Circulation Manager, SCIENTIFIC AMERICAN, 2 West 45th Street, New York 36, N. Y.

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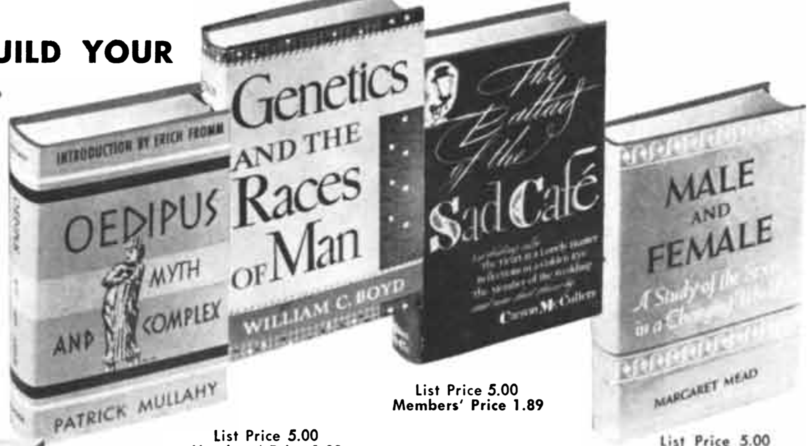

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W. MAYS

University of Manchester
Manchester, England

Sirs:

I was delighted to find Joshua Whatmough's article "Natural Selection in Language" in your April issue—apparently the first time statistical language analysis was presented to the general reader. However, the two examples chosen by Dr. Whatmough to show the application of this technique to modern English are quite unfortunate: both predictions are clearly wrong.

In the first example, one of the author's students, Robert Abernathy, is quoted as having calculated that strong verb-forms will have disappeared from English by about 2850. Mr. Abernathy did not consider the influence of public education and general literacy on such language trends; these factors tend to "freeze" linguistic forms and slow down or stop long-time trends (see my *The Art of Plain Talk*. It is therefore improbable that by 2850 we will say "seed," "speaked," or "readed."

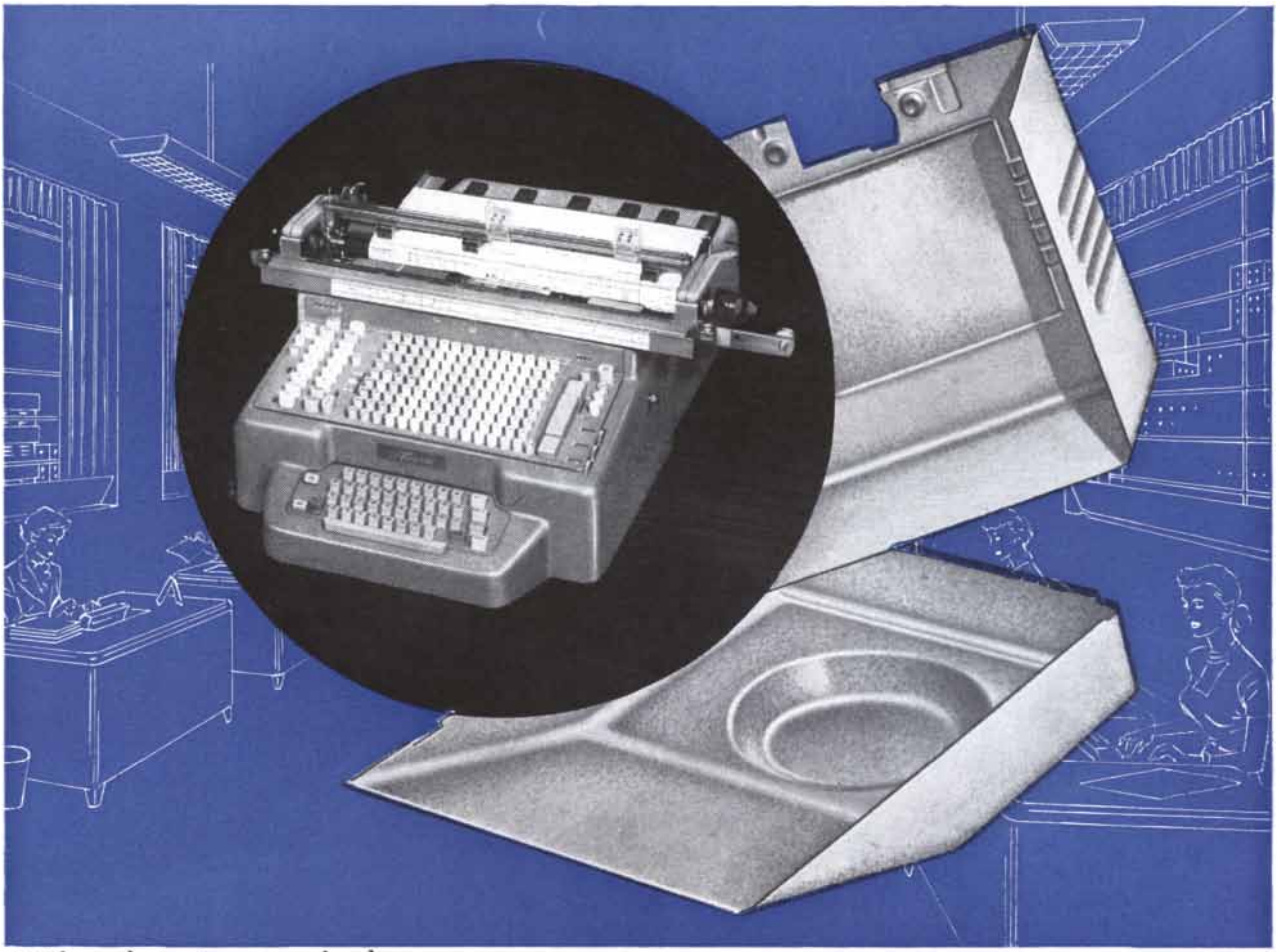
In the second example, another of the author's students, Leonard Opdycke, Jr., is reported to have observed a recent increase of compounds of the type "better-than-leather-miracle-covering." The inference is drawn that compound words are gaining in popularity—meaning, by implication, hyphenated compounds. The facts are otherwise: the present trend is clearly toward an increase of *open* rather than hyphenated compounds; typical examples are "atom bomb," "wire recorder," "cancer research." (See *American Punctuation*, by George Summey, Jr.)

RUDOLF FLESCH

Dobbs Ferry, N. Y.

Sirs:

Ever since the days of Varro, who died in 27 B.C., the trite assertion of the influence of the written form, of the schoolmaster, and of literacy, to stem linguistic evolution, has been invoked in all the textbooks, and all in vain. Not even the Pope talks like Cicero or Varro. Modern Americans have the greatest percentage of literacy, and send a higher percentage of youths to high school and college than any country in the world; yet millions of them, whatever they may write, actually use *I says, I gives, I shoots, says I, says who* just as they say *thrived, lied, shrinked, slinged, heaved, sheared, weighed, sweared*. What is truly quite unfortunate is that neither Rudolf Flesch nor I shall



(or is it *will?*) be alive in 2850 to hear all the weak verbs.

As for devices of printing, they make no difference: "better than leather miracle covering" is pronounced the same, hyphens or not. Meaning controls utterance (*e.g.*, pauses) and therefore punctuation; punctuation, therefore, is used to distinguish ambiguous or conflicting meaning; but it is the merest pedantry to suppose that punctuation controls meaning. The hyphen helps the eye, which is less accustomed than the ear to the new compound. Already *wire-recorder* (as one word) is appearing in advertising, exactly like *milkman, jailbird, horsefly, firehouse.* What learning and printing do is to preserve archaic variants in single words; there is not one example on record of an entire grammatical category that they have ever frozen into a living spoken language.

JOSHUA WHATMOUGH

Harvard University
Cambridge, Mass.

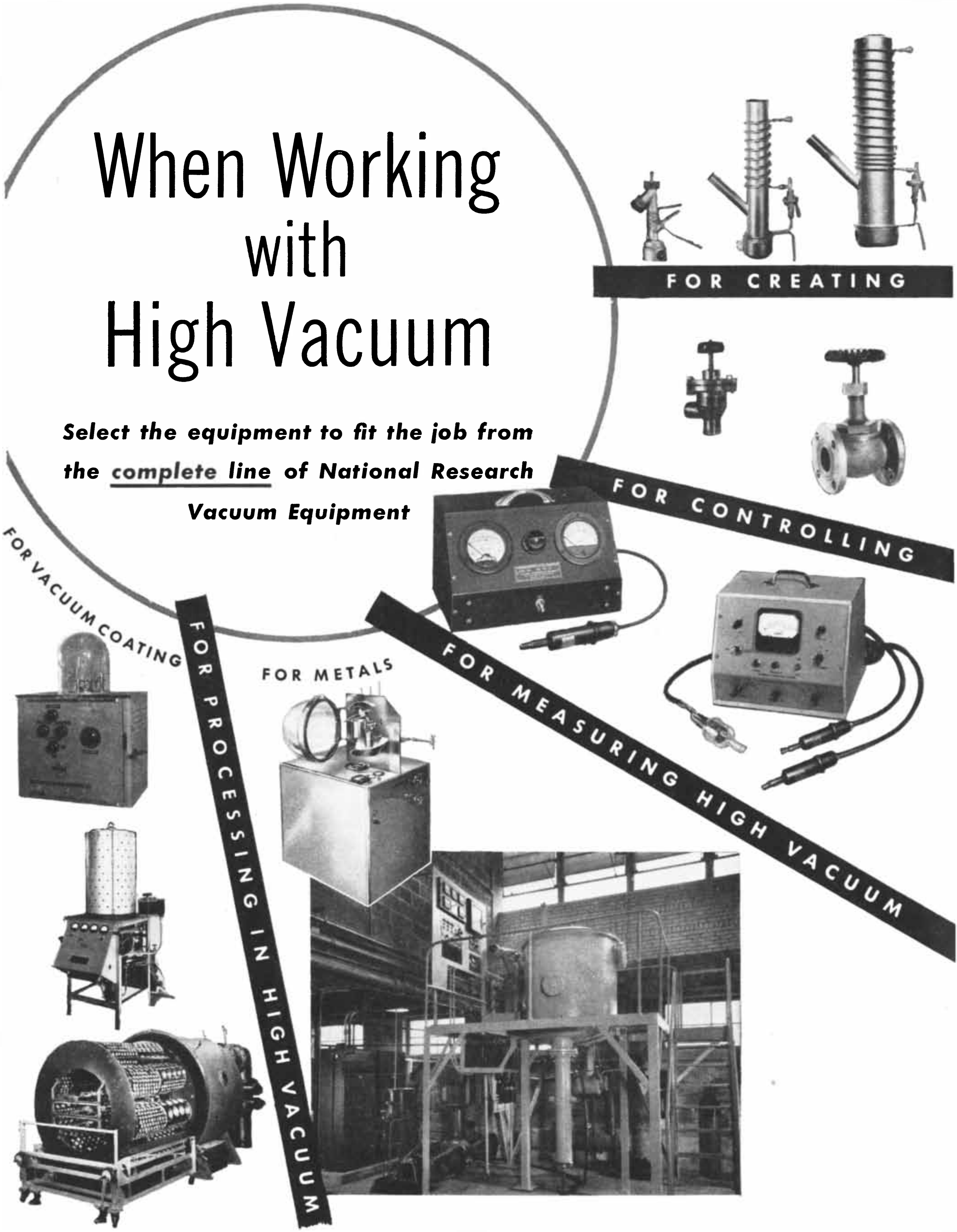
Sirs:

How often our lazy natures get the better of us and force us into postponements we later regret! A year ago I had the good fortune to receive a trial issue of *Scientific American,* which led to my immediate subscription. Each month I was impressed anew not only by your magazine's content, but also by its layout and particularly by the magnificent integration of art and science achieved in its cover designs. With each succeeding issue I determined to express my appreciation of this latter achievement by letter. Now, with your April issue, comes word of the death at 33 of your art director, K. Chester. Any words of praise expressed now must necessarily be robbed of all meaning to the man who deserves them so richly, but I feel bound to pay this belated tribute.

Early training in the preliminary phases of science, and later and fuller training and practice in modern architecture, have led me to the same realization and appreciation of the close relationship between science and art which K. Chester felt and demonstrated so keenly in the work he accomplished for *Scientific American.* Modern architecture has proven such an admirable common meeting ground for the practical demands of science and the aesthetic demands of art that it has developed in me a sense of search and discovery of the same relationships in other fields. K. Chester obviously found such a field, and the past four years of *Scientific American* will stand as a lasting tribute to his success and ability.

ROBERT DARLINGTON

Park Forest, Ill.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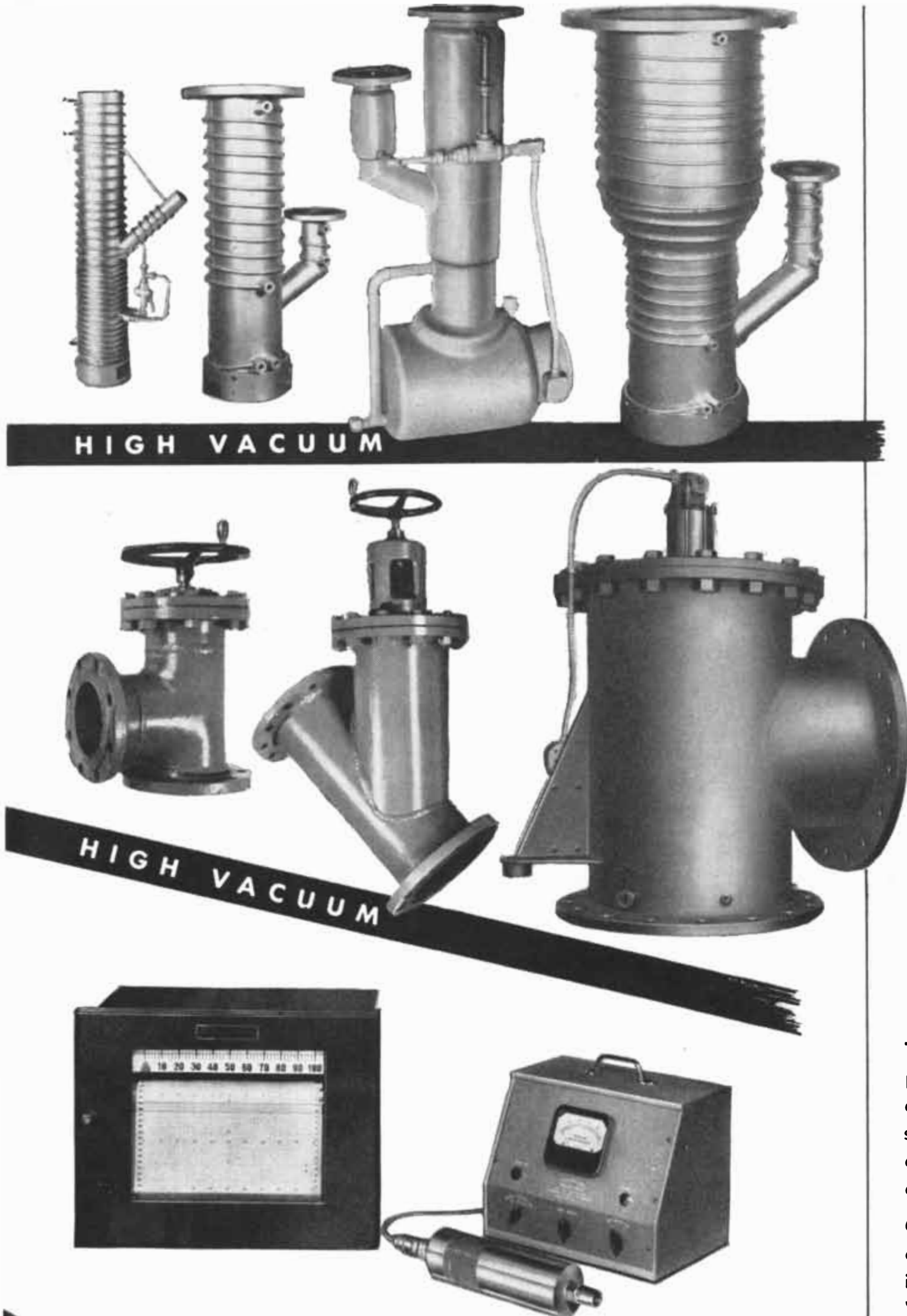

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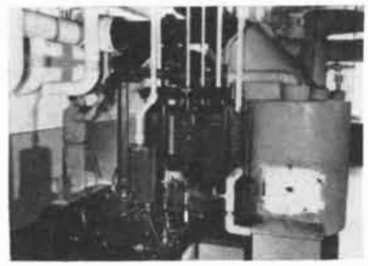

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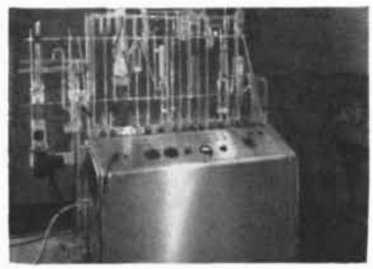

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50 AND 100 YEARS AGO

JUNE, 1902. "On Friday, March 7, Henri Becquerel delivered a discourse before the members of the Royal Institution concerning his researches in radioactivity. 'Toward the end of the year 1899,' he said, 'M. Giesel, and then M. Meyer and M. Schweidler, observed that the rays of radioactive preparations were deviated by a magnetic field in the same manner as are the cathodic rays. I observed the same phenomenon with radium. Very shortly afterward I observed that the rays from polonium are not deviated, and consequently that two kinds of rays exist. In fact there does exist a third kind of rays which are not deviable, but are extremely penetrating. Thus the activity of radioactive bodies comprises three kinds of rays—rays which are deviable in a magnetic field, which appear to be identical with cathodic rays, and two sorts of non-deviable rays, one kind being very easily absorbed, the other resembling X-rays and being very penetrating. Uranium emits principally the first kind, polonium gives only the second, and radium gives all three at once. As to the deviable rays; the material theory of Sir William Crookes and Mr. J. J. Thomson can be applied to them, and the consequences can be verified with the greatest facility. Experiments leave little doubt as to the identity of the deviable rays with cathodic rays. However, it was necessary to prove that they carry charges of negative electricity, and that they are deviated by an electric field. M. and Mme. Curie, in a beautiful experiment, have shown that the rays of radium charge negatively the bodies that receive them, and that the source becomes charged positively. For my part, I have shown and measured the electrostatic deviation by projecting the deviated shadow of a screen placed perpendicular to the field, on a photographic plate. I obtained figures for the velocity and for the ratio of charge-to-mass which are entirely of the same order in value as those which came from the measurements made with cathodic rays, and the theoretical considerations with regard to Zeeman's experiment. The proof of a regular variation in the calculated ratio of charge-to-mass is of considerable theoretical importance; if this relation was constant, as it seemed to be as the result of a large number of measurements, we might conclude that the slightly deviable rays have speeds considerably greater than that of light. On the other hand, theoretical considerations have given the idea that the speed could not surpass that of the propagation of electromagnetic disturbances, that is to say, the speed of light, and we have been led to consider the mobile masses in a magnetic field as endowed with a particular inertia which is a function of the speed. Under these conditions the calculated mass ought to be apparent, or at least partly so, and it should increase indefinitely as the actual speed approaches that of light. The figures published by M. Kaufmann bear out this hypothesis.' "

"In an article entitled 'Aepinus Atomized,' Lord Kelvin sketches a system in which the single fluid of Aepinus consists of exceedingly minute equal and similar atoms, which he calls 'electrons,' much smaller than the atoms of ponderable matter. These permeate freely through the spaces occupied by ordinary atoms and also freely through space not occupied by them. As in Aepinus' theory, there are repulsions between the electrons, and repulsions between the atoms independently of the electrons, and attractions between electrons and atoms without electrons."

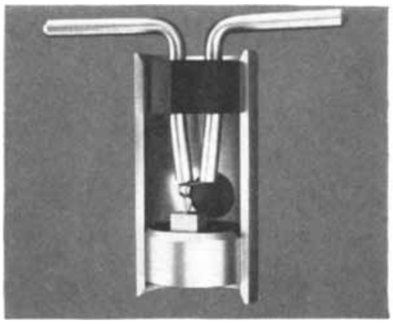
"A very novel idea has just been produced by Mr. Clarence M. Stiner, of New York City. He has designed a hairbrush for use in public places which at any time may be operated at a nominal expense to present a fresh, clean set of bristles for the user. The bristles are radially attached to hubs forming wheels, and the wheels are connected by a gearing. On the handle portion of the hairbrush is a mechanism for rotating the brush wheels. This mechanism can be started only on the insertion of a coin."

"It is gratifying to note that the international canal question is finally to be settled in a way that we have contended is the only practical one, that is in favor of the short Panama route—a route also favored by the Isthmian Canal Commission. The Senate on the 19th instant passed the Panama Canal bill by a vote of 67 in favor to 6 against."

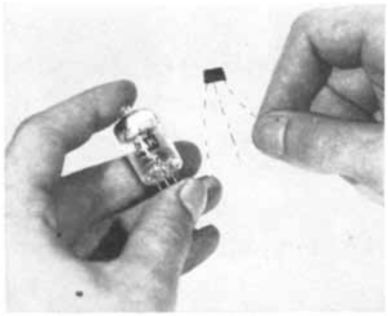
JUNE, 1852. "In many cases fumigation is essential to promote health, by the destruction of pestilential effluvia. That this can be done is a blessing for which we all should be grateful.

THE TRANSISTOR

A picture report of progress



FIRST TRANSISTORS were of this point contact type (picture three times life size). Current is amplified as it flows between wires through a wafer of germanium metal. These transistors are now being made at the Allentown plant of Western Electric, manufacturing unit of the Bell System. They will be used in a new selector which finds the best routes for calls in Long Distance dialing.



NEW JUNCTION TRANSISTORS, still experimental, also use germanium but have no point contacts. Current is amplified as it flows through germanium "sandwich" —an electron-poor layer of the metal between two electron-rich ends. This new transistor runs on as little as *one-millionth* of the power of small vacuum tubes.

MUCH HAD TO BE LEARNED, especially about the surface of germanium and the effect of one part in a million of alloying materials. Transistors promise many uses—as amplifiers, oscillators, modulators . . . for Local and Long Distance switching . . . to count electrical pulses.

ASSEMBLY PROBLEMS, such as fixing hair-thin wires to barely visible germanium wafers, have been solved through new tools and mechanized techniques. Finished transistors withstand great vibration and shock. Engineers see many opportunities for these rugged devices in national defense.

MOIST PAPER AND COIN generate enough current to drive audio oscillator using junction transistors. Half as big as a penny matchbox, an experimental two-stage transistor amplifier does the work of miniature-tube amplifiers ten times larger.

A tiny amplifying device first announced by Bell Telephone Laboratories in 1948 is about to appear as a versatile element in telephony.

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and especially since it can be done in a very simple manner. During the hot season it may be necessary to fumigate some buildings, and to do this the whole principle should be well understood. The only efficacious kinds of fumigation are by means of gases which decompose the miasmata or fumes and convert them into innocuous compounds; such gases are sulphurous acid, muriatic acid, nitrous acid, and chlorine; the last named, either in its free state or in combination with lime, or soda, being incomparably the most convenient, efficacious, and powerful."

"The observatory at Greenwich, England, is fairly placed in connection with the electric wires, by an arrangement with the Southeastern Railway. Instantaneous astronomical observations may be now undertaken in remote sections, clocks be regulated by national time, differences of longitude be ascertained with exact promptitude; and, by means of the submarine telegraph, European skill may be connected with the efforts of British science. Wires may soon be carried over the Rhine and the Elbe, to connect with Calais, Dover, London; perhaps thence to America. Who knows what is to be?"

"We do not know what will have to be done with all the comets and planets. Every few weeks we hear of a new comet being discovered, and no later than the 29th ult., Prof. Bond, of Cambridge, Mass., discovered another. In the early part of April it approached close to the earth's orbit. It goes at a tremendous speed, running through 100 degrees of right ascension in 24 hours. Two small planets, 'Irene' and 'Eunomia,' were discovered last year."

"The following is a cure for hydrophobia given by a gentleman in a French paper, of which he says: 'I have used it in 20 cases, and always with entire success.' This entitles the thing to an experiment; and, certainly, there are enough *outre* ingredients in the compound to ensure a chance of efficacy among some of them. Here is the recipe: Wash the wound, while recent, and the adjoining parts with cow's milk, boiled hot, daily, for nine days; for the same length of time, each morning before breakfast, drink a tumbler of the following potion, lukewarm: root of angeline, 30 grams; root of gentian, 30 grams; Venetian theriac, 30 grams; asafoetida, 'well crushed,' 15 grams; oyster shell, 15 grams; root of the sweet briar, 40 grams; scorzonera, the root unpeeled, 40 grams; rue, fresh stems, a good handful; sage, cut up finely; marine salt, 20 grams; a head of garlic, crushed; three heads of leeks, with their leaves; two small onions; a few spring daisies."

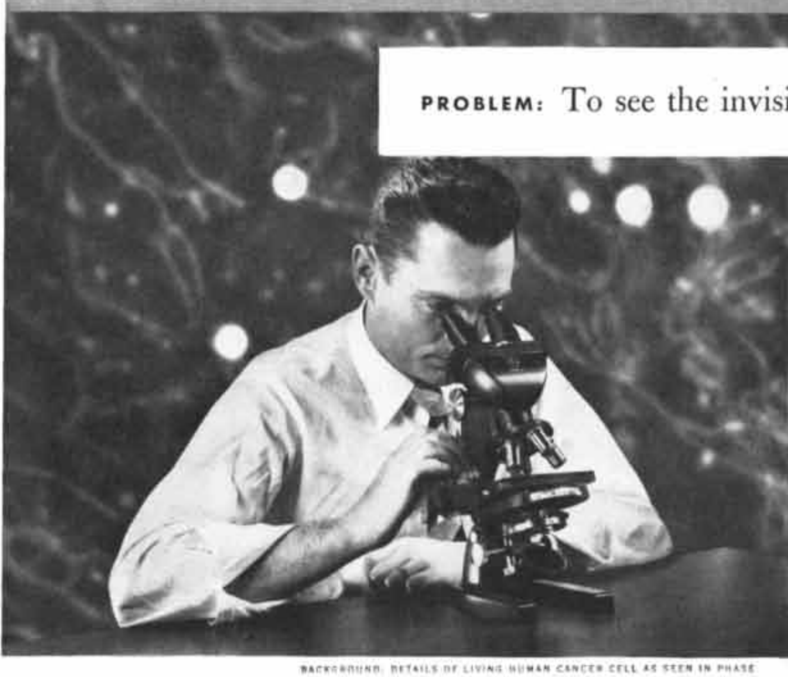
PROBLEM: To enlarge TV but not the fuzz

ANSWER: Radio Corporation of America and General Precision Laboratory both needed new, highly specialized optical systems to enlarge TV images from 7-inch tubes to 20-foot theatre screens without distortion. American Optical scientists transformed intricate formulae into *quantity production* units of precision reflecting mirrors and corrector lenses. Now theatre owners can afford equipment that gives sharp, full-screen television pictures with real box-office appeal.

PROBLEM: Are dark sun glasses better than light?

ANSWER: Not necessarily. Some dark lenses admit dangerous rays, distort what you see, even cause nausea. AO research shows the best sun-glass lens must absorb ultraviolet and infrared, let you see colors clearly, be precision ground to eliminate tiny defects. This kind of protection, in AO Cosmetan Calobar Sun Glasses, is available through the ophthalmic professions.

PROBLEM: To see the invisible



BACKGROUND: DETAILS OF LIVING HUMAN CANCER CELL AS SEEN IN PHASE MICROSCOPE PHOTO COURTESY DR. G. O. GEY, JOHNS HOPKINS HOSPITAL.

ANSWER: What does a living human cancer cell look like? Or clear plastic? Or a rayon filament? Details in such transparent objects are almost invisible under ordinary bright-light microscopes. With AO's *phase microscope,* it is now possible to see, in sharp detail, things only imagined before. Write us about your development problems. Address American Optical Co., 34 Vision Park, Southbridge, Mass.

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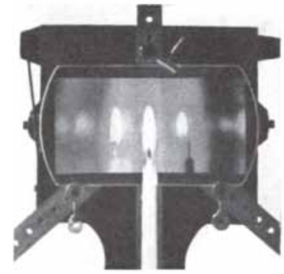

THE COVER

The photograph on the cover shows a 5⅛-inch diffraction grating on a test stand (*see page 45*). In front of the grating is a candle. On the surface of the grating to the left and right are the spectral images of the candle flame. The grating was made in the Department of Physics of the Johns Hopkins University.

THE ILLUSTRATIONS

Cover by Fernand Bourges

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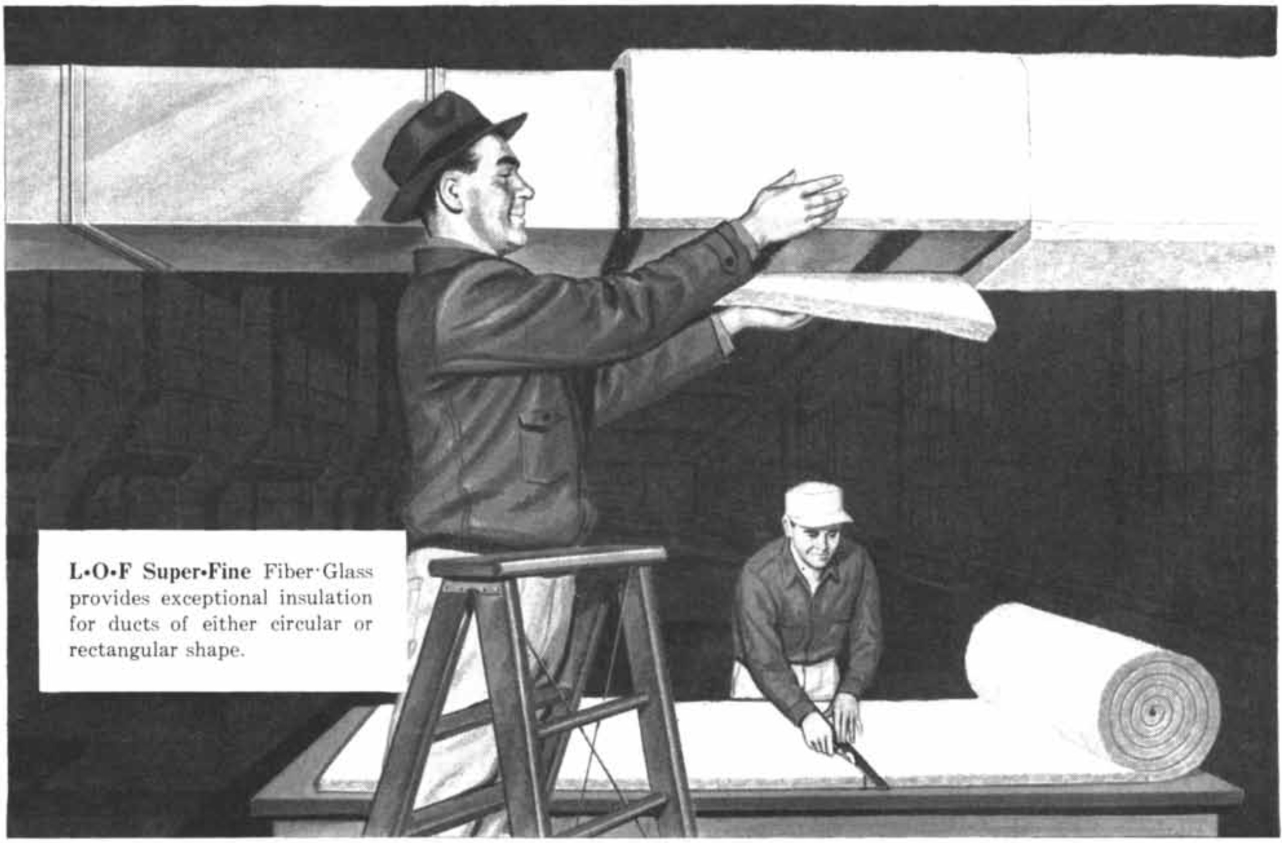

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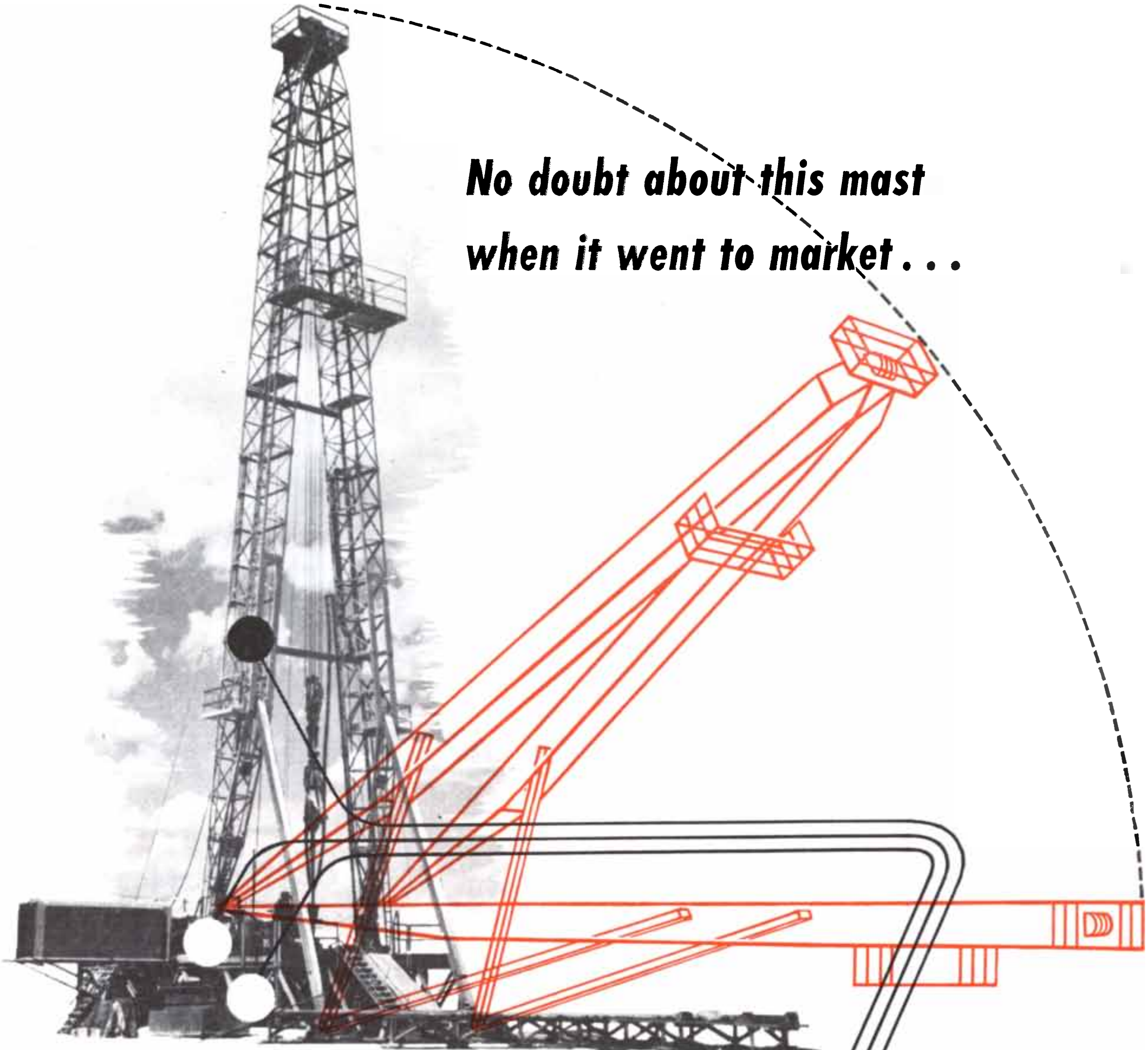

Raising a 35-ton mast of structural steel from horizontal to full vertical position is a problem in itself. Being certain that, once raised, the 143-ft.-high structure is able to support the tremendous weight of a string of drill pipe is still another problem. Add to these requirements the ability of the mast to be skidded across oil-field terrain, and you have a structural engineer's nightmare.

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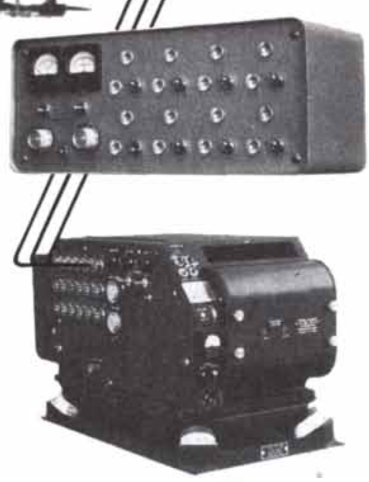

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SCIENTIFIC AMERICAN
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CONTENTS FOR JUNE, 1952

VOL. 186, NO. 6

ARTICLES

DEPARTMENTS

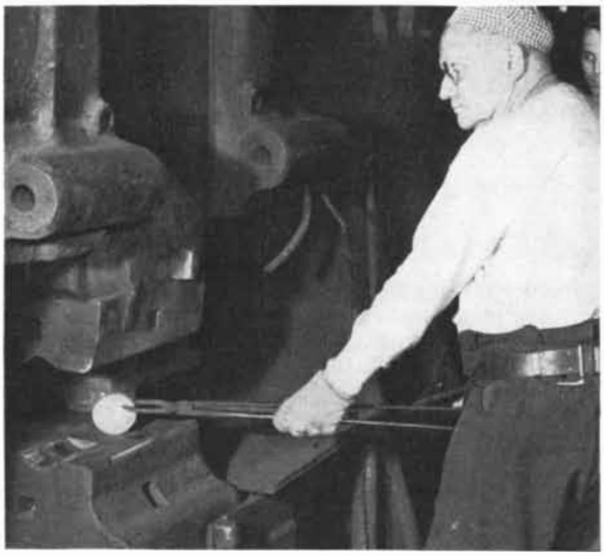
What's Happening at CRUCIBLE

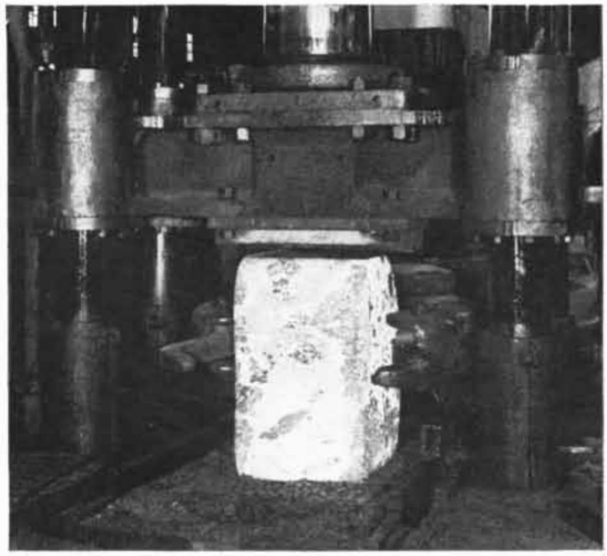
about tool steel forgings

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

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

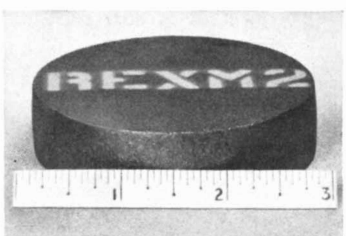
These forgings are good examples of Crucible specialists at work:

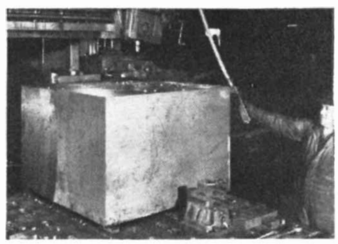




Rex M-2 High Speed Steel Disc Forging (1½ pounds)

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





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

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

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SCIENTIFIC AMERICAN
JUNE, 1952 VOL. 186, NO. 6

THE USES OF FISSION PRODUCTS

The radioactive "ashes" of the reactors that make plutonium are potentially a valuable source of radiant energy. A recent study summarizes the ways in which they could be put to work

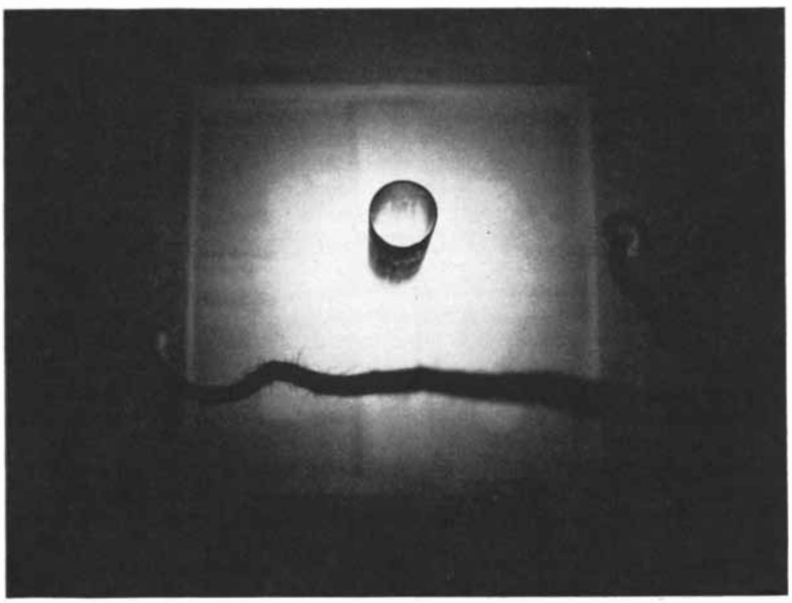
by Paul J. Lovewell

A GRAM of radium, with one curie of radioactivity, is worth $15,000 to $20,000. In the waste-tanks of the Hanford plutonium works lie millions of gallons of radioactive material, representing millions of curies, and day by day this vast store of potentially valuable radiant energy continues to pile up uselessly. Indeed, up to now it has been worse than useless: its disposal has been a headache.

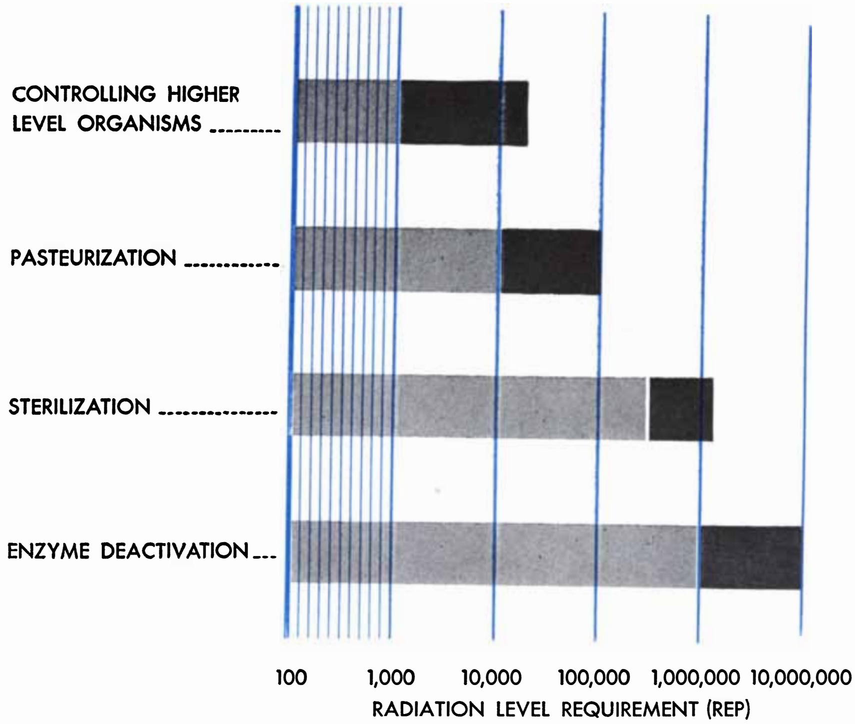
The problem of how to turn this dangerous liability into a national asset has occupied the time and thought of a great many atomic energy workers during the past few years. From the outset one of the chief aims has been to find ways to put it to work in industry. The chief questions are: What could it do, and how could it be harnessed safely? To these questions we now have some carefully studied answers. This article will report some of the findings of the most comprehensive analysis made to date—a survey carried out recently by the Stanford Research Institute for the Atomic Energy Commission with the aid and consultation of scores of scientists and engineers in universities and in industry.

Before discussing the industrial possibilities, we need to consider the nature of this strange, potent material that it is proposed to introduce into U. S. industry. It consists of the fission products formed as by-products of the operation of an atomic pile. When uranium 235 atoms split, they break down into a number of different medium-weight elements—iodine, barium, strontium, zirconium, cesium, cerium and so on. These radioactive fission products must be removed from the pile from time to time, because they act as ashes smothering the chain reaction. After being separated chemically from uranium and plutonium, the fission products are left mixed together in solution. For some industrial purposes this mixture, partly refined, could be used, but for many applications it will probably be necessary to extract individual elements.

The radioactive fission products emit gamma and beta rays. The uses to which such radiations may be put are varied: they can kill bacteria, make "X-ray" pictures of metals, measure thicknesses, trigger chemical reactions, speed the travel of a flame, ionize air, and perform a host of other functions. An X-ray machine or radium



THOUSAND-CURIE SOURCE of radioactive tantalum glows on the bottom of a water-filled canal at Brookhaven National Laboratory. This source was made in Brookhaven reactor for industrial experimentation.



BIOLOGICAL USES of fission products have various radiation requirements. The dark section at the end of each bar indicates maximum and minimum. The radiation units are roentgens equivalent physical (REP).

or radioisotopes made by irradiating materials inserted into a pile can do the same things, but the great importance of the fission products is that they make radioactivity available on a vastly larger scale and at much lower cost.

JUST how much fission products would cost is hard to determine, because we do not yet know on what terms the atomic energy enterprise would provide them or how expensive it would be to process them. But some of the best engineering opinion places the probable cost in the range of a few cents to a few dollars per curie. At such prices the use of radioactivity would become feasible for a very wide range of industrial purposes. Some of the more attractive possibilities are:

Sterilization. Radioactivity might have a very large field in processing foods and drugs. Heat, the treatment now generally used to kill bacteria and preserve food, destroys some of the nutrients and changes the flavor. With radioactivity food-processors could sterilize food without heat. The food would be exposed after packaging to radioactive material (a mixture of fission products would do) in an enclosed, shielded space. There would be no danger of the food becoming radioactive, because the gamma and beta emissions from fission products do not induce radioactivity. The penetrating gamma radiation would kill all organisms in the food, and no bacteria could get into the sealed package. Thus some foods that now need to be refrigerated after packaging could be kept at room temperature. Radioactivity could also be used to sterilize the surface of fresh foods that are not treated at all now, such as tomatoes, apples, oranges, melons, grapes and eggs. A relatively rapid treatment of the surface, where the organisms could be killed even by the non-penetrating beta rays, would prolong the shelf life of these foods and reduce the need for refrigeration.

In the case of certain drugs, the use of heat for sterilization is out of the question, for heat destroys their properties. Consequently such medicinals as the antibiotics, blood fractions, surgical dressings and vaccines now have to be prepared and handled by very costly aseptic techniques. Cold sterilization with fission products would make all these products much easier to handle and insure 100 per cent sterility.

The radioactive sterilization of foods would have commercial possibilities if fission products were available at a few cents per curie, and for drugs it would be feasible at up to $2 per curie.

Radiography. The inspection of metals for internal flaws is another important job for penetrating radiation. Its value to industry is already so well recognized that X-rays, radium or radiocobalt are commonly used to inspect castings and assembled machinery. Fission products, notably such gamma-emitters as cesium 137, could do the same job at lower cost. Even at a price of $5 to $50 per curie radiography could feasibly be extended to inspection of a wide range of industrial materials, opening a demand for hundreds of thousands of curies. This could mean better, safer, lighter, stronger or cheaper metals and metal articles.

Luminescence. Phosphorescent paints that glow in the dark all depend upon radiant energy. They are now expensive, because they are made with radium or radioisotopes. A fission product such as strontium 90, even at $50 per curie, would bring down the cost substantially. If luminescent markers were really cheap, a wide market might open up: *e.g.*, for exit signs in theatres, advertising displays, highway markers, cellar stairways, and so forth.

Static Elimination. Static electricity is a hazard or a nuisance in many industrial processes. In printing, for example, charges build up on sheets of paper, causing them to stick together or repel each other. One way to prevent the build-up of static charges on objects is to ionize the air around them; ionized air, being a good conductor, takes off the electricity as fast as it forms. Static eliminators containing radium or polonium are now on the market, but here again fission products, such as strontium 90, offer a cheaper substitute.

Measurement. By passing radiation through a layer of material whose absorbing qualities are known, and measuring the amount of absorption, the thickness of the layer can be determined. Thickness gauges which operate on this principle have already been built. Fission products in laboratory amounts are finding a market in instruments of this kind even at prices of $100 per curie.

Chemistry. In the chemical industry radioactivity may make possible completely new products. Beta and gamma radiations break up molecules into reactive fractions which can form new molecules that could not otherwise be synthesized.

Combustion. Since flames are propagated by the interaction of ions, fission products, by virtue of their ionizing ability, can speed up or control burning processes. This could lead to significant improvements in jet and internal combustion engines.

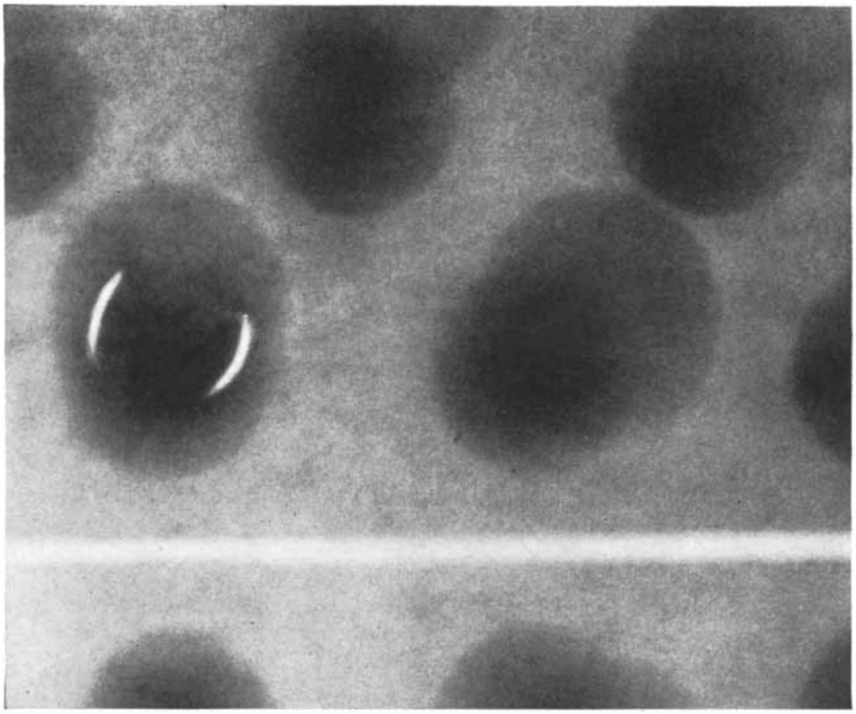
Power. A radioactive material can generate small amounts of electrical power. If a pure beta emitter is placed on an insulating post in an evacuated tube, it will build up to a high positive voltage as it loses beta particles (electrons), and the voltage may be tapped for power. Although the power that can practicably be obtained in this way is small (up to one watt), such a unit can go on generating for years without refueling or maintenance. One possible use for a generator of this kind is to power instruments, such as weather recorders, that could be left in remote locations.

Various other more speculative possibilities for the use of radioactivity have been considered. It might be employed to control and stimulate the fermentation process in converting grain starches to alcohol, to prevent fermentation in drilling muds, to control weevils and other insect pests in stored seeds and grain, to stop insect contamination of packaged flour, to protect underground cables against fungi that destroy the insulation and to guard instruments against fungus growth, a serious problem in the tropics.

THIS BRIEF summary by no means exhausts all the possibilities for the use of fission products. One thing it indicates is that in the immediate future the fission products are most likely to be helpful to existing industries, making possible better and cheaper production of their goods, rather than to bring into being new products or new industries. Any large-scale introduction of these new tools into industry would, however, create a few new business opportunities from the start: the processing of fission products, the manufacture of protective shielding, radiation engineering services for manufacturers.

Shielding, of course, will be one of the major problems. Cold sterilization would have to be carried out behind several feet of concrete. Any radioactive material exposed in public places, as in luminous signs, would need to be sealed to hold in its radiation. The signs would probably take the form of a plastic sandwich, with the fission products and glowing phosphors buried in the middle. The shielding expense was taken into account in estimating the costs of the various uses of fission products.

Costs will play the major part, of course, in determining how widely these new tools are accepted by industry. In general fission-product radiation will be more expensive than heat in any application for which either may be used; for example, food sterilized by radiation may cost more than food sterilized by heat or preserved by cold. On the other hand, radiation may have compensating advantages. Fission products will also be in competition with other sources of radiation, such as X-ray machines and Van de Graaff generators. It appears that fission-product radiation would be a good deal cheaper than X-radiation; at $2 per curie the former would deliver energy at about two cents per watt-hour as against 20 cents to $1 per watt-hour for the tube alone in the case of X-rays. But radiation-producing machines have certain important advantages: they can be turned on and off; they can vary the energy and quantity of their radiation output; they present no waste-disposal problem, as do depleted fission products. For some applications, such as the surface sterilization of foods, Van de Graaff generators, which fire a beam of high-energy electrons, may be more economical than fission products.



GAMMA-RAY PHOTOGRAPHY is a promising application of fission products. This photograph of the rivets in a pressure vessel, made by the radiation from radioactive cobalt, shows that one rivet (*left*) is too small.

A multitude of important technical and economic problems remain to be solved before fission products can be profitably used by industry on any large scale. One of the first major steps must be to select the best process for refining fission products. This will be a multimillion-dollar decision, because it will mean the construction of special facilities. But until it is done, industry will be frustrated in efforts to evaluate the fission products' usefulness. For some of the necessary tests they need much larger amounts of radioactive material than are now obtainable. A cold-sterilization pilot plant, for example, would require perhaps 100,000 to one million curies.

Studies of many of the problems connected with the use of fission products are, however, underway. The Brookhaven National Laboratory now has thousand-curie sources of cobalt 60 and tantalum 182 which are available to industry for irradiation of prepackaged materials. Many companies have already indicated interest in this service, and a number of actual tests have been run. A similar service will be set up in other parts of the country. Development-scale facilities for production of strontium 90 and cesium 137 are being built at the Oak Ridge National Laboratory. A supply of cesium 137 providing 1,500 to 2,000 curies is to be produced and given to the Oak Ridge Institute for Nuclear Studies for industrial research. Data from the operation of these facilities may be used in designing a fission-product plant for mass production of 1,000-curie sources of strontium 90 and cerium 144.

The General Electric Company and Oak Ridge are both working on the problem of preparing and packaging large quantities of radioactivity. The Massachusetts Institute of Technology, Columbia University and the University of Michigan are studying the irradiation of foods, to determine, among other things, its possible effects on taste and toxicity. At the Stanford Research Institute there will soon be underway a research program to develop the process engineering for sterilization of both drugs and foods, to work out industrial radiography systems, to investigate chemical reactions activated by gamma rays and to offer a radiation service to industry. Yale University and Columbia are working on radiation chemistry. Michigan is studying the ionizing effects of radiation on flame propagation.

Even if only some of the uses for radioactive wastes suggested in this article prove feasible, the problem may become not what to do with the fission products but how to obtain a big enough supply of them. At all events, the great stocks of radioactive material now lying idle in our storage tanks constitute a national resource that challenges our industrial ingenuity and can open new technological frontiers.

Paul J. Lovewell directed the study of the industrial uses of radioactive fission products for the Stanford Research Institute.

The Eradication of Malaria

In 1945 there were 411,600 cases in Italy; in the first half of 1951 there were 392. This success is an example of what might be done where the disease is still a grave problem

by Paul F. Russell

Here the earth breath is pestilence, and few
But things whose nature is at war with life—
Snakes and ill worms—endure the mortal dew.

SO THE POET Shelley wrote of malarious Italy in 1818. The pestilence already had an identity and a name; in 1740 Horace Walpole had mentioned "that horrid thing called the *mal'aria* that comes to Rome every year and kills one." For 2,000 years the "bad airs" had made the Holy City notorious to all Christendom as a fever spot. Malaria continued to plague Italy into the 20th century. Five decades ago it was still killing 8,000 to 10,000 victims each year, and as recently as 1945 there were 411,600 malaria cases in Italy, though the death toll, thanks to atebrin, had been reduced to 386.

Now, in six short years, Italy has utterly routed the pestilence. During the first half of 1951 there were only 392 cases of malaria in the whole nation, and not a single death from the disease has been reported in the past three years. Italy's achievement in eradicating malaria is resplendently exhibited in the Pontine Marshes not far south of Rome. In that ill-famed fountainhead of malarial miasmas, whose vast acres of fertile land were uninhabited for 20 centuries because of dread of the "summer-autumn" fever, the Italians have "cleansed to sweet airs the breath of poisonous streams," and today more than 100,000

NEW ITALIAN CITY of Littoria was built on land reclaimed from the Pontine Marshes. Drainage, however, was not the sole solution to the malaria problem. The mosquitoes continued to breed in the drainage canals.

people live on the marshes in health and prosperity.

Italy is a model of what can be accomplished with mankind's new weapon against malaria: DDT and such related insecticides as benzene hexachloride. These destroyers of malaria-carrying mosquitoes have at last made it economically feasible to eradicate malaria from a whole nation, instead of merely trying to control it in a limited area. The special virtue of these insecticides is their lasting effectiveness. Because they remain lethal to mosquitoes for many months after they are applied, they make it possible to wrest a region from the insects and hold it against reinvasion.

DDT has opened a new era in the world's health. But we are still only at the beginning of this era. The story of Italy's conquest of malaria is a great, heartening chapter in human history; what is more, it apparently foreshadows more brilliant chapters still to come.

WHAT LONG and painful centuries men spent in discovering the simple explanation of malaria! The early Romans noticed that the fever came most frequently to people who lived near swamps. In Julius Caesar's time the scholar Marcus Varro suggested that small, invisible animals from the marshes caused fever when they entered a man's nose or mouth. Vitruvius, military engineer to Augustus, wrote of the unwholesome effluvia and "fenny animals" arising from marshes. Throughout the centuries the Romans and later the Italians tried draining the marshes as a means of combatting malaria, but it had little success.

Apparently the first to suspect the actual culprit was the 18th-century papal physician Giovanni Lancisi. In 1717 he mentioned insects as among the dangerous "emanations" from the swamps, and he devoted special attention to mosquitoes. But not until more than a century and a half later was the criminal actually cornered. Sir Patrick Manson, a Scotsman practicing medicine in China, discovered definite proof that mosquitoes were carriers of filariasis, which in its late stages causes the hideous deformations of elephantiasis. Manson reasoned that if mosquitoes could be nursemaids to the filarial worms that infect man, they might also harbor other parasites responsible for malaria. The British physician Sir Ronald Ross, working in India, soon confirmed Manson's hypothesis, and in 1902 won a Nobel prize for doing so. He found parasites of human malaria in mosquitoes that had fed upon a patient. Unable to experiment with human patients, Ross ingeniously turned to the next best subject: birds. They also have malaria, and the parasite that infects them belongs to the same genus as the one which attacks human beings. Ross conclusively demonstrated that the cycle of transmission of the parasite in bird malaria was from bird to mosquito to bird. The *Culex* mosquitoes were the carriers of avian malaria.

Italian investigators quickly proved that the cycle was the same in human malaria, except that another genus of mosquitoes was the carrier. On November 18, 1898, Giuseppe Bastianelli, Amico Bignami and Giovanni Battista Grassi reported unquestionable evidence of the development of human malaria parasites in mosquitoes of the genus *Anopheles*. Furthermore, they were soon able to state that only the Anopheles transmits the disease among men. In 1900 some Anopheles were infected in Rome and sent to Manson in London, where they fed on two volunteers who thereafter developed malaria. This was the first of many corroborations that Anopheles was indeed the long-sought criminal.

A puzzle soon developed, however. The region around Viareggio in Tuscany was heavily infested with Anopheles mosquitoes, yet malaria was rare. The enigma was not cleared up until 1931, when it was learned that the Italian Anopheles, which had been thought to be a single species (*maculipennis*), actually included at least six different species, all superficially alike but each with its own behavior pattern. The Anopheles of Viareggio was not the same as the insect of the Campagna and the Pontine Marshes; it preferred to feed on animals, and thus did not spread the disease among men.

Now at last the way was open to control malaria. How to get rid of the baleful Anopheles? Draining the marshes could not do the job, because the mosquito larvae flourished in the drainage canals. The Italians began to dust the mosquito-breeding places with Paris green. They developed all sorts of sifters, mixers and dusters, and the Italian technique became a standard malaria-fighting method all over the world.

By 1939 a many-sided effort—draining the swamps, killing mosquito larvae, screening houses, distributing quinine—had reduced the number of malaria cases in Italy to 55,000. But the measures were expensive and not practicable in every province. During World War II they were largely dropped and malaria rose again to more than 400,000 cases. But the war also launched DDT as a weapon against malaria.

DDT CAME to Italy with the Allied Army in 1944-45. The Malaria Branch of the Allied Control Commission did some experiments which showed that the disease could be effectively and cheaply controlled in Italy by spraying houses with DDT solutions. At the end of the war Albert Missiroli, Italy's leading malariologist, formulated a five-year plan for eradicating malaria from the whole country. The ceilings and inside walls of every house and animal shelter in every malarious area of Italy were to be sprayed once a year, just before the malaria season. With some financial backing from UNRRA in the first year, but chiefly through its own efforts, Italy has successfully carried out the Missiroli plan at the low cost of approximately 50 cents per capita per year.

MEN ON BICYCLES carried DDT to each house in Italian campaign.

Sardinia was made the subject of a special test, the object of which was to find out whether it was feasible to eradicate a malaria mosquito completely from a region where it had been at home for centuries. The work in Italy had already shown that a mosquito population could be reduced to a level at which it could not maintain the disease, and an insecticide campaign in Brazil had proved that it was possible to wipe out a newly arrived immigrant species (the *Anopheles gambiae*, which had been brought to Brazil from Africa). The

MALARIAL ZONES were posted. Every house and animal dwelling in every malarial zone of Italy was given a spraying with DDT once a year.

question remained: Was it worth while to try to exterminate an Anopheles species once and for all?

Leading Italian malariologists cooperated with UNRRA, ECA and the Rockefeller Foundation in a five-year experiment on Sardinia which cost $12 million, approximately two dollars per capita per year. Thousands of scouts sought out every possible breeding place of the malaria mosquito. These were regularly sprayed with DDT in oil. Some particularly difficult spots were drained or filled. To kill adult mosquitoes every house on the island was sprayed with DDT. By 1951 Sardinia, formerly one of the most severely afflicted regions on earth, was entirely free of malaria. But the malaria-carrying mosquito on Sardinia (*Anopheles labranchiae*) escaped annihilation. Its numbers are now far too few to propagate malaria, and it seems likely that a yearly DDT house-spraying program will prevent its resurgence. What the experiment appears to demonstrate is that it is not practicable or necessary to try to eradicate the mosquitoes: malaria can be controlled adequately by spraying houses without attempting to attack all breeding places.

Italy is only one of the regions that have been wrested from malaria since the end of the war. Successful campaigns have been carried out in Ceylon; in Bombay State, where the spraying of two million houses with DDT has protected nine million persons at a cost of less than 10 cents per person per year; in Venezuela, where every house in every malarious area has been sprayed and the disease has been suppressed to insignificance; in Brazil, where in 1950 2.5 million houses were sprayed at a cost of $9.5 million; in British Guiana, in Greece, in Mauritius, and in other places. Most of the world's malarious countries today have made at least a start in malaria control with DDT. The U. S. is producing DDT at the rate of 120 million pounds a year and will export some 25 million pounds this year.

THE RESULTS of the anti-malaria work in the past few years have been spectacular. But skeptics suggest that perhaps man takes too much credit. Malaria has been declining in the U. S. and in Northern Europe for many years. Are not natural factors mainly responsible for this decline?

The fact of the matter is that malaria in the U. S. has not died unassisted, though no single bullet dispatched it. It has been going down steadily since 1875, and at an accelerated pace in recent years. By 1912-1915 it was largely confined to the South; there were still an estimated one million cases annually, however, in 12 Southern states with a population of 25 million. Today malaria is an exotic disease in the U. S.; in 1950 the Public Health Service found only 26 positive cases in the whole country. The few cases that turn up have usually been contracted abroad. Such sporadic infections do not spread.

So far as one can determine, there have been no significant changes in the power of the malaria parasite to infect man, in the ability of the mosquito to transmit the parasite, or in the susceptibility of people in the U. S. to the disease. Americans overseas readily become infected. Volunteers at home can easily be inoculated with local strains of the parasite by local mosquitoes, and our mosquitoes can also transmit foreign strains.

Probably one reason for the decline of malaria in the U. S. is a reduction in the population of *Anopheles quadrimaculatus,* the chief carrier of the disease in this country. Our Anopheles, unlike its Italian relative, breeds best in standing pond water; it does not thrive in the running water of ditches, in acid swamps or in brackish marshes. Our great land-improvement projects since 1875, and anti-mosquito drainage work done since 1915, have drained many of the stagnant breeding places. During World War I the U. S. Army and the Public Health Service carried out no fewer than 43 anti-mosquito projects in 15 states. During the depression years of 1933 to 1935 the Works Progress Administration and other government agencies constructed some 32,000 miles of ditches to drain an estimated 623,000 acres of land. During World War II the Army and the Public Health Service, cooperating with state health departments, carried out 2,200 mosquito-control projects in 19 states. Such great enterprises as the Tennessee Valley program and the many well-directed state and county campaigns have also played a part.

Anopheles quadrimaculatus continues to abound in some areas of the U. S., but the insect no longer spreads malaria because there are few infected people and therefore few parasites. The reasons for the decline of the parasite are many and various. One of them is the economic advance of the South, which has brought better housing and education, more medical care, more effective screening, increased use of domestic mosquito sprays and other hygienic measures. The increase in the U. S. cattle population has diverted the attentions of mosquitoes from men to animals. The urbanization of the South has taken people out of malarious rural areas, and many people with chronic malaria have moved North, where their parasites have gradually died out, under conditions unsuitable for transmission of the disease.

Nevertheless, all this does not detract from the importance of the well-directed

20th-century campaigns against mosquitoes and malaria in this country. Since 1946 large DDT spraying programs have been carried out in the South. Furthermore it should not be forgotten that quinine has been cheap and widely available in the U. S.; the price was reduced from about $4.50 per ounce in the 1880s to only 25 cents by 1915. It is clear that to prevent the embers of malaria from flaring up again we must keep vigiliant.

Probably malaria has receded in Northern Europe for much the same reasons as in the U. S. The disease, which a century ago was common in England, Sweden, Finland, Germany and the Alsace district of France, has generally subsided, though it broke out in some areas during the recent war.

WHEREVER malaria has been brought under control, modern drugs and preventive measures make it relatively easy to keep it in check. But on a world scale the battle against the disease is just beginning. In the malarial regions of Asia, the Near East and Equatorial Africa, the Anopheles mosquitoes this year will infect some 300 million people, more than twice the total population of the U. S., and about three million of its victims will die. The effects will not be restricted to those areas, for malaria has a huge impact on the world's economy and politics. It is a major cause of poverty and malnutrition, and therefore of unrest, in the backward regions. It cuts heavily into the production of some of the world's key materials, such as rubber, minerals, spices, oils, gums and hardwoods; malaria probably increases the cost of these items by at least five per cent. And it limits the afflicted peoples' world buying power and progress toward industrialization.

Within the next 15 years this picture may change profoundly. Great praise is due the malariologists of the World Health Organization, of the U. S. Public Health Service and of many national and international organizations for their brilliant work with the new insecticides. Yet we cannot afford to be complacent. DDT will not automatically rid the world of malaria; we have already seen disquieting signs of the development of resistance to it by some houseflies and mosquitoes, though Anopheles, fortunately, has not yet become immune. Strong support for continued research and for international control is still a matter of vital interest to countries such as the U. S. and Italy, in spite of the fact that they have eradicated the disease from their own lands.

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INSIDE WALLS AND CEILINGS of each house were sprayed. This was found more practical than attempting to eliminate the mosquito entirely.

TURBULENCE IN SPACE

A turbulent stream of water consists of eddies within eddies within eddies. These are only a small sample of the hierarchy of eddies which may extend even unto the motions of galaxies

by George Gamow

UNTIL a decade or two ago the phenomenon of turbulence in a fluid stream was of interest only to engineers; it seemed to have very little significance in what is usually called "pure" science. Turbulence is that extremely irregular internal motion which can be observed in fast-flowing liquids and gases. When a smooth-flowing stream breaks up into a chaotic mixture of whirlpools or eddies of all different sizes, we say it has become turbulent. You can see this happen in the flow of water from the kitchen faucet. When you open the faucet a little bit, the water streams out smoothly in what is known as laminar (or streamlined) flow. Increase the speed of the stream by opening the faucet all the way, and the motion becomes turbulent.

Turbulence can be highly useful. It supplies the force that drives ships and airplanes, for if there were no turbulence in the streams produced by propellers, they would have hardly any pushing force. Turbulence in the atmosphere is what makes our weather. What is more important, it now appears that but for the cosmic turbulence of the universe, neither we nor our planet nor the universe as we know it would be in existence. The part that turbulence probably played in bringing the universe into being is the theme of this article.

One can conveniently study turbulence by sending through a glass tube a stream of water containing a large number of small suspended particles, for example, tea leaves. If the stream flows slowly, the particles float along the tube as smoothly as the little swans in Tchaikovsky's ballet. As soon as the velocity of the stream passes a certain limit, however, the languid swan-dance turns suddenly into a wild *Danse Macabre*.

This kind of study was first undertaken many years ago by the British physicist Osborne Reynolds, who established the basic laws of turbulent flow. On the basis of numerous experiments with various liquids in tubes of various diameters, he showed that the critical velocity at which turbulence sets in varies in direct proportion to the viscosity of the liquid and in inverse proportion to the diameter of the tube. Thus a stream of castor oil passing through a tube must travel 2,000 times as fast as pure water to become turbulent, because castor oil is about 2,000 times as viscous as water. The other part of Reynolds' law says that a stream of any fluid needs only half as much velocity to become turbulent in a two-inch tube as in a one-inch tube. The critical condition for the appearance of turbulence depends on the quantity: the diameter of the tube times the velocity of the stream times the density of the fluid divided by the molecular viscosity of the fluid. This quantity is known as Reynolds' number. So long as this number is smaller than 1,000 (approximately), the flow remains smooth; if it exceeds that value, turbulence is likely to set in.

ONE important thing that happens to a fluid when its motion becomes turbulent is a tremendous increase in internal friction. We can understand the effect by considering a rather unlikely analogy which nonetheless illustrates the point. Suppose that an express train is passing a slow local train and the passengers of both trains, becoming angry for some reason or other, start throwing their luggage at each other through the windows of the passing cars. The suitcases coming from the express train will tend to accelerate the slower local train when they land inside it, because of their higher inertial speed. On the other hand, the slower-moving bags from the local train will tend to slow down the express when they land in it. In short, the luggage barrage between the two trains will produce a kind of "frictional force" tending to equalize the trains' speeds.

This is what takes place whenever two streams of fluid (liquid or gas) pass each other at different speeds. The flying pieces of luggage correspond to the molecules of the fluid, which are always in thermal motion. Two adjacent layers of fluid constantly throw molecules at each other, even when they flow smoothly, with the same effect as we have discussed in the case of the two trains. This friction accounts for the fluid's normal molecular viscosity.

When turbulence breaks out, however, the "barrage" between two layers of the fluid becomes much heavier. The layers now exchange not only individual molecules but whole eddies. Going back to our railroad analogy, we might say that the passengers are not only tossing suitcases but have opened the baggage cars and begun to heave big trunks and crates across the tracks at each other. In a fluid stream the friction from such exchange is called turbulent viscosity.

For a long time the study of turbulence remained purely empirical. It seemed almost hopeless to attempt to reduce this extremely complicated phenomenon to simple mathematical principles. Recently, however, the combined efforts of mathematicians and theoretical physicists have begun to yield some insight into the complex hydrodynamics of turbulent flow. In the modern theory of turbulence the notion of statistical disorder—the same notion that is used to describe the thermal motion of molecules—has been applied to the sizes and velocities of eddies in a turbulent stream. We speak of a hierarchy of eddies, which can be of all possible sizes, from large bodies almost as big as the flow-pipe itself down to microscopic ones nearly as small as the distances between molecules in the fluid. The large eddies should be considered as being built up from the smaller ones.

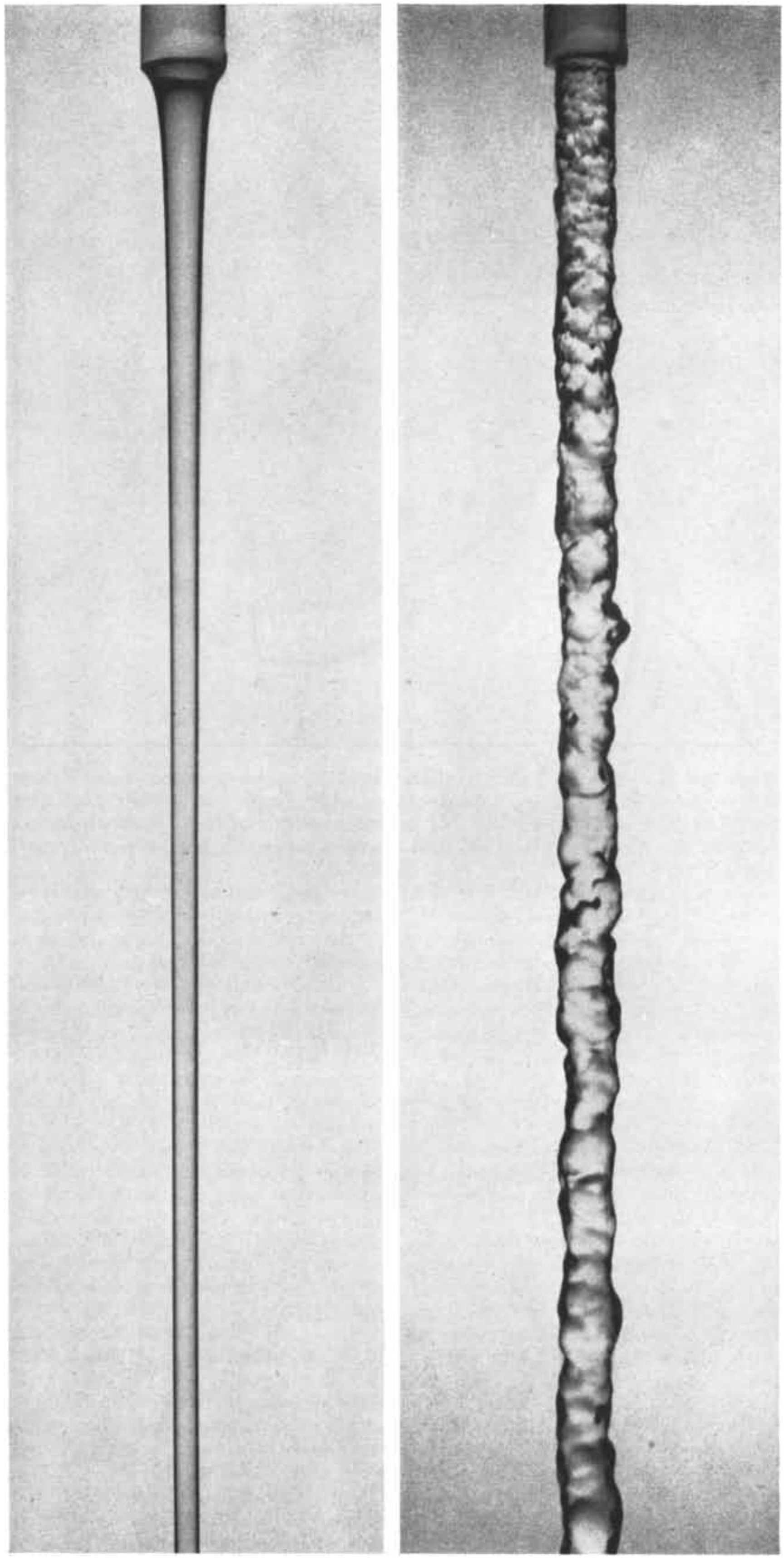
ALTHOUGH it is impossible to give an exact graphical representation of the complicated motions within a turbulent fluid, the diagram on the next page may give some idea of them. This is a hypothetical head-on view showing what an observer would encounter as he moved along with the main stream. The fat curved arrows, each representing an individual eddy, indicate the general direction of motion in a region of the fluid. Of course in an actual stream the eddies are not sharply defined, as the arrows are; the eddies merge into one another.

Within any one of the eddies pictured in this diagram will be many smaller streams, also irregular. And these smaller eddies in turn are built from still smaller ones. Extend this picture all the way up to the dimensions of the main stream and all the way down to intermolecular dimensions, and you will have an idea what one means in talking about the statistical nature of turbulence. As mentioned above, the situation is like the molecular disorder in gases, where individual molecules dash about in irregular random motions with all possible velocities in all possible directions. But in the case of turbulence the statistical treatment is additionally complicated by the fact that, unlike the molecules of a gas, the eddies are constantly breaking up and being rebuilt into new systems. When, for example, you produce a single large eddy with a stroke of the oar in a rowboat, the eddy immediately begins to decay into smaller ones. Its original energy is gradually dissipated into smaller and smaller units, until finally all visible motion fades out and the water seems still. The original energy of the eddies has been transformed into the energy of individual molecules, *i.e.*, into heat. If we continually supply energy to stir up the water, a steady state of turbulent motion will be established, with energy passing continuously from larger eddies into smaller ones and so on all the way to the thermal motion of molecules.

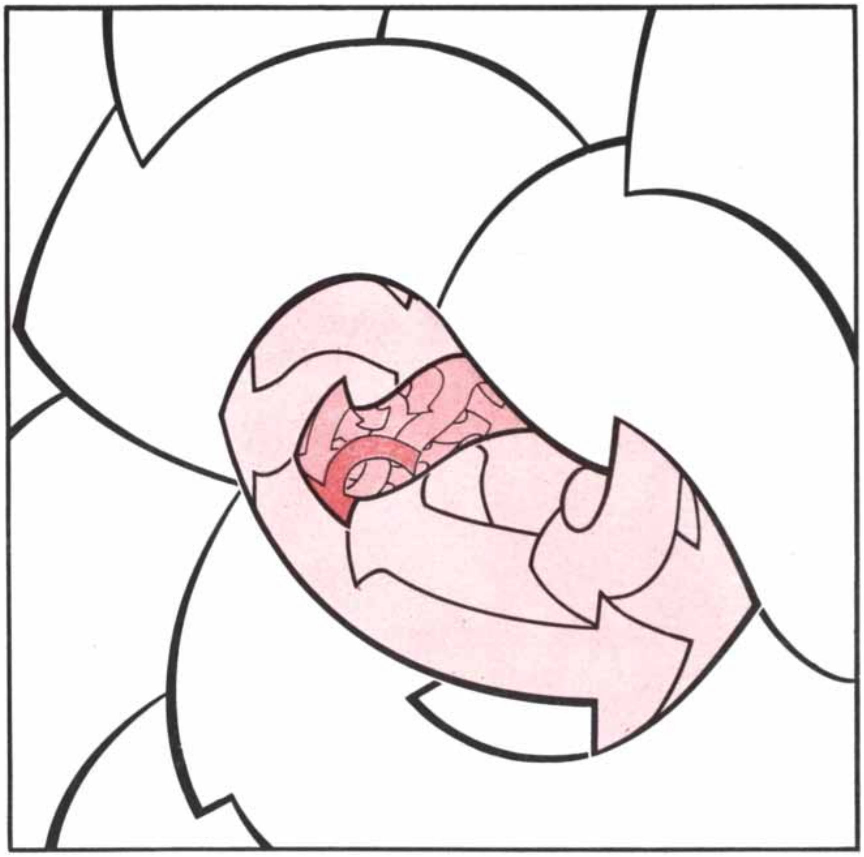
The situation was described perfectly by L. F. Richardson in the verse:

Big whirls have little whirls,
That feed on their velocity;
And little whirls have lesser whirls,
And so on to viscosity.

It goes without saying that the mathematical theory of statistical turbulence



LAMINAR AND TURBULENT FLOW are demonstrated by two streams of water passing out of a glass tube. The slow-moving stream at the left is laminar; the fast-moving one at the right is turbulent. These photographs are published through the courtesy of the Johns Hopkins Magazine.



HIERARCHY OF EDDIES is illustrated by arrows. Each large arrow represents an eddy. If we examine one eddy (*light red arrow*), we find it is composed of smaller eddies. If we examine one of these eddies (*darker red arrow*), it is composed of still smaller eddies (*darkest red arrow*).

is extremely complicated and it is still far from being completed. However, many important results are already at hand. The first steps in the mathematical treatment of turbulent motion were made by the celebrated Hungarian hydrodynamist Theodore von Karman. More recently the German theoretical physicist Werner Heisenberg was able to start with the statistical theory of turbulent motion and derive from it Reynolds' law. The Russian mathematician A. N. Kolmogoroff has worked out the important problem of the relation between the size and velocity of eddies: he has shown that as eddies increase in size, their velocities, on the average, must increase in the ratio of the cube root of their gain in size. We also have information concerning the rates at which eddies break down into smaller ones.

NOW LET US look at the role that turbulence plays in astronomy. As the first example we take the well-known speckled appearance of the visible surface of the sun. Turbulence can easily account for this. Because the sun does not rotate with absolute uniformity, its hot gaseous surface breaks up into a multitude of irregular eddies. Some of the eddies expand, cool slightly and become less luminous; others are compressed, grow hotter and become brighter. As a result the surface of the sun is speckled with bright and dark spots.

Another excellent place to study cosmic turbulence is in the gigantic clouds of dust and gas that fill great expanses of the Milky Way like a thin fog. Some of the clouds are quite dark; indeed we can detect their presence only by the fact that they obscure the light of stars lying behind them. But some clouds, brightly illuminated by clusters of stars dispersed in them, are distinctly visible as a vast white haze. One such is the Orion Nebula. This brightly-lit cloud offers as good an example of turbulent motion as the smoke rising from a lighted cigarette.

The Lick Observatory astronomers W. W. Campbell and J. H. Moore studied internal motions in the cloud with the spectroscope. Observing the light emitted from various small areas within the nebula, they found that its spectral lines were shifted slightly (the Doppler effect), indicating complicated irregular motions in the cloud. From a number of comparative measurements of velocity-differences between two different points, each pair of points being the same distance apart, they obtained an average of the change in velocity corresponding to a given distance. They did this for various distances.

Analyzing the results of these measurements, the German astronomer S. von Hoerner was able to show that they are in complete agreement with the laws of turbulent motion. In accordance with Kolmogoroff's law, the velocities in the cloud increased as the cube root of the increase in the distance between the observed points. In other words, when the distance between points was increased eight times, the radial velocity of the gaseous material in the cloud was found to increase by a factor of about two; when the distance was increased 27 times, the velocity rose threefold.

Let us turn now to cosmic phenomena on a still larger scale. The space of the universe, as far as the largest telescopes can see, is filled with a multitude of galaxies like our own Milky Way; within the range of the 200-inch telescope on Palomar Mountain there are no fewer than a billion of them. From the grand point of view we can consider the universe to be filled with a gas the molecules of which are represented by individual galaxies. Must we conclude that this "gas" is also in a condition of turbulent motion?

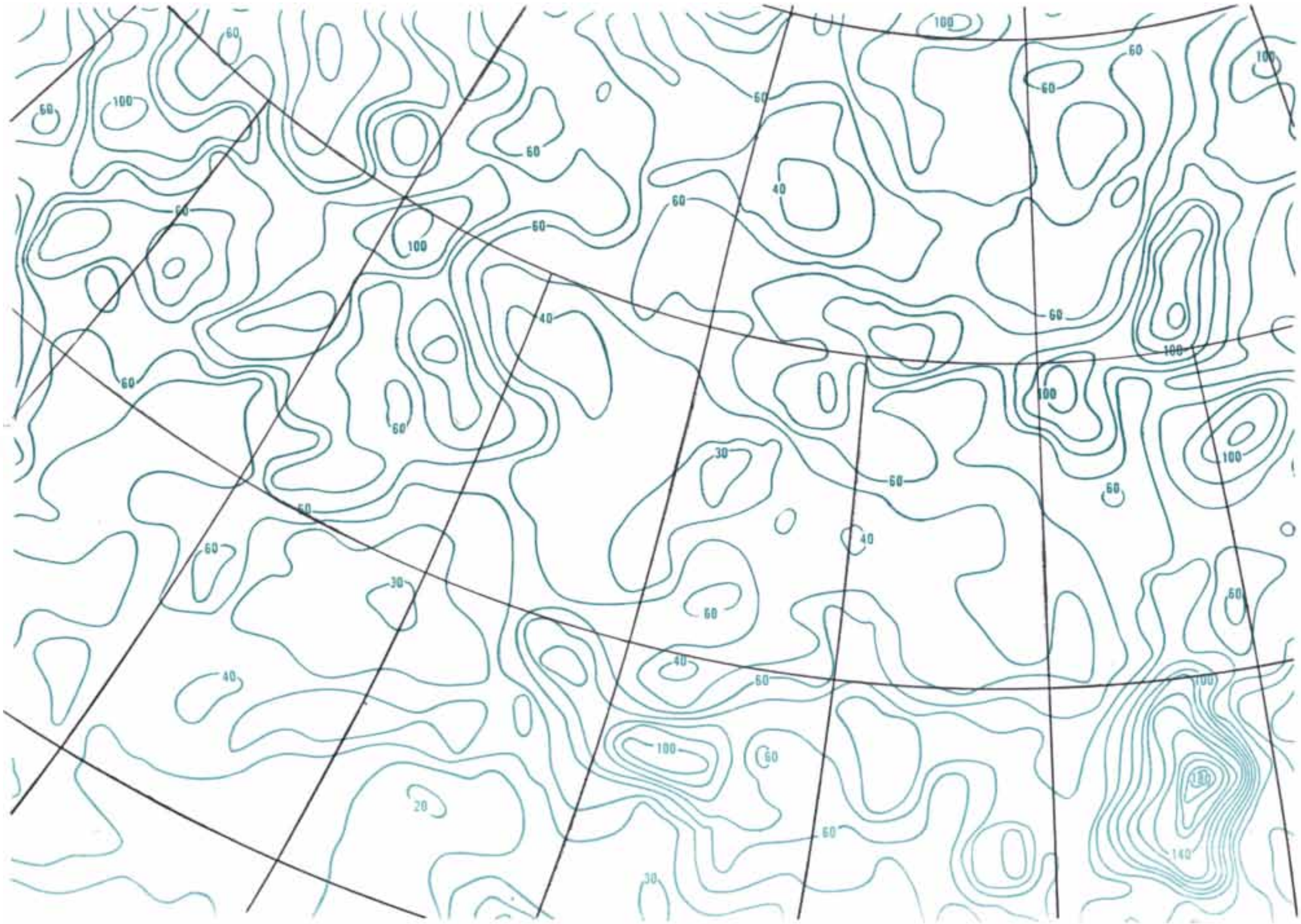
This question can be answered by detailed studies of the distribution of galaxies through space. Such studies have been carried on for many years, notably by Harlow Shapley of the Harvard College Observatory and by C. D. Shane of the Lick Observatory. Shapley plotted the distribution of galaxies over a part of the celestial hemisphere near the north polar region. Each point on this diagram represents a galaxy, the position of which was carefully measured. A look at his diagram shows at once that the galaxies are far from uniformly distributed in space. Some regions of the sky have dense concentrations of them; others have few. The map looks like an area sown with grass seed by hand, where the seed has fallen more thickly in some places than others.

Shane's map of the distribution of galaxies shows the variations even more strikingly (*see diagram on page 30*). Instead of giving the position of individual galaxies, he plotted a kind of contour map with lines tracing out their levels of concentration; each line marks a "contour" along which the number of galaxies per square angular degree is about the same. When the celestial sphere is plotted in this way, it is divided into great whirls that look remarkably like eddies.

There seems to be hardly any doubt that these irregularities in the space distribution of galaxies cannot be caused by chance fluctuations. Most likely the compressions and rarefactions are caused by irregular turbulent motions of the matter in the universe.

Thus no matter where we cast our

TURBULENCE OF ORION NEBULA was demonstrated by two sets of spectroscopic measurements at Lick Observatory. First the radial velocity of the nebula was measured at seven pairs of points the same distance apart (*top*). Then the radial velocity was measured at seven pairs of points twice as far apart (*bottom*). The difference in the average velocity of the two sets of points was found to conform to a law of turbulence.



TURBULENCE AMONG GALAXIES is suggested in this diagram made by C. D. Shane of Lick Observatory. The black lines are coordinates of the celestial sphere, *i.e.*, the sky as seen from the earth. The coordinates running from upper left to lower right are parallel to the Milky Way. The green lines are contours indicating the distribution of galaxies in this area. The numbers on the contours denote the number of galaxies per square angular degree. The density of galaxies shown here runs from 20 to 180 per square degree.

glance—whether at the earth's atmosphere, the surface of the sun, the giant dust-and-gas clouds in the Milky Way, or the "gas of galaxies" in the large-scale universe—we always find the characteristics of violent turbulent motion! And this is exactly what is to be expected, since it can easily be shown that in each of these cases the Reynolds number is much larger than the critical value of 1,000.

WE MAY return now to the statement made at the beginning of the article: that without turbulence the universe could never have developed into its highly differentiated state as we know it now.

It goes without saying that the principal force governing the evolution of the universe is the force of Newtonian gravity. In the primordial gas that constituted the universe during the early stages of its existence, gravity forces must have brought together concentrations of matter to form the giant gaseous clouds from which our present universe was later to be made. It must have been the same force that coalesced these clouds into galaxies of stars and the gaseous material around the stars into families of planets.

The theories attempting to explain the formation of the hierarchy of condensations that brought the universe to its present shape have always encountered a serious difficulty. Assuming, as such theories usually assumed, that the primordial gas at the beginning was distributed through space with complete uniformity, the collection of matter into clouds and its condensation into stars would have taken much too long—far longer than the three billion years now estimated to be the age of the universe.

Apparently the only way to make the time scale come out right is to assume that matter was not uniformly distributed at the beginning; in other words, that there must have been some rudimentary condensations to start with. This is where the notion of turbulence comes to our aid. If there were turbulent motions in the primordial gas, they could easily have produced the necessary irregularities and rudimentary condensations. Thus we come to the conclusion that turbulence and gravity must be considered co-sponsors of the evolutionary development of our universe.

The question remains: How did this turbulent motion originate in the first place? We do not know the answer, but one possible explanation may go as follows: We are accustomed to think of smooth flow in a fluid as "natural" and of turbulence as unusual. But this is due to our terrestrial, small-scale point of view. As the dimensions of the space in which a fluid moves become larger, turbulence becomes much more likely. In the universe all dimensions are so large that from the cosmic point of view we must consider turbulent motion the natural thing and laminar flow a special case. We should accept turbulence among the large-scale masses of the universe as the natural condition in the same way as, at the microscopic level, we accept as natural the irregular thermal motion of molecules.

George Gamow, the author of numerous popular books about the physical sciences, is professor of physics at George Washington University.

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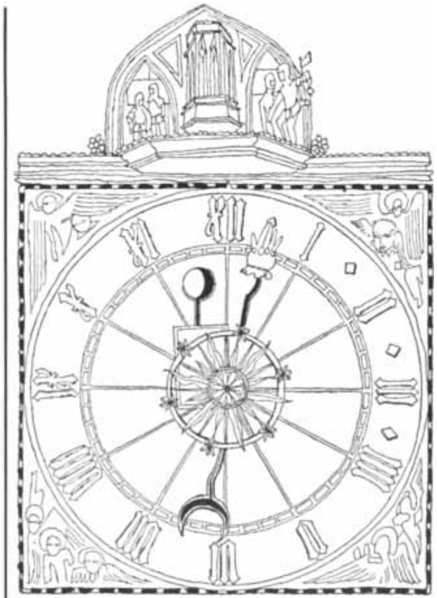


Chemical Refining

A RADICALLY new process for extracting metals from ore has been developed to the point where several commercial plants are being built for operation within the next year or two. The process, which substitutes chemical treatment of ore-concentrates for the traditional smelting and refining methods, is expected to increase the potential supply of several strategic metals by making practicable the working of low-grade ores. Its sponsors believe that it will speed the conversion of ore to metal and eventually lower prices. The process was developed by Chemical Construction Corporation, an American Cyanamid subsidiary, in collaboration with Sherritt Gordon Mines Ltd. of Canada. William N. Porter, president of Chemical Construction, estimates that in many cases the cost of scrapping present smelting and refining facilities can be made up in three years by operating-savings from the chemical technique.

Refiners using the new method will prepare a concentrate of their ores by the conventional flotation process. This enriched ore in solution will then be treated with ammonia or an acid under heat and pressure. The metals will be separated and extracted from the resulting leach solution by the use of appropriate reducing agents. Metals refined in this way appear as powders of high purity; in most cases the reagents are recovered. The equipment is compact and relatively inexpensive and can be operated with a small staff. As a consequence, the plant can often be set up at the mine, thus effecting additional large savings in transportation. Furthermore, the process is so flexible and produces metal from ore so rapidly that a refinery can adjust itself readily to market conditions and need not maintain a large inventory of material at various points of processing.

Chemical Construction is now building a $2.5 million plant to refine cobalt for the Howe Sound Mining Company near Salt Lake City. It is rated at 2,000 tons of pure cobalt a year, a figure that will raise the world output of this metal —most of which comes from Central Africa—by 40 per cent. The plant will be able to produce about half the tonnage of cobalt consumed in the U. S. in 1950. Under construction at the Fredericktown, Mo., mine of National Lead Company is another plant, costing $5 million, which will have an annual production rate of 700 tons of cobalt, 900 tons of nickel, 700 tons of copper and 7,500 tons of fertilizer-grade ammonium sulfate. In Manitoba, Sherritt Gordon is building a $17 million plant designed principally to extract nickel (8,500 tons a year). It will also refine substantial tonnages of copper, cobalt and ammonium sulfate.

The Biologists Meet

AN ATTENDANCE of nearly 6,000 persons and the presentation of some 1,600 papers made this year's meeting of the Federation of American Societies for Experimental Biology the country's largest gathering of scientists outside the annual convention of the American Association for the Advancement of Science. The great number of reports underlined the fact that the amount of work done in U. S. scientific laboratories has grown to staggering proportions and become highly specialized. It gave further point to the recent decision of the A.A.A.S. to devote more attention in the future to "broad problems which involve the whole of science" and leave the detailed reports on laboratory studies to the meetings of specialized groups.

One of the highlights of the Federation meetings in New York was a group of papers concerning research on poliomyelitis. David Bodian of the Johns Hopkins University and Dorothy M. Horstmann of the Yale School of Medicine reported that they had independently discovered a fact which may be of revolutionary importance. For 40 years investigators have been examining the blood of patients showing the symptoms of polio, and they have never found the virus in the blood except in one instance. It has therefore been assumed that the virus does not spread through the bloodstream but through the nervous system, where it is safe from attack by drugs or antibodies.

Bodian and Horstmann found that several days after monkeys and chimpanzees were fed live virus, it did appear in their blood. After a few days antibodies began to appear in increasing numbers to clear out the virus. But three to seven days after the virus had disappeared from the bloodstream, the animals showed the familiar symptoms of polio, including paralysis.

Reasoning from these facts, the scientists postulated a new concept of the course poliomyelitis runs in the human body. Their theory is that the virus may enter the body through the mouth, be absorbed in the bloodstream from the alimentary canal and multiply briefly in organs associated with the blood. Often antibodies are formed quickly enough and in sufficiently large quantities to destroy the viruses before they can reach the nerves, in which event the patient does not even know he has been infected with the virus. (Some 80 per cent of adults carry polio virus antibodies.) Only when the viruses manage to penetrate into nerve tissue does the patient show symptoms of the disease.

If this concept is correct, it should be possible, say the doctors, to protect human beings against the destructive stage of the disease by attacking the virus during the brief period when it is spreading through the bloodstream. Three possible ways of doing this were suggested. One would be a renewed attempt to develop a vaccine with weak or dead virus; Howard A. Howe of Johns Hopkins reported that chimpanzees had shown immunity 19 months after being inoculated with a strain of polio virus that had been inactivated by formalin. No safe vaccine for human beings has ever been achieved, however. The second suggestion was that people might be given immunity by injections of serum containing antibodies from patients who have recovered from polio. Bodian has immunized monkeys and chimpanzees by giving very small doses of a blood fraction containing such antibodies. One difficulty with this line of attack is that there are three different types of polio virus, and blood serum from a person who has recovered from one will still contain no antibodies effective against the others. But since most adults have survived mild attacks of at least one type, pooled human blood may contain antibodies against all three. Gamma globulin, a blood fraction rich in antibodies, is derived from such pooled blood. The National Foundation for Infantile Paralysis announced that it will test gamma globulin against polio this summer in three or four epidemic areas.

The third suggested approach is a preventive drug to destroy the virus while it is in the bloodstream. It would have to be given before the symptoms of polio appear. The problem is to find an effective and safe drug that can be given generally.

A new test for polio was reported by Nada Ledinko, Joseph L. Melnick and John T. Riordan of the Yale School of Medicine. Testicular tissue from monkeys, cultured in test tubes, exhibits easily detected changes when it is exposed to poliomyelitis virus. One monkey can supply enough tissue to serve for 150 tests, and the determinations can be made quickly.

Among other interesting papers at the Federation meetings:

Josef Brozek of the University of Minnesota reported that people ought to eat less and less as they grow older; they should reduce their intake about 7.5 per cent every 10 years after their 25th birthday. He based this advice on the fact that year by year fatty tissues account for a larger percentage of body weight and produce inevitable overweight. Eating less at least reduces the amount of overweight.

George Wald of Harvard University reported further progress in his studies of the biochemistry of vision ("Eye and Camera," SCIENTIFIC AMERICAN, August, 1950). He has found, among other things, that synthetic Vitamin A does not correct night-blindness; the synthetic product is the wrong isomer of the substance. For this purpose the natural vitamin in cod-liver oil is needed.

Personality and Cancer

WHY DOES the same type of cancer grow rapidly in one patient but slowly in another? "A partial solution may be hidden in the emotional makeup of the individual," three scientists from the University of California reported last month at the annual meeting of the American Association for Cancer Research in New York.

At the Veterans Hospital in Long Beach, Calif., Philip M. West, Eugene M. Blumberg and Frank W. Ellis selected 25 patients whose cancers were growing rapidly and 25 in whom growth was slow. They examined all 50 with the Minnesota Multiphasic Personality Inventory, a standard psychological test which indicates the general type of personality. On a group basis the personality patterns of the two types of patient were distinctly different. "The findings," said West, "suggested that the person with a rapidly growing tumor has a strong tendency to conceal his inner feelings and is less able to reduce tensions by doing something about them . . . than the person with a slowly growing tumor."

The doctors did not suggest that a tense individual is more prone to be attacked by cancer, but that a worrier is likely to die of his cancer sooner. They

say that measures to relieve psychological tension might prolong the life of a cancer patient.

Goldsmith Award

THE *Bulletin of the Atomic Scientists* has given its first Hyman Goldsmith Memorial Award to Walter Gellhorn for his book *Security, Loyalty and Science.* Goldsmith, a founder of the *Bulletin* and for several years director of Information and Publications at the Brookhaven National Laboratory, was one of the leaders in the dissemination of public information on atomic energy in the U. S. He died in a swimming accident in 1949. The *Bulletin*'s memorial to him is an annual award for "the best article, book or public pronouncement which contributes to the clarification of the right relations between science and politics." Professor Gellhorn's study of U. S. security policies and their effect upon science and scientists was selected for the first award by a committee composed of Samuel K. Allison, Cyril S. Smith and Clifton Utley.

Beyond the Horizon

A GROUP of U. S. physicists have found a way to transmit very high-frequency radio waves reliably over considerable distances. These waves (30 to 300 megacycles), used principally in FM radio and television broadcasting, have hitherto been considered effectively restricted to line-of-sight distances, because they pass through the ionosphere in the earth's atmosphere and are not reflected around the curvature of the earth as long-wave radio is.

The new experiments have been conducted for more than a year at a transmitting station in Cedar Rapids, Iowa. The physicists have transmitted a narrow, high-powered beam at 49.8 megacycles which has been received uninterruptedly at Sterling, Va., 800 miles away, irrespective of season, time of day or magnetic disturbances. The scientists who conducted the tests estimate that this method of transmission should be effective for ranges between about 650 and 1,200 miles.

Their method makes use of irregularities in ionization of the ionosphere. Henry G. Booker, professor of electrical engineering at Cornell University, had calculated that irregularities in the ionosphere's E-layer would scatter VHF waves in a predictable way and would return detectable amounts of energy to the earth. The experimenters used a highly directional antenna with a narrow beam-width and verified Booker's prediction. They found that ionospheric disturbances which disrupted ordinary short-wave communication actually enhanced the strength of their signals.

Because the transmission must be directional, its usefulness apparently

will be limited to point-to-point communication; it will not work for general broadcasting in all directions. The signal obtained in the experiments thus far is steady enough for wireless telegraphic communication and possibly for voice transmission. It is not nearly good enough for television, nor is there any assurance that it can ever be made so.

Work on the new method was undertaken originally for the Voice of America. The National Bureau of Standards, the Massachusetts Institute of Technology and the Collins Radio Company of Cedar Rapids have cooperated in the study. It was directed by the Harvard University physicist Edward M. Purcell, and his associates were Booker, Lloyd V. Berkner of the Carnegie Institution of Washington, Winfield W. Salisbury of the University of California, Jerome B. Wiesner of M.I.T., and Dana K. Bailey, G. F. Montgomery and R. Bateman of of the National Bureau of Standards.

Transistors

ANYONE who wants a junction transistor now can buy it. The arrival of this revolutionary substitute for the vacuum tube on the general commercial market was announced last month. Developed by scientists in the Bell Telephone Laboratories ("The Transistor," SCIENTIFIC AMERICAN, September, 1948, and "A Revolution in Electronics," August, 1951), the transistor has been extensively studied by Bell, General Electric and the Radio Corporation of America, all of whom have made refinements in the device. The competitive rush to market it has now begun. One distributor quoted a price of $30 for a transistor.

Jet-Engine Noise

THE NOISE of jet-turbine motors in aircraft has begun to receive the attention of doctors and engineers.

Leo Beranek of the Massachusetts Institute of Technology told the Acoustical Society of America last month that jet aircraft would produce far more serious noise levels around airports than propeller planes. Four scientists at the Army's Wright Air Development Center concluded after tests that "jet engines at full power probably represent one of the most powerful sound sources known." *The Journal of Aviation Medicine* recently published accounts of how rats, exposed to jet-engine noise for an average of 66 minutes, died from a complication of internal injuries, including hemorrhages and atrophy of glands and organs. Researchers at Princeton University found that the ears of guinea pigs exposed for only 15 minutes were severely damaged. Two Swiss doctors established that the greatest noise pressure occurs when the engine is idling.

The Swiss doctors suggested hard rubber ear covers for ground crews. The

Wright Field investigators suggest work on the engine. Since still more powerful jet engines are in prospect, they warn that "the reduction of this noise power right at the source seems to be the only escape from tremendous and costly noise problems."

Atomics, Unlimited

"THE SAME genius in man that made it possible for him to unleash the forces that are locked in the hearts of atoms will make it possible for him to put these forces to work for him safely. If we believe this and continue to work toward it there is no reason why man cannot some day enjoy the fruits of what we have come to refer to as the atomic age." With these words Gordon Dean, chairman of the Atomic Energy Commission, last month announced a proposed $5 billion expansion of the U. S. atomic energy production capacity.

The AEC is already proceeding with plans to spend $1 billion for a new plant to produce uranium 235. It will be built somewhere in the Ohio River Valley, will cover 5,000 to 6,000 acres, employ some 4,500 workers and require 1.8 million kilowatts of electric power.

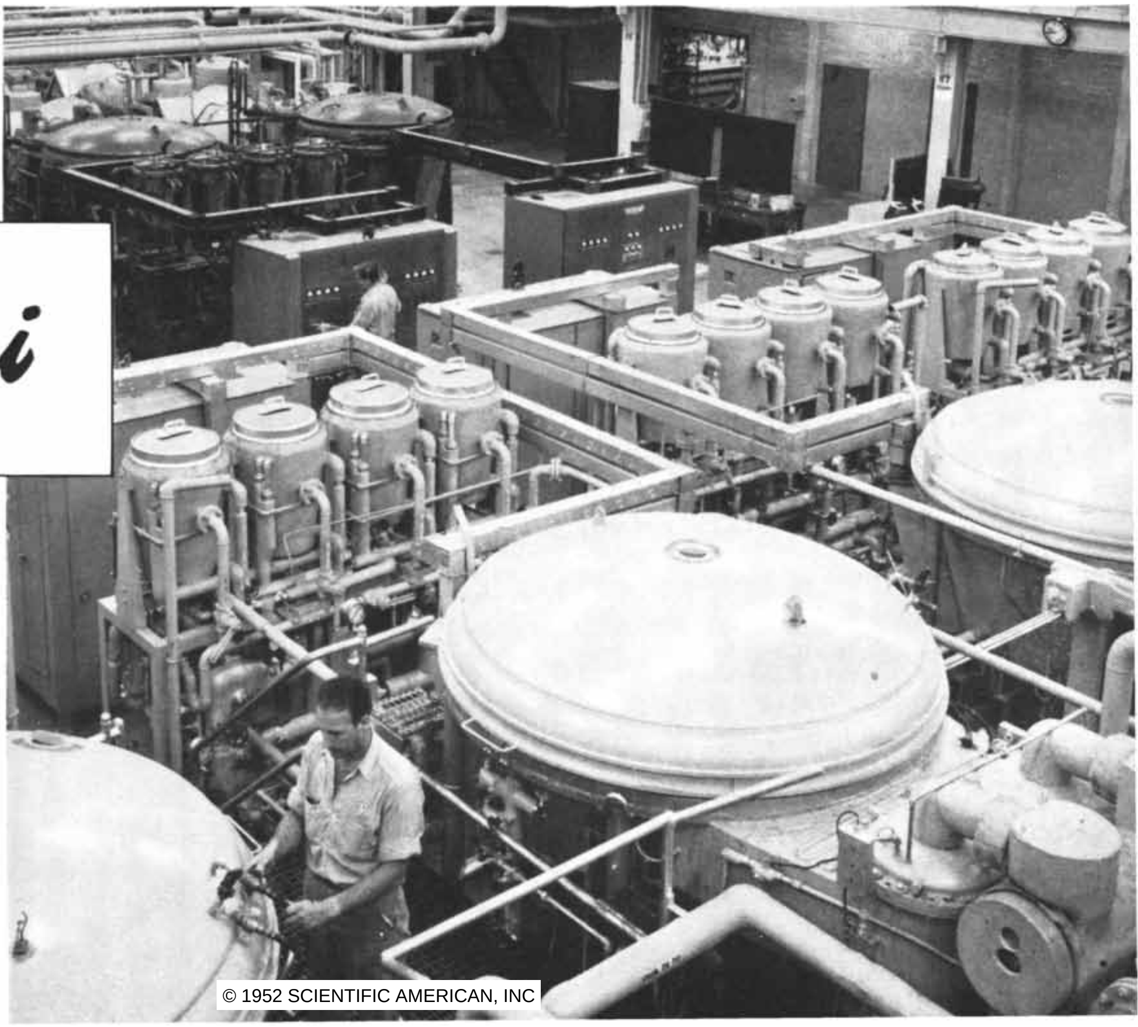
The Commission last month began exploding a new series of atomic bombs. To the first explosion it invited the entire U. S. press and other communication media. Described by Chairman Dean as "a sizable bang," and deduced to be far more powerful than the blast that destroyed Hiroshima, the phenomenon was seen by the U. S. public for the first time on television. Two thousand soldiers got a close look from deep trenches about four miles from the target. They moved into the target area immediately after the blast.

The primary purpose of this demonstration, according to Dean, was to show the possible use of atomic missiles as tactical weapons. The realization that they can be used "by military forces in the field against other military forces in the field," he said, opens the way to the most varied application of the atom's destructive energy. "The assumption that there is an early saturation point in the development and manufacture of atomic weapons is no longer valid."

Alcoholics

IN 1948 there were almost four million alcoholics in the U. S., about one million more than in 1940, according to estimates made recently by E. M. Jellinek and Mark Keller of the Yale Center of Alcohol Studies.

Reported cases increased in every section of the country, Louisiana and Kansas being the only states to show declines. For the past 10 years Nevada, California and New York, in that order, have been the three most heavily af-



flicted states. The latest figures for Nevada show an alcoholism rate of more than eight cases per 100 adults.

Jellinek and Keller found that Alcoholics Anonymous is having a considerable effect. The percentage of increase in alcoholism was generally lower where AA was active.

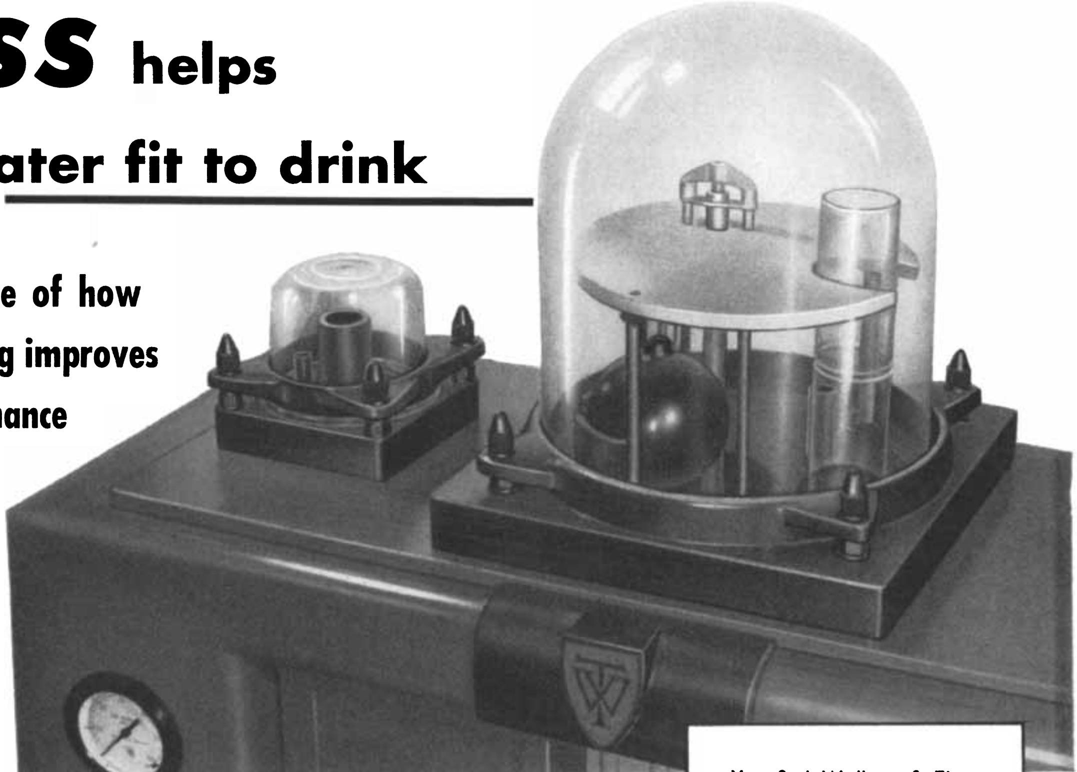
Evolution Observed

BIOLOGICAL evolution is a slow process which man seldom has an opportunity to see in progress. A group of Columbia University workers recently reported that they have observed a clear case of it. In populations of colon bacteria kept in an unchanging environment they have seen new strains evolve and become dominant purely through spontaneous mutation and natural selection.

Francis J. Ryan and two laboratory assistants at Columbia carried out the experiments. They began with a population of bacteria that had been exposed to X-ray bombardment. Some of the bacteria had lost the ability to synthesize the amino acid histidine. This strain, named H-minus, was isolated and put under observation. Before long, although there had been no change in the environment, bacteria that had mutated back to the original hereditary state and could synthesize histidine appeared in this colony. Later some of these H-plus bacteria mutated again, producing a new H-minus strain. As the generations went on, it became clear that mutations were occurring at a constant rate.

There were more mutations from H-plus (synthesizing) to H-minus (non-synthesizing) than the other way around. The scientists calculated from the mutation rates that the two types of populations would eventually stabilize at something like 99 per cent H-minus and 1 per cent H-plus. But this did not happen. After some 200 generations, the proportion of H-plus had stabilized at only one per million instead of the expected one per 100. Mrs. Lillian Wainwright, one of the laboratory assistants, hazarded an explanation which was later proved to be correct. The original H-plus mutation was only one of many that had occurred; there had been a host of others at the same time. All of these were H-minus, but they differed from one another in various ways. Some were not only stronger than the H-plus but also stronger than the parent H-minus strain; these had survived and eventually become dominant. When they in turn produced mutations, the new H-plus strains that appeared were better adapted for survival in the environment than earlier H-plus groups. But at the same time, hardier strains of H-minus, well adapted for survival, appeared as well. And the reason H-plus strains almost disappeared was that the law of averages gave H-minus a far better chance.

GLASS helps make water fit to drink



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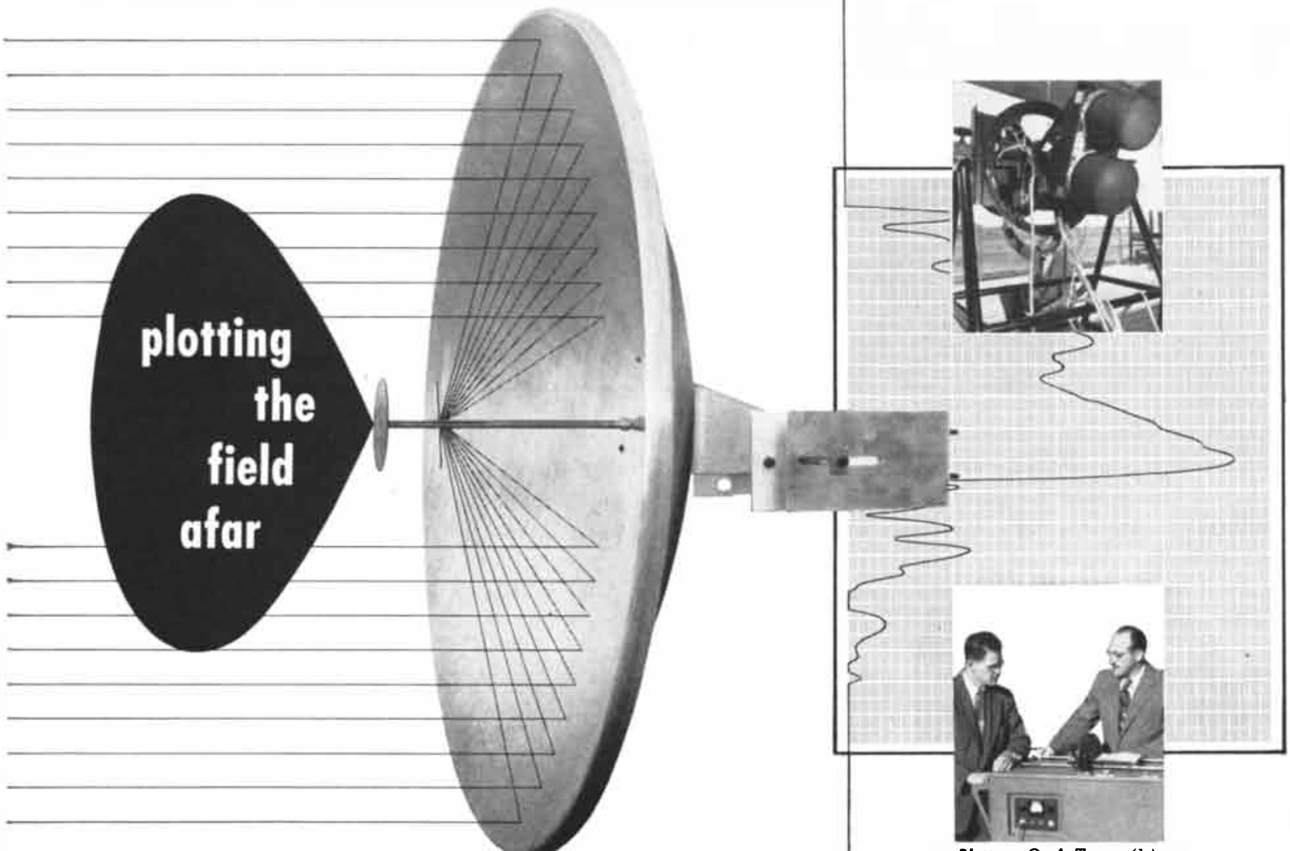
Plotting the radiation pattern of a microwave antenna is typically time consuming and laborious. For some time, workers in this field have felt a need for a continuous non-manual means of performing this operation. The extensive microwave activities of its Research and Development Laboratories have created at Hughes a special interest in such automatic pattern-measuring equipment.

The first automatic machines that were at all accurate were of the fixed location type and weighed nearly a ton. The new Hughes recorder weighs just one hundred pounds, is more accurate, and has higher writing speeds than the earlier machines. Its recording range covers 80 decibels in the audiofrequency spectrum. The writing speed is approximately 25 inches per second, with an 8″x11″ plot, and the abscissa or angle scale is controlled by an electrical take-off system.

In the field of microwave measurements, this machine assists in determining many things—such as



Plotters. *O. A. Tyson (l.) and Dr. L. C. Van Atta worked together in developing this new machine at Hughes.*

the correct shape of reflectors and the proper location of feeds. The development of such improved laboratory tools is an interesting by-product of a large research activity, such as that conducted by the 3500 men and women of the Hughes Research and Development Laboratories.

The growing requirements of both the commercial and military electronics programs at Hughes are creating new positions within the Hughes Research and Development Laboratories. Physicists and engineers who are interested are cordially invited to address correspondence to:

Hughes Research and Development Laboratories • Engineering Personnel Department • Culver City, Los Angeles County, California

Ruling Engines

The increasing demand for diffraction gratings, which sort out the colors of light, is currently stimulating new improvements in the fantastically accurate machines which manufacture them

by Albert G. Ingalls

IT IS no exaggeration to say that the splitting of light into the colors of its spectrum is man's most powerful tool for investigating the universe. Science and technology today could hardly get along without the spectrograph. Astronomers use it to study the stars, physicists to probe the atom, chemists to identify molecules, biologists to explore living substances, metallurgists to inspect alloys, food processors to test food, and detectives to analyze bloodstains.

The simplest way to sort out the colors of light is to pass it through a prism, which bends the light of each wavelength at a different angle and spreads out the separated colors in a band that is recorded on a photographic plate. Most spectrographs still use prisms, as Newton did nearly 300 years ago when he first studied the amazing mixture of rainbow colors in ordinary white light. But the really high-powered modern research spectrograph is based on the diffraction grating. If the spectrograph is man's most potent tool, the diffraction grating is his highest achievement in mechanical precision.

A diffraction grating (*see cover*) is a series of very fine parallel grooves, so narrow and close together that the individual grooves are only indistinctly visible even under a microscope. The grooves, which approach the dimensions of a wavelength of light, deflect light waves over a wide angle, and the waves then interfere with one another to produce a pattern. When a large number of identical grooves diffract a beam of light, the light is dispersed into its spectrum of wavelengths. The principle is altogether different from that of a prism, and a diffraction grating has much more resolving power than a prism of equal width. It also spreads, particularly at the red end of the spectrum, where the prism is of little use.

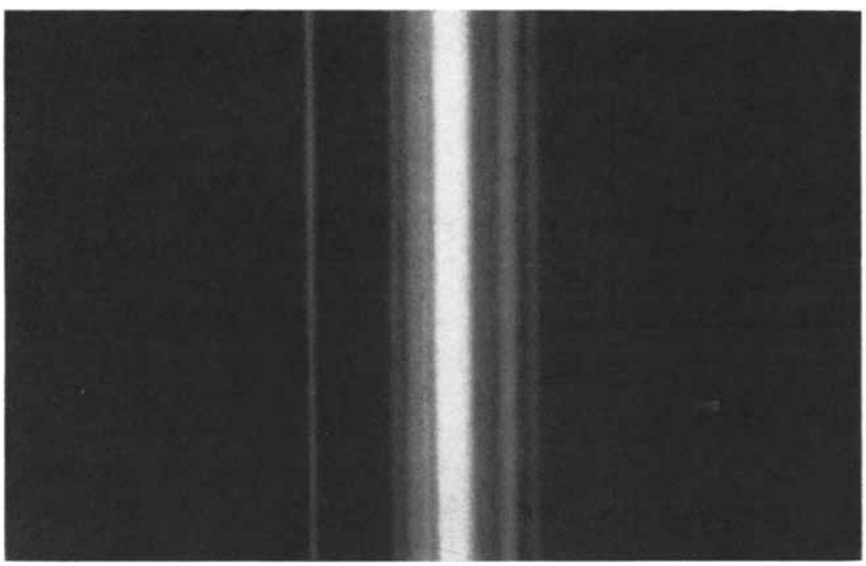
The grating on the cover is a typical specimen of the kind used in research spectrographs. It is made on an optically flat piece of Pyrex six inches wide that has been coated with a layer of aluminum only one-10,000th of an inch thick. In this aluminum layer are ruled the tiny, shallow grooves—14,400 of them to the inch, about 75,000 in the grating as a whole. The minuteness of these grooves is difficult to imagine; they are no wider than the gossamer spun by a spider. And small as they are, all of those grooves must be identical in width, in depth and in contour. Most important, they must be exactly parallel to one another and all spaced precisely the same distance apart: the spacing between one groove and the next cannot vary by more than one-millionth of an inch from the specified distance of one-14,400th of an inch.

The Machine

The specifications are fantastic, but even more fantastic is the ruling engine that has been contrived to do the job. This machine, less complex in structure than a typewriter, is the most precise mechanism ever made. It is so transcendently difficult to build and operate properly that it has challenged man's mechanical genius and humbled his pride for more than a century. Fewer than a dozen ruling engines in the whole world have ever been able to turn out diffraction gratings in any appreciable number, and some of these machines have spent more time in the "repair shop" than in production. Most of the world's research gratings have been produced by three dependable engines at the Johns Hopkins University, which have ruled about 1,000 since 1882. So difficult is the ruling of gratings, and so great the demand, that applicants must often wait two years to get one.

There is no regular manufacturer of ruling engines. Each is designed and built individually, usually by an experimental physicist and his scientific instrument-maker or technician. All are different, yet nearly all are variations on the classic three at Johns Hopkins. The top drawing on page 48, based upon one of these but very greatly simplified, shows how a typical ruling engine is constructed.

The grooves of a grating are plowed,



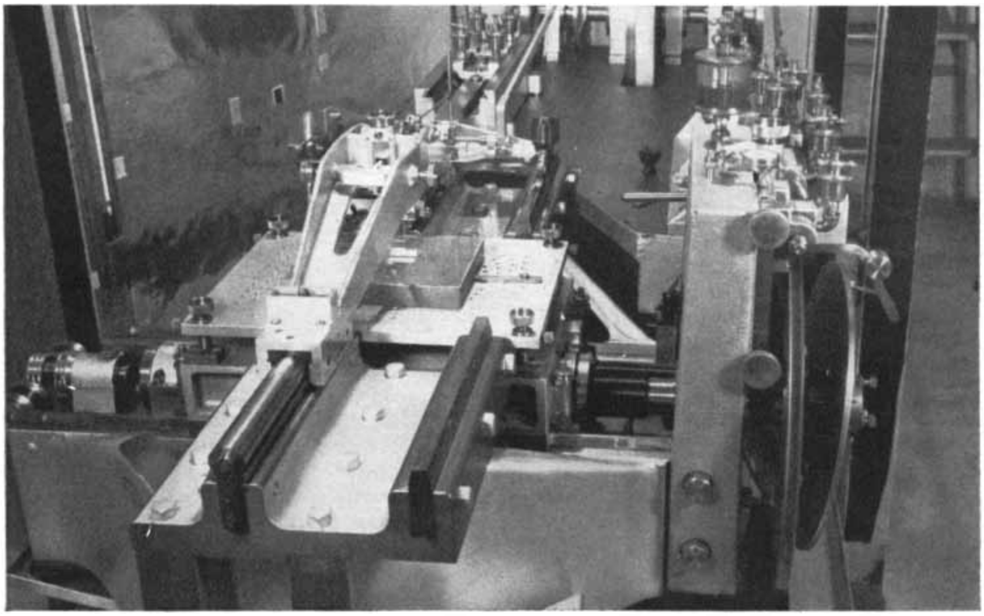
GREEN LINE of the mercury spectrum is split into finer lines by a 5-1/8-inch grating from the new engine at the Johns Hopkins University.

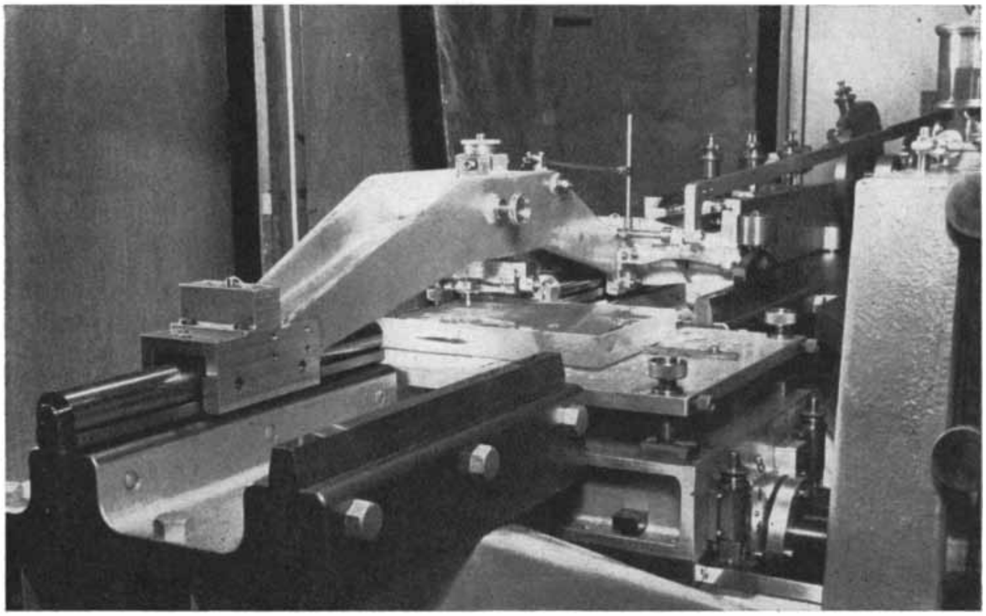
edge to edge, by the right-angled keel of a diamond about one-sixteenth of an inch long. The diamond is attached to a sliding carriage that shuttles back and forth on lubricated crossways. Pressing lightly on the aluminum layer with no more than the weight of a coin, the diamond rules a groove, displacing but not removing the soft metal, and then is lifted by a cam and lever and returned for the next work stroke. While it is returning, the grating is shifted into position for the next groove. It lies on a second carriage driven by a high-precision screw, which turns a tiny fraction of a revolution for each shift of the grating carriage.

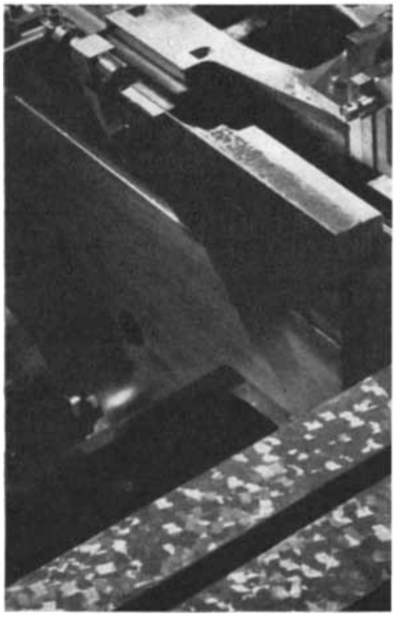
These simple motions, very similar to those of the human hands in ruling parallel lines on paper, are made at the rate of about 10 cycles a minute. The machine plods patiently, all but inaudibly, through an uninterrupted six-day stretch to rule a grating 5⅛ inches wide on which there will be three miles of grooves each 3⅜ inches long.

Why has this simple machine frustrated so many able men? The dream of building a ruling engine has haunted hundreds and ruined many. Recently a friend hauled out of a dark cubby an embryo screw for a ruling engine, fondly fingered it as he showed it to me, and talked of long-deferred plans to quit his vocation and build an engine. "Over my dead body!" exclaimed his wife, to whom he had once unwisely revealed that a man might spend 10 nonproductive years curing a chronic case of ruling-engine fever the hard way. One mechanic recently rushed to his basement to "build an engine in three weeks." Some months later he surrendered, minus $15,000 and plus "experience." When an Australian nurseryman named H. J. Grayson died after years of this acute malady (in the course of which he did, however, accomplish much), his widow bitterly burned all his ruling-engine papers.

The central difficulty that has defeated so many efforts is the inherent deformability of any material of which a machine may be built. The spectros-

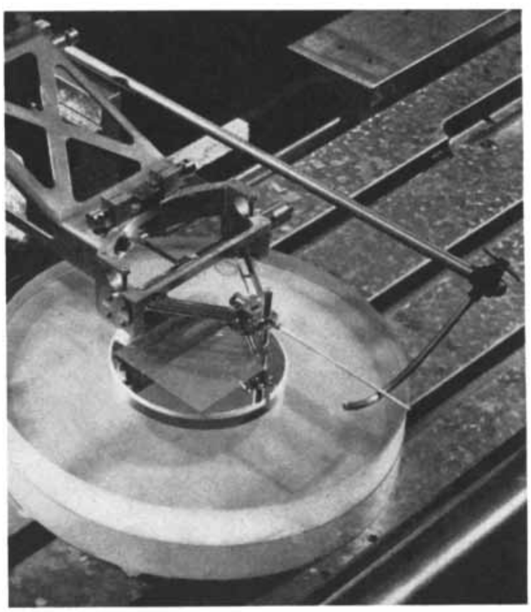






TWO RULING ENGINES are shown in these four photographs. At the upper left is an over-all view of the engine of the Mount Wilson Observatory at Pasadena, Calif. At the lower left is a close-up of the Mount Wilson engine with a square grating blank under its diamond point. At the upper right is an over-all view of the engine of the Bausch & Lomb

copist John A. Anderson, for years in charge of the ruling engines at Johns Hopkins and today the dean of authorities on the art, has calculated that a hypothetical ruling engine made of perfectly rigid materials might rule grooves within one five-millionth of an inch of perfect uniformity—five times the necessary precision. Unhappily no perfectly rigid materials exist. In any real ruling engine the elastic deformation of its parts as the engine moves greatly exceeds the groove tolerance of one-millionth of an inch. For example, in the engines at Johns Hopkins the large steel screw that shifts the grating carriage bit by bit is elastically compressed at the start by one-100,000th of an inch—10 times the error tolerated on the grating it pushes. Elastic deformations elsewhere, and changes in the thickness of the lubricating films between the screw and the nut in which it turns, raise this uncertainty of position of the diamond to one-10,000th of an inch, which is 100 times the tolerance. On the scale of ultra-ultra precision with which we must deal in a ruling engine we may regard the machine as made of rubber. In effect it has just about the same problem as an intoxicated man called upon to pass a test of sobriety: it must place the tip of its finger (the diamond) on the tip of its nose (the groove position) within a millionth of an inch, and it must do this with a rubber arm and body!



Optical Co. in Rochester, N. Y. At the lower right is a close-up of the Bausch & Lomb engine with a round grating blank in place.

It is impossible, of course, to visualize a millionth of an inch. The vertical shaft of the letter "i" in this type is a hundredth of an inch wide. Mentally divide it into 10,000 parts. This is the scale on which a ruling engine must operate with controlled fixity. Not only must the engine position the diamond within a millionth of an inch, but it must control the diamond with equal precision all along the groove. And it must do this thousands of times, always in exactly parallel paths.

Seven Demons

Ruling-engine workers speak of seven demons that bedevil their work. Of these the archfiend is friction. If the machine's elastic deformations were the same at each stroke, the grating carriage would still shift uniformly and there would be no problem. Unfortunately the friction of the grating carriage on its ways cannot be held uniform within better than one part in 200. The trouble lies in the limitations of lubrication. If the carriage ways and screw were given complete lubrication (*i.e.*, a plentiful film of oil), the friction would be virtually uniform, but variations in the thickness of the oil film would shift the diamond out of line. This error is avoided by using what is called boundary lubrication—oil films only a few molecules thick. But now we sit uncomfortably on the other horn of the dilemma. The thin films are continually disrupted at shifting spots along the ways, and wherever they break down we get the friction of metal-to-metal contact. The friction is of the "stick-slip" kind, with the carriage sticking and then suddenly slipping as the broken film repairs itself. In other words, we have a continually varying mixture of fluid and solid-to-solid friction, with the proportion of each kind always changing. The physical principles that govern these two kinds of friction are entirely different, fluid friction being proportional to area and independent of load, and solid friction *vice versa*. Hence the force required to overcome them is also different. All this explains why the friction cannot be held more uniform than one part in 200.

The second of the seven devils is wear of the engine parts. Wherever the metal of the moving carriage grabs the metal of the ways through the oil film, it removes bits of the surface. With the diamond carriage traversing its ways 150,000 times per grating, this is serious, in terms of the tolerance of millionths of an inch. The ways wear crooked, putting errors on the grating.

The third devil is warpage of the grating ways. A piece of hard metal is not the inwardly contented thing it seems to be; it contains locked-up stresses that were put into it by its cooling from the molten state and by forging, grinding and machining. Unless these stresses are totally removed by heat treatment and aging, they will warp the metal as they seek to relieve themselves. Although the ways of a ruling engine are made fantastically straight to begin with, a little warpage always occurs after a time.

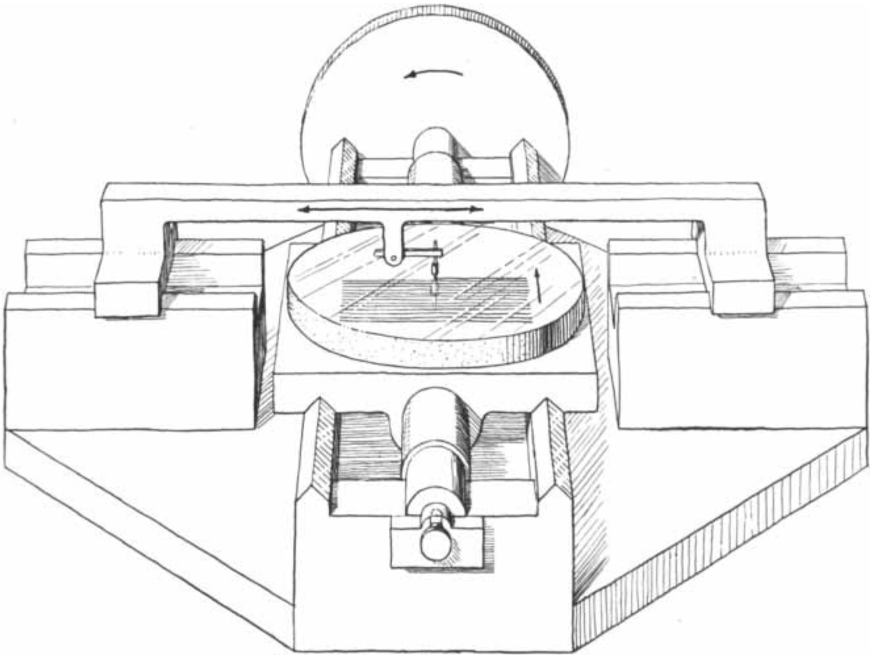
The fourth devil is creep, a gradual and permanent deformation that takes place in metal over long periods even when the stress on it is below its elastic limit.

The fifth devil is vibration. Any vibration at the diamond that exceeds an amplitude of one-millionth of an inch will produce a crooked groove. Even the swaying of trees in the vicinity of a basement-grounded ruling engine may alter the position of the diamond, as a puzzled and exasperated operator once learned after a long search for the culprit.

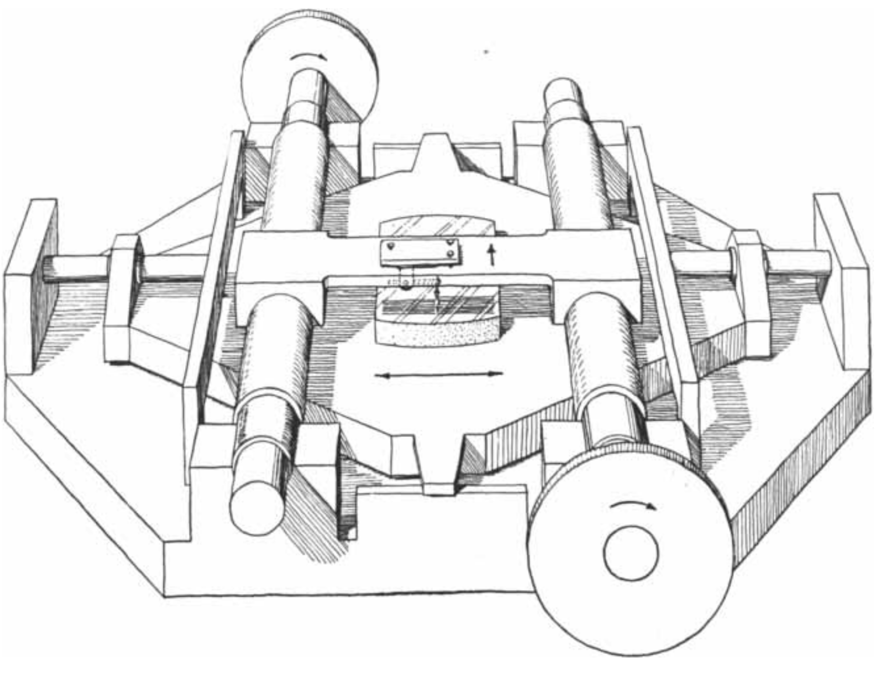
The sixth devil is dust. The fit between the screw and the nut must be so nearly perfect that a single particle of dust between them will cause the screw to bind and throw off the spacing. And any dust particles that get under the diamond will affect the ruling of the groove.

The seventh devil is changing temperature. Since a rise or drop in temperature expands or contracts the parts of the engine unequally, it will affect the grating-carriage shift and spacing. The temperature in the room where the machine is operating must therefore be kept constant within one-hundredth of a degree. While watching a ruling engine at work at Johns Hopkins, I discovered I was a stove. In the room outside the doubly glazed enclosure around the engine I ran the mercury up from 85 degrees Fahrenheit to 85.1 within a few minutes, and I had to depart to avoid damaging the thousand-dollar grating that was being ruled inside the enclosure.

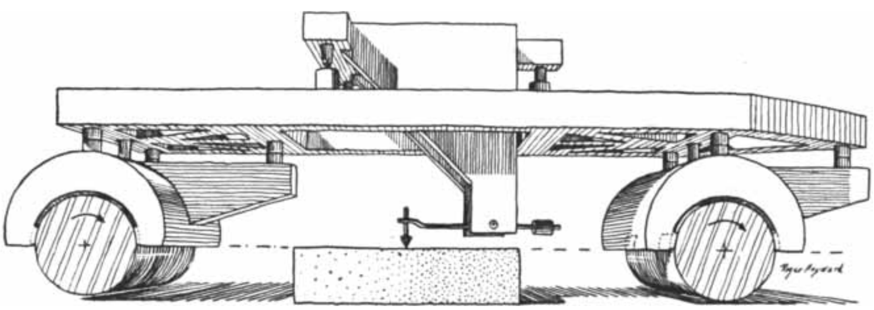
The seven devils go into huddles, conspire, chuckle and confound the harried operator. Scarcely a ruling-engine builder has been able to undevil his engine in fewer years than he needed for building it; in fact, the devils never stay exor-



ROWLAND ENGINE, shown in simplified drawing, has a single screw which shifts the grating carriage. The diamond point shuttles over the grating.



STRONG ENGINE has two screws which shift the diamond point rather than the grating carriage. The grating shuttles beneath the diamond point.



DIAMOND POINT of the Strong engine is suspended from a carriage that rests on two long nut sections. Only these "fingertips" touch the screws.

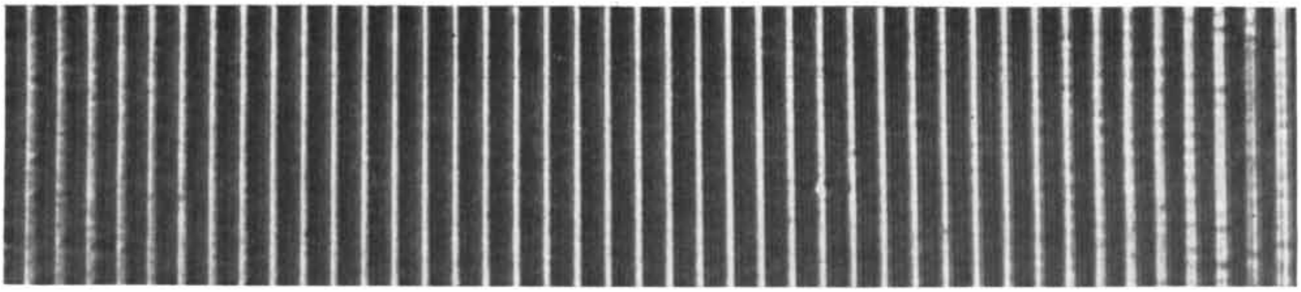
cised, and the battle against them is perpetual.

All this helps to make clear why the widest grating ever ruled was but 9.4 inches. The wider a grating (*i.e.*, the more grooves), the more sharply it will separate the myriads of wavelengths in the spectrum of light. With more minute resolution of the spectrum, physicists could examine the interior of the atom more intimately. For 50 years ruling-engine makers have pursued the dream of ruling gratings 10, 12, 18 or even 24 inches wide. But six to eight inches has generally been the limit of feasible accuracy. The errors injected by the seven demons are cumulative; indeed, they increase more rapidly than the step-up in width. The basic difficulty is that friction grows in proportion to the weight of the grating and carriage, which in turn grows in proportion to the cube of the grating width. Other aspects of the principle of dimensions or of "similitude," so lucidly set forth by Galileo, heavily penalize increasing scale in mechanics, as they do in animals.

Many have proposed to get rid of the screw's various errors by throwing it out altogether. They have suggested that the diamond be shifted instead by a hydraulic-jack type of micropump or by the alternate magnetization and demagnetization of an iron bar, which shrinks microscopically each time it is magnetized. The trouble with these substitutes is that each of their strokes is a separate performance, and any error in the length of the stroke is cumulative. The screw, on the other hand, is all of one piece and therefore has "memory"; it knows just where it has been, where it is and where it is going. Thus with its unified performance it can rule a grating as a geometric whole; it can position every groove with relation to the very first one. If the screw did not exist, it would be necessary to invent it for the ruling engine. In fact, it was the invention of a method for making a high-precision screw that made the ruling engine possible.

The Rowland Machine

The man who did this was the Johns Hopkins physicist Henry A. Rowland, who died in 1901 but will remain immortal as the father of the ruling engine. Rowland had been preceded by a few earlier pioneers: in 1814 Joseph von Fraunhofer, the father of the spectroscope, had made a crude ruling engine with which he ruled a grating half an inch wide with 4,000 grooves; about 1845 a Prussian instrument-maker, F. A. Nobert, had ruled 6,000 better-spaced grooves in an inch, and in the 1870s a New York amateur astronomer, L. M. Rutherfurd, had made gratings, almost two inches wide with 35,000 grooves, which surpassed the prism in resolving



GROOVES of a grating made at Johns Hopkins are made visible by a photomicrograph. There are 14,400 grooves to the inch. The steeper face of each groove (*see drawing at bottom of page*) is lighted from the right.

power. But by modern standards none of these early gratings had uniformly spaced grooves.

In 1882 Rowland and his mechanic, Theodore Schneider, in one great leap forward achieved the modern ruling engine. Rowland devised a lapping nut for finishing the high-precision screw that moves the grating carriage (*for details of the method see page* 90). With his very first engine he ruled gratings six inches wide and far more uniformly spaced than those of his predecessors. Rowland built two more engines, and those three machines have not only ruled most of the research gratings produced to date but have been the models for nearly all the other engines made since Rowland died in 1901.

In 1909 Anderson took over the job of ruling gratings on the Rowland engines. He rebuilt one machine and made a new screw for another. He ruled scores of six-inch gratings with more than double the resolving power of Rowland's, because their grooves were spaced better. Anderson's work was so precise that until very recently his gratings, made in the second decade of this century, were the closest to perfection ever ruled.

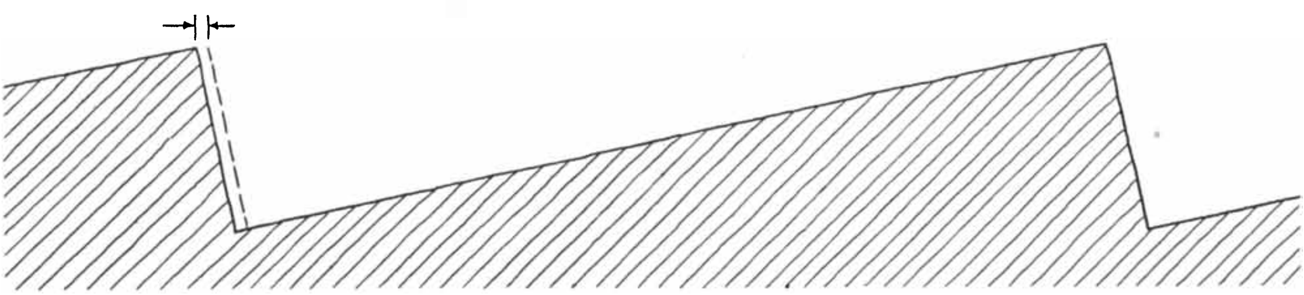
The fashioning of the screw itself is only the beginning. To make screw threads accurate enough to deliver precision within a millionth of an inch is a sufficiently difficult task, but according to Anderson it is five times more difficult to bring into proper alignment the end bearing pivots on which the screw turns. The axis of these pivots must be brought into coincidence within a millionth of an inch with the axis defined by the screw threads. This problem is illustrated in the drawing on page 50. It shows a faulty screw in which the two axes are not in coincidence. It is easy to see that when this is the case, the screw will wobble as it rotates. The result is an irregular grating that produces spurious spectral lines called ghosts. Besides this, ghosts may be caused by periodic endwise motions of the screw against its end-thrust bearing, a gemstone flat within a millionth of an inch and at right angles with the screw within two seconds' angle. That alone is a greater source of trouble than imperfections in the screw itself.

The apparently simple problem of attaching the grating carriage to the nut that moves it (*via* the screw's rotation) involves double the difficulties of mounting the screw. The trouble arises from the fact that the carriage ways and the screw are not absolutely parallel. Mechanical perfection being only approachable, never attainable, the pivots of the screw can never be set exactly parallel with the ways along which it pushes the grating, nor can the axis of the screw be perfectly coincident with its pivots. In an automobile a very small deviation from the parallel in alignment of the wheels is unimportant. On a ruling engine everything is important, especially very little things. Due to this departure from geometrical perfection, deforming stresses build up in the engine as the screw forces the grating along the ways, and sometimes it moves by little sudden slips, which are magnified because the screw is under compression. These slips put errors on the grating. The coupling between the nut and the carriage, a kind of two-dimensional hinge, is designed to render these crampings innocuous. It succeeds in part, at least when cajoled by the technician.

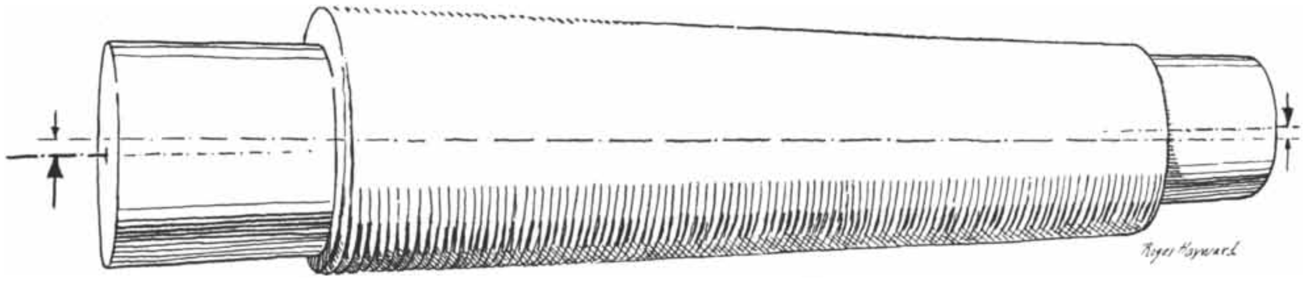
Finally, to top everything, there is the fact that the diamond carriage wears its guide ways crooked while it travels six miles in the course of ruling a grating; Anderson has found this problem of wear many times more troublesome than any other.

In short, the machine has an "impossible" assignment. Yet the gratings are made—by prodigies of ingenuity and pains and large doses of intuition. For a grating is ruled by the operator as much as by the machine. Descend these basement stairs. Enter this vault. Gaze through this glass wall into the coop where stands the machine itself. The engine is running but not ruling. It will take five hours to "warm up" to the point where the temperature rise from friction (2.5 degrees) will level off so that the temperature thereafter stays uniform. After about 15 hours' more "dry run" the machine's lubricating films will reach the necessary uniformity in thickness. Only then will the diamond be lowered and begin to rule a grating. If the operator is trying to rule an exceptionally good grating, these meticulous preparations are but the final stage of a much longer process. Before the engine was even set running, the technician and the operator had already spent weeks or months making test rulings and infinitesimal adjustments for this one job.

Bemused, you strain to see what else is done to make possible the impossible. But you finally give up; it must be something the technician whispers to the engine, to which he has been married for



CROSS SECTION of the grooves has the shape of a flight of shallow steps. Each step is one-14,400th of an inch wide. The accuracy with which they are ruled is within a millionth of an inch (*two arrows at upper left*).



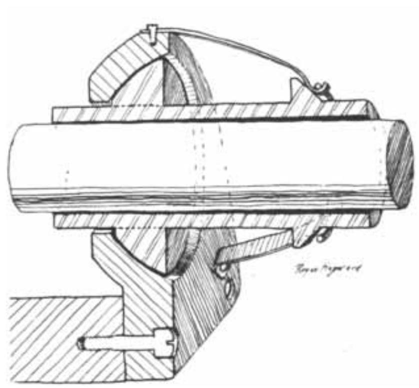
WOBBLING SCREW may result from incorrect alignment of pivoting ends, as shown here in exaggerated form. The axis of the threads and through the end pivots must then be the same to within a millionth of an inch.

enough years to know its every kink.

The ruling engine is a cantankerous prima donna which Anderson likens to cats—inscrutable and unpredictable. The Nobel-prize physicist A. A. Michelson, who himself became deeply involved with ruling engines, once wrote: "When the accumulation of difficulties seems to be insurmountable, a perfect grating is produced, the problem is considered solved, and the event celebrated with much rejoicing—only to find the next trial a failure. One comes to regard the machine as having a personality—I had almost said a feminine personality—requiring humoring, coaxing, cajoling, even threatening!"

These capricious performances occur because a ruling engine operates at the ragged outer edge of the barely possible, where logic and fact seem scarcely to control. The bridge between the impossible and possible is largely the technician's intuitive feeling for mysterious causes of trouble.

Is there no way to do the job more reasonably, or to make larger gratings? After Rowland built his three machines, there came 50 years of hopes and disillusionment—a series of long struggles like those of the sweating Sisyphus in Hades vainly trying to roll his rock to the hilltop. Since the end of the war the increased demand for gratings has generated a new ferment in the little ruling-engine world. One very promising engine of a completely new type has emerged, and attempts to solve the problem of ruling wider diffraction gratings have also been renewed. Let us look at the various efforts that have been made to improve on Rowland's design.



TAPERED SLEEVE in the Strong engine keeps itself centered on the cylindrical ways by pressure of oil.

Michelson's Beauty

In 1906, after six years of work, Michelson produced a modification of the Rowland engine. Hoping to cope with the stick-slip friction that distorts the machine, he placed ball bearings under the screw and grating carriage. His engine was designed to rule gratings 14 inches wide, and it did produce the world-record 9.4-inch grating. The grating set no record, however, for quality. Michelson soon turned from this machine to build another. His original engine is now at the Massachusetts Institute of Technology, where it has been rebuilt since 1948 by the spectroscopist George R. Harrison in an experiment based on a new approach. The idea is that it might be better to give up the attempt to refine the ruling engine further, and instead try to build an error-correcting mechanism into the machine: in short, the feedback idea, which M.I.T. has been pioneering in many fields. To the Rowland engine the M.I.T. workers have attached an electronic servo-mechanism which is designed to correct the diamond as soon as it begins to deviate by as much as one five-millionth of an inch from its charted course. The hope is that this symbiotic electronic-mechanical combination will perform precisely enough to rule good gratings 20 inches wide. The exquisite machine, as large as a grand piano, is so delicious a piece of workmanship that a craftsman is tempted to hug it, though this would be messy, for the engine is submerged to its ears in 350 gallons of lubricating oil.

But let us get back to Michelson. Between 1910 and 1917 he built his second machine, this time with the more modest goal of 12-inch gratings instead of 14-inch. The great experimental physicist, rich in honors won for other work on light, spent the rest of his life (until 1931) trying to rule wide gratings with this machine. His contemporary R. A. Millikan has reported: "Michelson often said he regretted that he ever 'got this bear by the tail,' but he would not let go, and, in spite of endless discouragements, at the end of about eight years of struggle he had produced a good six-inch grating containing 110,000 lines, which was 50 per cent better than the best otherwise produced at the time."

After Michelson's death the University of Chicago physicist Henry G. Gale completely rebuilt his engine. To minimize friction and flexure Michelson had floated the grating carriage in mercury, which took most of its weight off the carriage ways. Gale also relieved the screw of variable elastic deformation by mounting the carriage on ball bearings. These rolled on top of a second carriage that slid on oiled ways. The second carriage was moved by a non-precision screw of the same pitch that brought the grating nearly to position for each groove, the precision screw then doing only the final positioning. It should have worked wonderfully well, but ironically the simple Rowland engines at the Hopkins, resembling old meat slicers, kept turning out good gratings while the luxury engines, with their ball bearings and beauty, did not seem to arrive. Down through the decades the Plain Jane engines of Rowland and Anderson, taken over later by R. W. Wood and Wilbur Perry, have delivered reliable research gratings at the rate of 30 or 40 a year.

At the end of a decade Gale had ruled only a score of high-grade six-inch gratings. In 1947 the University of Chicago gave the Michelson-Gale machine to the Bausch & Lomb Optical Co. of Rochester, N. Y. There it has been rebuilt again by David Richardson and his technician Robert S. Wiley. They have ruled 30 gratings of very high quality with up to 30,000 grooves per inch, a spacing that gives spectra in the ultraviolet. The Bausch & Lomb workers have set a goal of 6-by-8-inch gratings for 1953 and possibly 6-by-12-inches by 1955.

Let us shift the scene and read the annals of another ruling engine at Pasadena, Calif. Beginning in 1912 the Mount Wilson Observatory built a monster Rowland-type machine with capacity for 18-by-24-inch gratings. Then followed a heartbreaking tussle for 30 years before the engine faded away without ruling a grating wider than eight inches. The troubles were mainly warpage and wear. Even with all we have learned about the hardening and stress-relieving of metals to cope with

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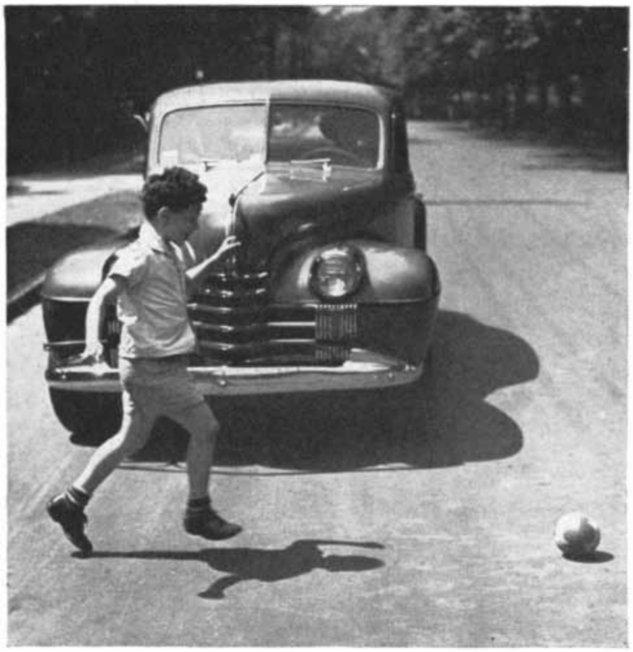

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warpage and wear, the 24-inch grating remains a dream; the physicist today would settle for 15 or even 12 inches.

Realistically, Mount Wilson lowered its sights after its 24-inch engine failed. The physicist Harold D. Babcock and others built a 10½-inch engine of the Rowland type with essential innovations in design and materials. By 1948, after designing and redesigning, building and rebuilding, Babcock and his skilled instrument maker E. D. Prall had brought the machine to rule excellent 7½-inch gratings, with grooves six inches long, for critical research uses. Since then Harold Babcock's son, Horace, has ruled 12 gratings of the same dimensions for use in astronomical spectrographs. At least half a dozen of these, ruled with extraordinary pains, are the finest gratings in existence today.

The Strong Engine

We come now to a really radical postwar innovation in the ruling-engine field. In 1950 the Johns Hopkins experimental physicist John Strong entered the sweepstakes with an engine far different from the Rowland type. The capacity of his first model is a modest six inches, but its strength is its reliability and its production potential. Strong invented powerful immunities against friction, variable oil-film thickness, flexure, wear and thermal expansion. His machine is so contrary to the Rowland design that technicians remark he has "turned the ruling engine upside down"—though some think he may have found it upside down and turned it right side up.

Strong came to ruling-engine work with uncommon qualifications: a knowledge of both theoretical and experimental physics, a familiarity with machine tools, natural mechanical ability and a willingness to get his hands dirty (he grew up on a Kansas farm). During the 1930s Strong, then a young experimenter at the California Institute of Technology developing a practical method of depositing aluminum films on glass for mirrors and gratings, was a member of a select group in California known as the Hundred-to-One-Shot Club. It consisted of a dozen physicists, astronomers, chemists, mechanics and telescope makers, including Roger Hayward, the illustrator of this article. The ruling-engine expert Anderson, who had come to California to help build the 200-inch Hale telescope, was also a member of the club. The group often went on desert camping trips, mainly for conversation, and around the campfire Anderson would discuss his pet subject—the ruling engine. One of Anderson's observations especially stuck in Strong's mind: he suggested that a proper starting point for improving the machine would be the invention of a substitute for the diamond-carriage ways.

In 1945 Strong found himself at Johns Hopkins in charge of the very engines Anderson had operated 30 years before. With Anderson's early advice in mind and after three years' observation of the strategic limitations of the Rowland type of engine, he designed his new engine. With the help of Office of Naval Research funds he assembled a group of six engineers and fine mechanics and built the six-inch machine.

When the glistening steel engine was finished in 1950, its gratings soon met standard requirements, without the usual agonizing years of taming the shrew. The scheme of his machine is shown in the middle drawing on page 48. What Strong did was to make the grating carriage shuttle back and forth under the diamond, instead of the other way around. The diamond is stationary during the work stroke and then is shifted for the next groove. It is inched along by not one screw but two.

The Demons Slain

By this stratagem Strong with one blow killed off the worst of the demons that bedevil the Rowland engine. Only the light diamond, rather than the heavy grating-carriage, is shifted by the screws. Out go the carriage ways, and with them out goes most of the stick-slip friction. The diamond carriage simply rests on the screws, which move it along by turning in nut-threads on the carriage's underside. The ways for the grating carriage, so troublesome in the Rowland engine because of wear, also are eliminated. Instead, the hollow, light grating-carriage slides back and forth on cylinders within sleeves at the ends of the carriage. Between each cylinder and its sleeve is a good thick film of oil, providing complete lubrication. Yet by an ingenious arrangement Strong made sure that the oil-film around the cylinder-guide stays uniform in thickness, thereby keeping the cylinder centered in the sleeve. Here is how he did it: The cylinders are made round and straight within a millionth of an inch (by a method he invented), and the sleeves that encircle them are purposely made to fit only loosely around the cylinders. At the left hand end in each case there is a thousandth of an inch of space between the cylinder and the sleeve; at the right hand end, half again as much. The shape is like that of a gradually sloping funnel (*see drawing at bottom of page 50*). As each sleeve slides endwise on its cylinder, it scoops up the oil and crams it into a converging circular wedge. The sleeve centers itself on the cylinder as the oil trails out of the narrow circular orifice. The forces that center the sleeve are strong, and rapidly increase with distance off-center. At one millionth of an inch the correcting force is two pounds; at one-10,000th of an inch, 200 pounds. Should the carriage try to yaw, changing its angle, the oil

imbalance would shoulder it quickly into line.

The two identical screws serving as ways, and the self-centering slider guideways, are the cardinal features of the Strong engine. They virtually get rid of the most satanic of the seven devils—inconstant friction and wear. Harrison declares that Strong's engine "marks the greatest improvement in the ruling art since the days of Rowland."

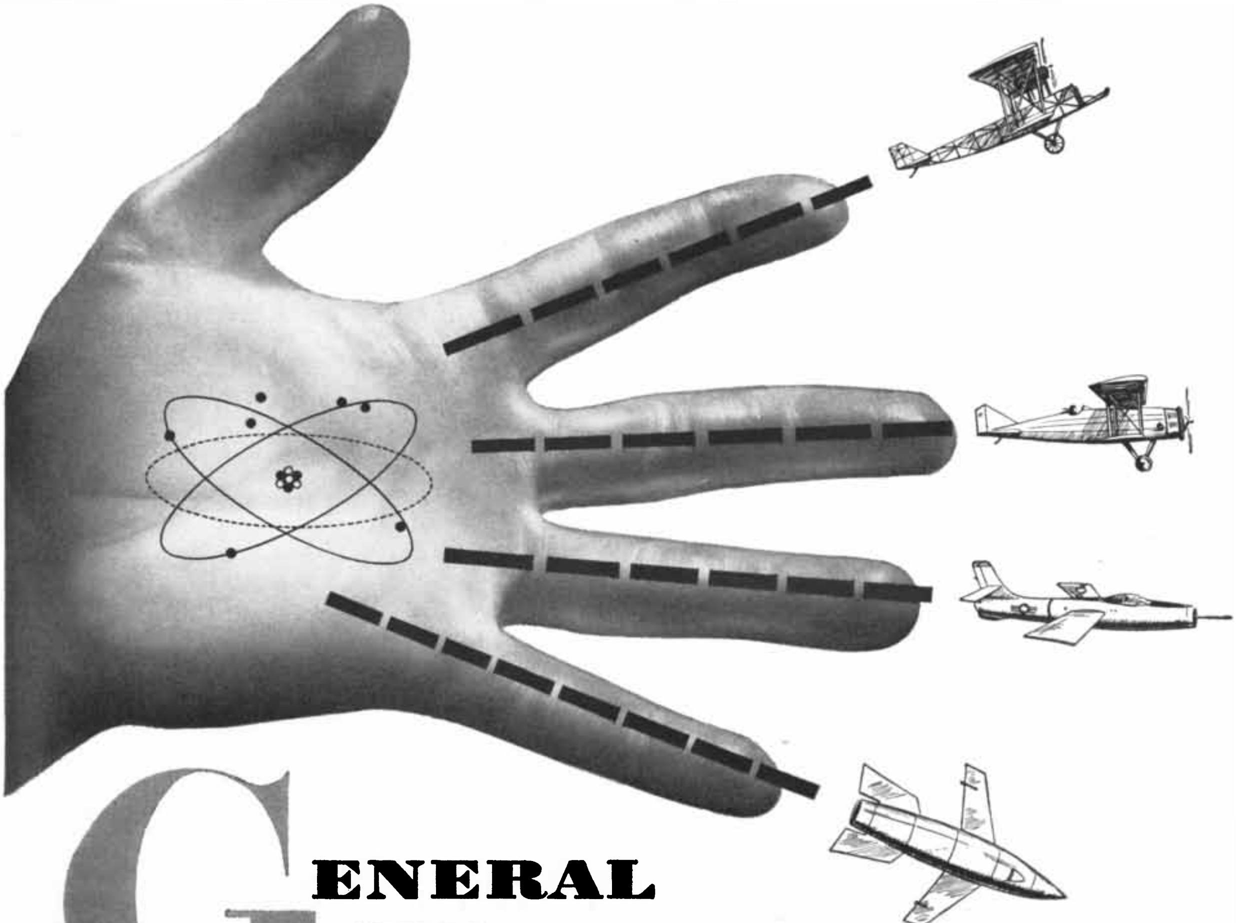
This is not all. The Strong engine embodies additional immunities against error. The nut sectors that rest on the screw, gripping it like fingertips, are shrewdly contrived. They make their contact on the sides of the screw at points almost level with the neutral central axis, and thereby eliminate any error due to gravitational sag of the screw. They also counteract the effect known as "snaking"—a side-to-side motion due to drunkenness (wobbling) in the screw-threads. Moreover, because the diamond is in the plane of the screw, the arrangement forestalls another evil known as "caterpillaring": an up-and-down pitching motion. Such pitching would seriously alter the grating spacing. Again, the open-bottomed nuts resemble pipe wrenches, and behave like them, much to the advantage of the engine. As the screws rotate to advance the diamond, they tend to open the flexible nuts so that they pinch less firmly, and this minimizes stick-slip friction. After the screw has finished turning, the nuts automatically pinch again. Strong calls this "negative pipe-wrenching."

Since the Strong engine started work last year, it has ruled 65 gratings. Not all of them were first-class—no engine ever does that. The percentage of near-perfect large gratings from any ruling engine is like the percentage of superlative compositions by a Beethoven. The Strong engine, however, is not only reliable but rules gratings in half the usual time of a Rowland engine, because its strokes are faster.

A second Strong engine of the same size as the first, but designed to rule 28,800 grooves per inch, is now almost completed. What a much larger engine of the Strong design could accomplish is still to be seen. Strong plans to build a 12-inch machine next.

Who can say which of the several approaches to the large grating is the best? Is the classic type, with modifications, quite capable of excellent performance in a larger version, as the Babcocks think? Is the classic engine designed wrong for success with large gratings, as Strong thinks? Or is its conception wrong for ruling large gratings unless it can be made to correct its own errors, as Harrison thinks? The next 10 years may tell.

Albert G. Ingalls is a contributing editor of this magazine.



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WILLIAM HARVEY

The 17th-century English physician who discovered the circulation of the blood was a poor experimenter but laid the basis of modern biology and medicine

by Frederick G. Kilgour

AND I remember that when I asked our famous Harvey, *in the only Discourse I had with him, (which was but a while before he dyed). What were the things that induc'd him to think of a* Circulation of the Blood? *He answer'd me, that when he took notice that the Valves in the Veins of so many several Parts of the Body, were so Plac'd that they gave free passage to the Blood Towards the Heart, but oppos'd the passage of the Venal Blood the Contrary way: He was invited to imagine, that so Provident a Cause as Nature had not so Plac'd so many Valves without design: and no Design seem'd more probable than that, since the Blood could not well, because of the interposing Valves, be sent by the Veins to the Limbs; it should be sent through the Arteries, and Return through the Veins, whose Valves did not oppose its course that way.*

The Irish chemist Robert Boyle reported this interview with William Harvey in his *Disquisition about Final Causes of Natural Things,* published 31 years after Harvey's death. It is the only recorded statement from Harvey of the clue that led him to his great discovery—an Alpine peak in the history of biology. This man who laid the basis of modern medicine is hardly known today except as a name. His classic work, written in Latin and titled *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* (Anatomical Studies on the Motion of the Heart and Blood in Animals), is widely celebrated but little read. Both the man and the work are actually much more interesting than their conspicuous obscurity might suggest.

"Our famous *Harvey*" was born of yeoman stock at Folkestone in 1578; his father later became mayor of the city. Harvey was a schoolboy of 10 when the Spanish Armada sailed against England; he set up practice as a physician in London in the last year of Elizabeth's reign; he gave his first lecture on the circulation of the blood in 1616, the year that Shakespeare died. Like Shakespeare, Harvey left us his works but not very much about himself. Most of our knowledge about his person and character derives from the librarian and biographer John Aubrey, who wrote a "Brief Life" on him. Harvey, says Aubrey, was a very short man with a "little eie, round, very black, full of spirit." He was temperamental and had his eccentricities. As a young blood he wore a dagger in the fashion of the day and was wont to draw it on slight provocation. It is a matter of record that he married at the age of 26, but nothing is known about his wife or family life, except that he had no children. In his later years (he lived to the age of 79) Harvey liked to be in the dark, because he could think better, and he had underground caves constructed at his house in Surrey for meditation.

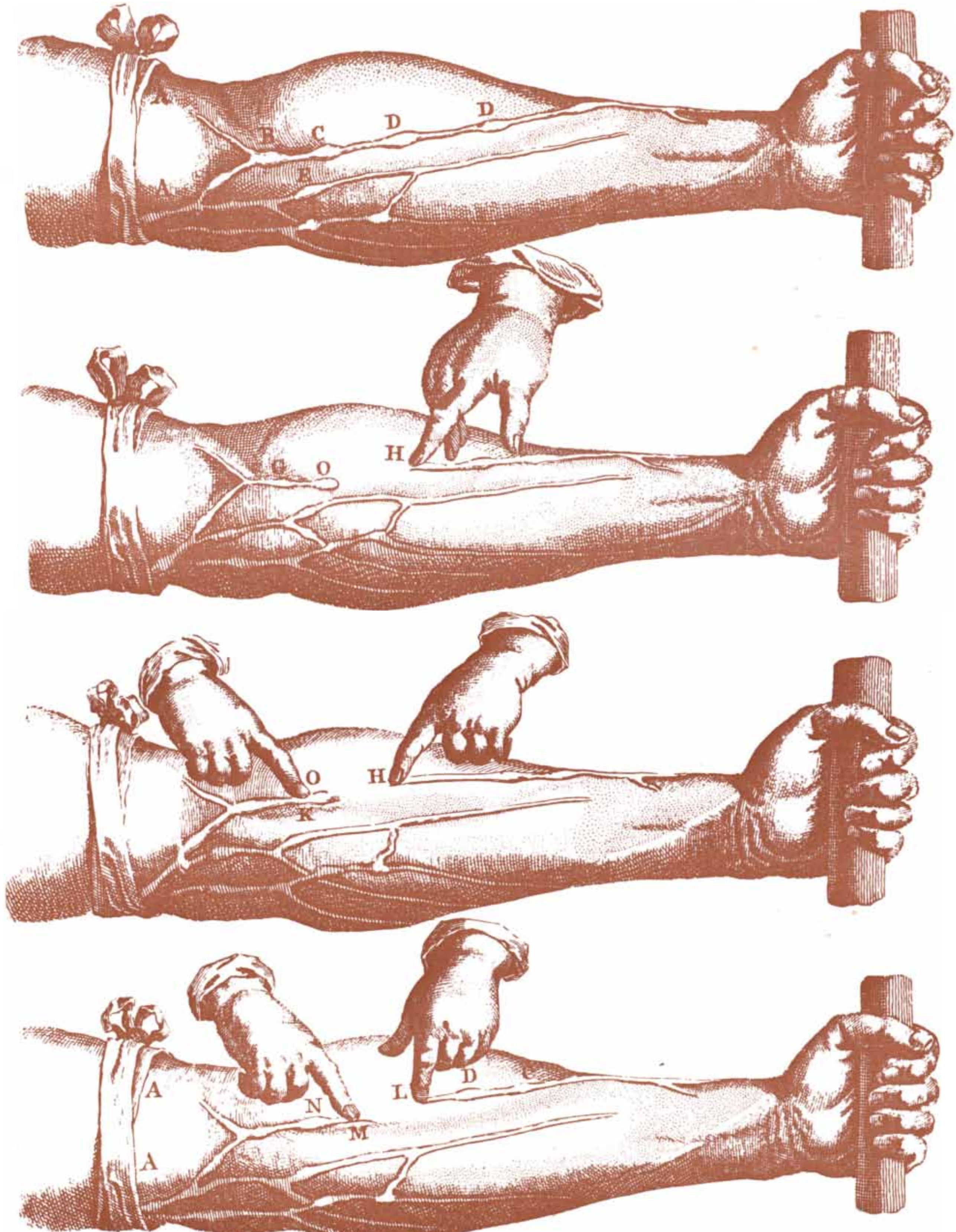
Harvey is known to have been a copious scribbler. He wrote hastily, and all but illegibly, in a mixture of Latin and English, and was a careless speller: in one place in his notes appears the word "piggg"—an unusually liberal number of "g's" even for 17th-century English. Aside from his classic *De Motu Cordis,* few of his writings survive. One reason is that he lost many of his papers during the Civil War of 1642, when rioters looted his house in London and destroyed his manuscripts while he was away in Nottingham with Charles I, to whom Harvey was Physician-in-Ordinary. Harvey later said this loss was the most crucifying he had ever experienced.

A dynamic little man, he spent his life in the ardent pursuit of learning, and he wrote at least a dozen treatises on various subjects, but these, like the manuscripts destroyed by the looters, were never published and none is now known to exist. Of his few published works perhaps the most important, next to *De Motu Cordis,* was *De Generatione* (On Reproduction), which made several valuable contributions to embryology.

HIS WORK on the circulation of the blood remains, however, his one great monument. It was remarkable not only as a history-making discovery but as a pioneering expression of the scientific method in biology. Harvey was a contemporary of Galileo, Kepler, Bacon and Descartes. The scientific revolution of the Renaissance, which swept away the systems of classical philosophy and established the methods upon which modern science is based, found in him one of its earliest prodigies. Harvey was the first biologist to use quantitative methods to demonstrate an important discovery. To weigh, to measure, to count and thus to arrive at truth was such a new idea in the 17th century that even a man of Harvey's genius could do it only badly. But his application of quantitative procedures to biology ushered in the modern age for that science.

Harvey graduated from Cambridge University in 1597 and went to study medicine at the University of Padua, the greatest scientific school of the day. The anatomy and physiology of the heart, arteries, veins and blood then being taught was still mainly the system that had been constructed 14 centuries earlier by the Greek physician Galen. According to Galen, chyle (a kind of lymph) passed from the intestines to the liver, which converted it to venous blood and at the same time added a "natural spirit." The liver then distributed this blood through the venous system, including the right ventricle of the heart. Galen knew from experiment that when he severed a large vein or artery in an animal, blood would drain off from both the veins and the arteries. He realized, therefore, that there must be some connection between the veins and the arter-

PORTRAIT OF HARVEY appears in an edition of his works published in 1766, a century after he had died.



EXPERIMENTS ON THE ARM are depicted in engravings made from those in Harvey's original book for the edition of 1766. The top drawing shows that if the arm is tied off above the elbow (A), nodes appear at the location of valves in the veins (BCDEF). The second drawing shows that if the blood is pressed out of the vein between O and H and a finger placed at H, the vein remains empty. The third drawing shows that if a second finger is then pushed down the vein toward O, the vein still remains empty. The fourth drawing shows that if a finger is placed at L and a second finger pushed along the vein from L to N, the vein will likewise remain empty. By such experiments Harvey deduced that the blood flowed along the veins toward the heart.

ies, and he believed he had found such a connection in the form of pores in the wall dividing the left side of the heart from the right. He argued that the venous blood oozed through these supposed pores to the left heart, was there charged with *vital spirit* coming from the lungs and thus took on the bright crimson color of arterial blood. According to the Galenic scheme, blood flowed to various parts of the body through both the veins and the arteries to supply the body members with nourishment and spirit. There was no real circulation or motive power; the blood in the vessels simply ebbed back occasionally to the heart and lungs for the removal of impurities.

To Galen's scheme two important modifications had been made by Harvey's time. Andreas Vesalius of Padua, the founder of modern anatomy, had announced in 1555 that Galen's "pores" did not exist, and Vesalius' successor Realdo Colombo had discovered the system whereby the blood flows from the right side of the heart through the pulmonary arteries to the lungs and thence *via* the pulmonary veins to the left side of the heart. He showed by animal experiments that the pulmonary veins contain arterial blood, not "vital spirit." The second important discovery, made by Fabricius ab Aquapendente at Padua, had been that the veins possess valves—"little doors," he called them. Fabricius did not realize their function; he suggested, following Galen's ideas, that they were designed to slow the flow of blood into the extremities.

HARVEY, with his doctor's degree from Padua, returned to England in 1602. Whether or not he had begun to form his notion of the circulation of the blood when he left Padua we do not know. In any event, he proceeded to practice medicine in London and rose rapidly in his profession. In 1615 the Royal College of Physicians, of which he was a fellow, honored him with the lifetime post of Lumleian Lecturer. In his first series of Lumleian lectures, given in 1616, he began to describe the circulation of the blood. We have his 98-page set of notes outlining these lectures. In them he describes some of his experiments, including the one which satisfied him "that so Provident a Cause as Nature had not Plac'd so many Valves without design" and which gave him the idea of the circulation, as he later told Robert Boyle.

The notes make clear that Harvey was already convinced that the blood circulates through the body and that the heart is its pumping engine. He concluded his 1616 series of lectures with this statement:

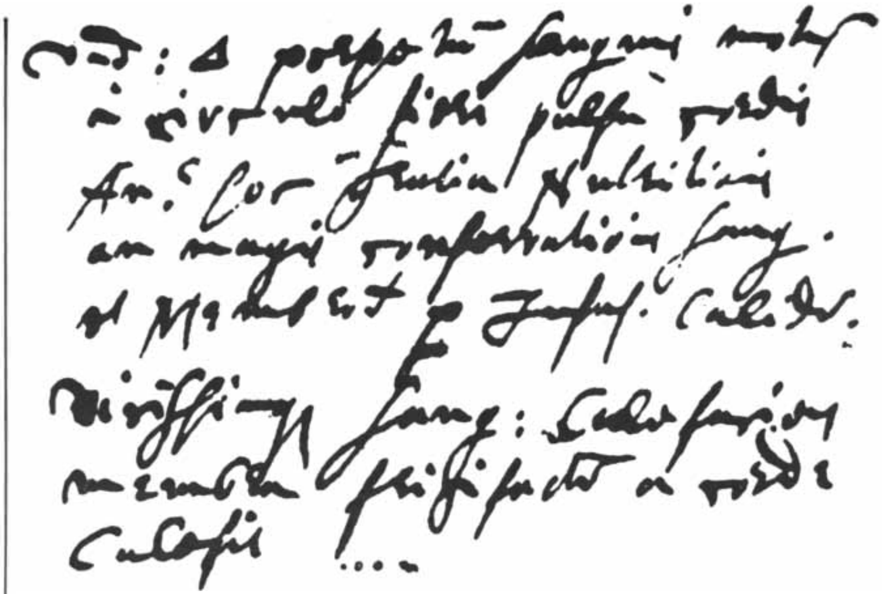
"It is proved by the structure of the heart that the blood is continuously transferred through the lungs into the aorta, as by two clacks of a water bellows to raise water. It is proved by the ligature that there is a passage of blood from the arteries to the veins. It is therefore demonstrated that the continuous movement of the blood in a circle is brought about by the beat of the heart. Is this for the sake of nutrition, or the better preservation of the blood and members by the infusion of heat, the blood in turn being cooled by heating the members and heated by the heart?"

Twelve years later Harvey, having carried out further experiments to prove his circulation theory, published *De Motu Cordis*. It is a book of only 72 pages. The volume contains two dedications (to King Charles and to Doctor Argent, President of the Royal College), an introduction and 17 brief chapters presenting his arguments.

After giving in Chapter I his reasons for writing the book (among them the desire to protect himself from ridicule), Harvey devoted the next four chapters to a remarkable analysis of the movements of the heart, arteries and auricles and an equally remarkable analysis of the functions of the heart. He had despaired at first of ever understanding the movement of the heart in warm-blooded animals, because its pulsation was so rapid, but he had found that he could analyze heart motions in cold-blooded animals and in dying warm-blooded ones. So far as direct inspection is concerned, such observations are still our principal sources for knowledge of heart motion.

Harvey gave the first clear statement of the apex beat, of the muscular character of the heart, and of the origin of the heartbeat in the right auricle and its conduction to the other auricle and the ventricles. He also demonstrated that the pulse in the arteries is due to the impact of blood ejected by the heart, as when "one blows into a glove," an image he used first in his 1616 lectures. Harvey correctly concluded that "the principal function of the heart is the transmission and pumping of the blood through the arteries to the extremities of the body."

He went on to review the movement of the blood from the right side of the heart through the lungs to the left side of the heart, as Colombo had described it, and to demonstrate how the blood passes from the left heart through the arteries to the extremities and thence *via* the veins back to the right heart. This section of the book contains the core of Harvey's discovery. He employed three "propositions" to prove that the blood must circulate: 1) the amount of blood transmitted from the veins to the arteries is so great that all the blood in the body must pass through the heart in a short time; this quantity could not be produced by the food consumed, as Galen held; 2) the amount of blood going to the extremities is much greater than needed for the nutrition of the body; 3) the blood continuously returns



DISCOVERY OF THE CIRCULATION of the blood was first recorded by Harvey in this illegible handwriting in one of his many notebooks.

to the heart from the extremities through the veins.

IT WAS to prove the first proposition that Harvey engaged in his famous quantitative work—the determination of the volume of blood pumped by the heart. To make this calculation, he had to measure the amount of blood that the heart ejects with each beat and to establish the pulse rate. The measurement of cardiac output is a tough problem, and even today there are wide variations in the measurements obtained by the various methods. But Harvey got a figure that is only one-eighteenth of the lowest estimate used today. How could he have arrived at such a ridiculously incorrect figure and at the same time have used it successfully to demonstrate such an important discovery?

Harvey based his reckoning on the fact that in a cadaver he once examined the left ventricle of the heart held more than two ounces of blood. (It must have been a dilated heart.) He assumed that between contractions the ventricle might hold as little as an ounce and a half. Assuming further that the ventricle with each contraction ejects "a fourth, a fifth, sixth or only an eighth" of its contents (we now think it ejects nearly all), he finally calculated that the cardiac output must be at least 3.9 grams per beat. According to a present-day estimate, it is actually in the neighborhood of 89 grams. Harvey can certainly be excused for not obtaining any close estimate of the output of the human heart, but he got virtually as poor results when he tried to measure the output of a sheep's heart. If he had severed a sheep's aorta and weighed the amount of blood ejected in one minute while counting the heartbeats for that minute, he could have obtained a reasonably accurate figure for cardiac output in sheep. But he never performed that obvious experiment.

Harvey also missed the mark widely in his other important measurement—the pulse rate. Somehow he counted it to be 33 per minute, about half the actual average rate, and although he obtained other values, he generally used this figure. We cannot explain this error on the ground that it is a difficult measurement to make; why he went so wrong will always be a mystery. With his two estimates—3.9 grams for cardiac output and 33 pulse beats per minute—he obtained a figure for the rate of blood flow which is one-36th of the lowest value accepted today. One of his calculations reads: "In half an hour the heart will make 1,000 beats, in some as many as two, three, and even four thousand. Multiplying the number of drams ejected by the number of beats there will be in half an hour either 3,000 drams, 2,000 drams, 500 ounces or some proportionate quantity of blood transferred into the arteries by the heart, but always a larger quantity than is contained in the whole body." In this summation, the lowest weight, 2,000 drams, equals 17.1 pounds, which is well in excess of the total of 15 pounds of blood contained by an average human body weighing 150 pounds.

Even with his faulty calculations, Harvey proved his main point: that each half-hour the blood pumped by the heart far exceeds the total weight of blood in the body. This was a blow to the Galenic concept, for it was obvious that the food a man eats could not produce blood continuously in any such volume.

Less impressive was Harvey's demonstration of the second proposition: that the amount of blood going to the extremities is much greater than is needed for the nutrition of the body. He used no specific measurements and argued

largely by inference. However, in this discussion he made the important point that the blood must pass from the arteries to the veins in the extremities. And he described here the experiment that had first suggested the circulation idea. By employing a bandage in such a way as to stop the flow in the veins while leaving the arteries open, he showed that the veins would swell but not the arteries. When he increased pressure enough to cut off the arteries as well, the veins did not swell. From these observations, Harvey reasoned correctly that the blood entered the extremities through the arteries and passed somehow to the veins. He later looked for the channels of connection but could not find them.

By another historic experiment Harvey proved his third proposition: that the blood flows in the veins toward the heart and not away from it, as the Galenic concept held. He showed that if one pressed a finger on a vein and moved the finger along the vein from below one valve to above the next, the blood thus pushed up the vein did not return to the emptied section. In short, the valves were one-way; the blood did not flow back and forth in the venous system.

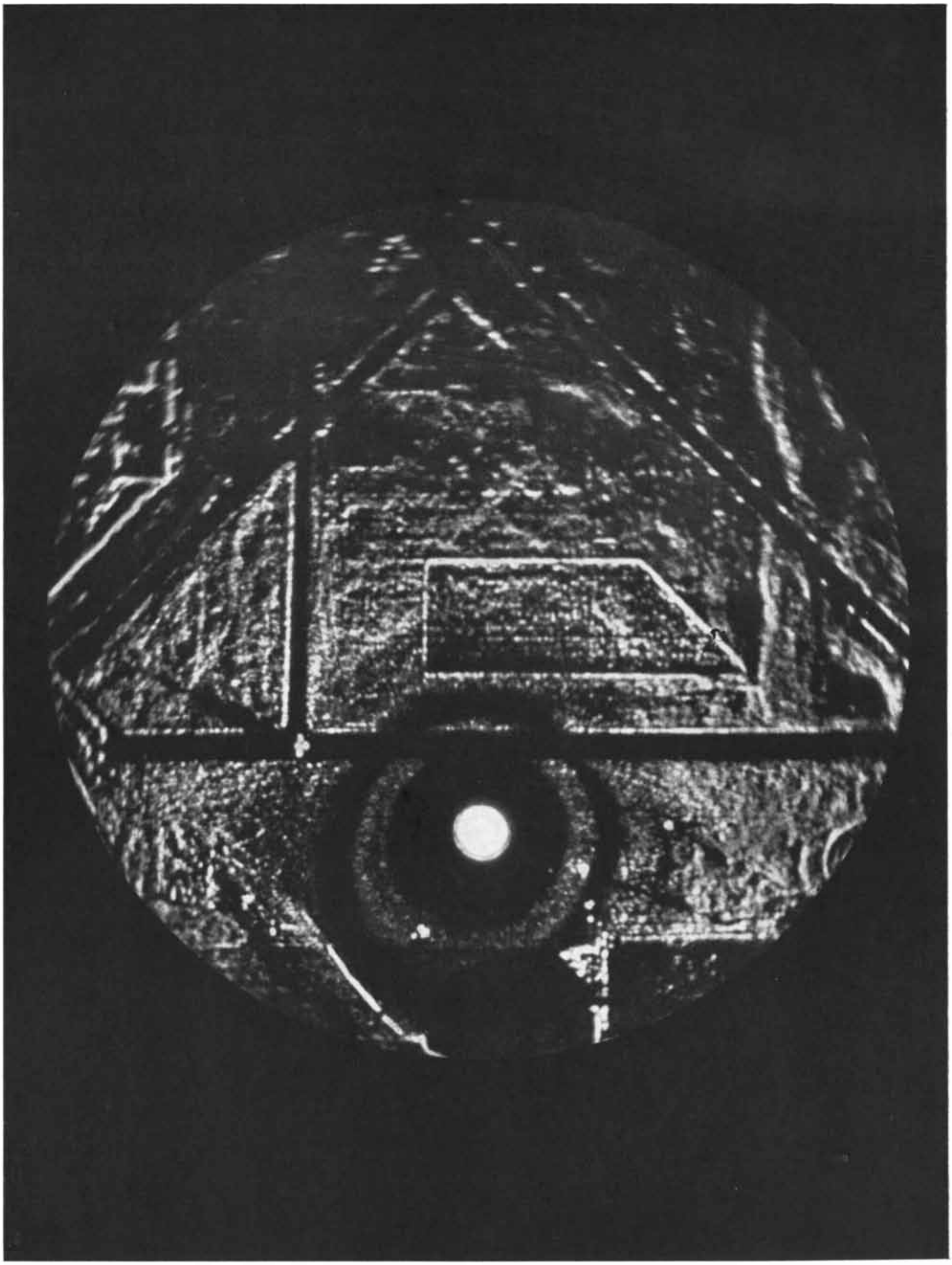
WHAT ARE the principal features of Harvey's discovery? The essential factors of the cardiovascular system which effect the circulation of the blood are the pumping heart, the passage of the blood from one side of the heart through the lungs to the other side and its subsequent passage through the arteries to every part of the body and back through the veins to the heart again. Harvey already knew of the passage through the lungs when he began his work; his great contribution was to demonstrate the circulation through the arteries and veins and to integrate it with the pulmonary passage, thus establishing one comprehensive system for the movement of blood through the body. There remained, of course, one final uncharted link: How did the blood pass from the arteries to the veins in the extremities in order to return to the heart? Thirty-three years after the appearance of *De Motu Cordis* the Italian anatomist Marcello Malpighi filled in that link by discovering the capillaries and so completed Harvey's scheme.

The direct contributions of Harvey's discovery to medicine and surgery are obviously beyond measuring: it is the basis for all work in the repair of damaged or diseased blood vessels, the surgical treatment of high blood pressure and coronary disease, the well-known "blue baby" operation, and so on. It is general physiology, however, that is most in his debt. For the notion of the circulating blood is what underlies our present understanding of the self-stabilizing internal environment of the body. In the dynamics of the human system the most important role is played by the fluid whose circulation Harvey discovered by a feat of great insight.

Frederick G. Kilgour is librarian of the Yale Medical Library.

ANATOMICAL EXERCISES, CONCERNING The motion of the *Heart*, and *Blood*, in Living Creatures.

ENGLISH TRANSLATION of Harvey's *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* was published in London in 1653.



RADAR SCOPE of ASDR (Airport Surface Detector Radar) bears a picture of the Weir Cook Airport in Indianapolis. The diagram on the opposite page identifies some of the surface features which appear in the picture. The remarkable definition of this radar system can be seen in the separation of the runway light stand-

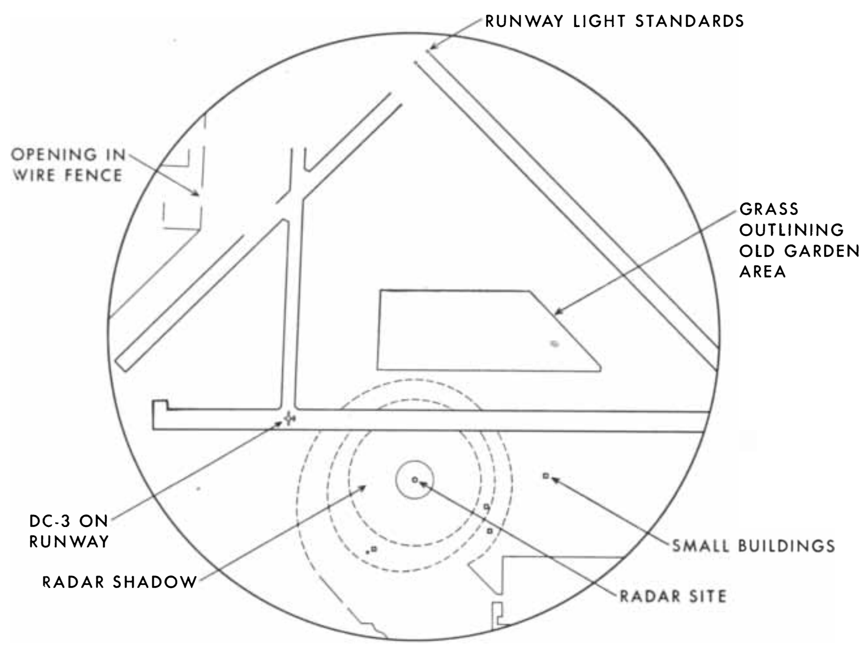
AIRPORT RADAR

A new microwave set presents a remarkably detailed picture. It is presently being tested as an adjunct to the control of air traffic which shows the location of planes on the ground

RADAR techniques have come a long way since the early sets on the English coast helped win the Battle of Britain. One of the latest advances, still in the testing stage, is a radar developed for the Air Force by Airborne Instruments Laboratory, Inc. It is being used to map the surface of airports for purposes of traffic control. Sweeping the field once a second with its rotating antenna, the new set gives a continuous picture which shows in amazing detail the location and movements of planes on the runways and aprons. As may be seen from the picture on the opposite page, its definition and sensitivity are so high that it begins to compete with the television camera and the eye itself. Aircraft appear on its scope not merely as "pips" or undefined blobs of light, but in easily recognizable outline. It can show a man walking across the field more than a mile away, and has even detected crows lighting on a runway.

ASDR (for Airport Surface Detection Radar) operates like any other radar: it bounces pulses of radio waves off reflecting objects and records the returning echoes. That this essentially crude technique can be made to give almost photographic information, as it does here, is due to the use of very short pulses of short wavelengths in an extremely sharp scanning beam. This equipment operates at the one-centimeter wavelength. The waves are compressed by the antenna into a vertical, fanlike beam. The slice of radio waves is so sharply defined that it separates objects only a few yards apart at distances as large as a mile.

While one-centimeter radar provides very high definition and can pick out objects against a crowded background, it is limited to a rather short range, no more than a few miles. Waves of this size are strongly absorbed by water vapor and gases in the air. Within the limited area of an airport, however, it works very well. As air terminals become increasingly congested, the problem of handling traffic grows more complex. Taxi radar, as its engineers call ASDR, should materially simplify the operation. Even in clear weather it will help by giving the traffic controller a complete and compact picture of the airport which he can take in at a single glance. It provides all the necessary information to clear runways for take-offs and landings, guide airplanes to runway turn-off points, and in general direct the movements of taxiing planes and service vehicles. At night, and under conditions of poor visibility, it will be especially valuable. The Civil Aeronautics Administration is now evaluating the performance of ASDR in all kinds of weather. Eventually the system might be made automatic, so that the radar would not only locate planes but transmit the appropriate information and traffic directions directly to their pilots. The traffic controller would simply monitor the operation of the equipment.



ards, the clearly marked opening in the fence, and the almost photographic outline of the plane. The sharp representation of the runways and grass demonstrates great ability of the system to distinguish different backgrounds.

ANTENNA, mounted on small tower, rotates once a second, sweeping the field with an extremely narrow beam.

PLANT CANCER

The tumorous growth of plants called crown gall is analogous to malignant animal tumors. Because its origin is understood it is a valuable tool for the study of abnormal growth in cells

by Armin C. Braun

THE CELLS of cancerous tissue have been described as "anarchists in an otherwise well-organized cell state." It is an apt figure. Normal cells live in fixed relation to their neighbors, strictly obeying the laws of their society. They grow in an orderly way under rigid control to a definite end. The growth of tumor cells, on the other hand, is for the most part unorganized, independent and without relation to the needs of the community.

Now this kind of cell behavior is not confined to animals; there are anarchists among plant cells as well. The author believes that the tumorous growth in plants called crown-gall bears at the cell level a very real analogy to malignant animal tumors. Unlike animal cancer, which may be induced by a variety of factors, crown gall is initiated by a specific bacterium.

When Erwin F. Smith and C. O. Townsend of the U. S. Department of Agriculture isolated the crown-gall bacterium in 1907 and showed that it could produce tumors in a healthy plant, their discovery attracted wide interest, because at that time no animal tumor had yet been produced experimentally. Smith worked on crown gall intensively for the next 20 years and showed it to be similar in many ways to malignant animal tumors. Still, there seemed to be a crucial difference: growth of the crown-gall tumor was thought by Smith to depend on continued stimulation by the bacterium, and therefore it was not truly independent growth, as is animal cancer. A clue as to the real nature of these plant overgrowths was given, however, by C. O. Jensen as early as 1910. This distinguished Danish pathologist presented some evidence that plant-tumor cells might reproduce themselves independently. He grafted beet tumors from one plant to another and found that they continued to grow in the absence of any recognizable infective agent. But his work was almost completely disregarded.

About 10 years ago our group at the Rockefeller Institute for Medical Research began to study this problem. The writer, working with crown gall in sunflower plants, had noticed that many of the secondary tumors which developed at places in the plant distant from the original point of infection were free of bacteria. Philip R. White had developed a new technique for growing certain plant tissues sterilely in culture ("Plant Tissue Cultures," by Philip R. White; SCIENTIFIC AMERICAN, March, 1950). Thus we had a bacteria-free source of tumor tissue and a means of growing it under controlled conditions.

Our first experiments showed beyond a doubt that the bacteria-free crown-gall cells reproduced themselves independently, in the same way as do cancer cells. When fragments of this tumor tissue were planted on the culture medium, they grew profusely and in a completely uncoordinated manner. On the other hand, normal sunflower cells of the type from which the tumor cells were derived developed very poorly on this medium and their growth was limited. The striking difference in behavior clearly demonstrated that the tumor cells had undergone a drastic and permanent change. The crown-gall bacterium served merely to induce the cellular change. Once altered, the cells continued to multiply pathologically and transmitted their new character to their descendants, independently of the bacteria. We found further that when we implanted small pieces of the culture-grown, bacteria-free tumor tissue in a healthy sunflower plant, they grew into typical crown-gall tumors, similar in every way to the tumors originally produced by the bacteria.

HAVING established that the cells were permanently changed, we next made attempts to discover what the change was and how the bacterium produced it. Two theories of the origin of tumor cells are now current. According to one, the transformation from a normal to a tumorous cell is genetic, the result of mutation of one or more genes. According to the other, the change is brought about by the arrival of a self-perpetuating entity that takes over control of the cell—either an agent that invades the cell from outside, such as a virus, or a factor formed inside the cell itself by a change in its normal constituents.

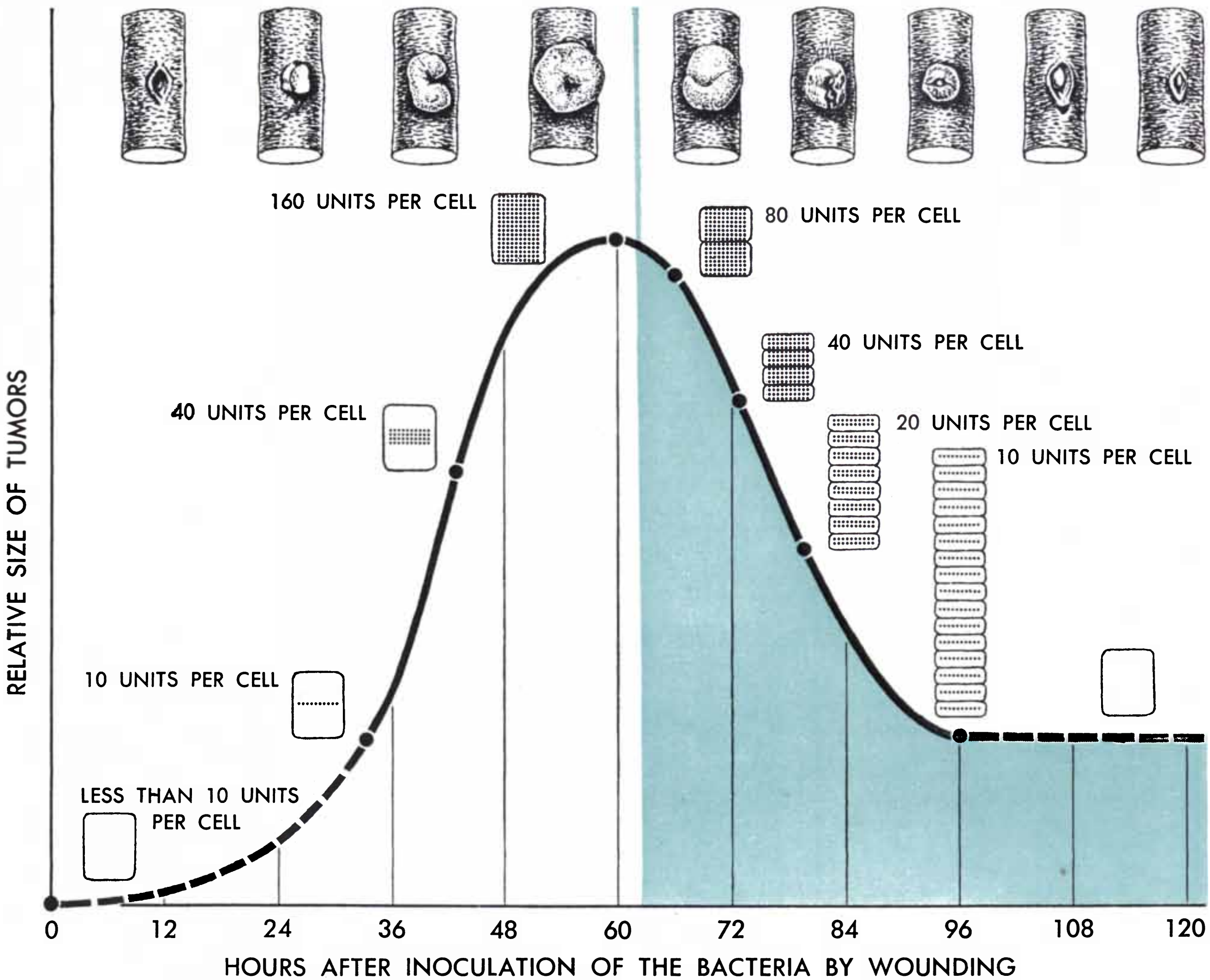
To find out which of the theories best explains crown-gall tumors, we made use of a familiar biological principle. It is well known that some types of self-duplicating elements in the cytoplasm (*i.e.*, the part of the cell outside the nucleus) can be eliminated through a process of dilution. If the cells are made to multiply very rapidly, their division outstrips the ability of such elements to reproduce themselves, with the result that after a number of generations the element in question disappears. Gene mutations, however, cannot be diluted out in this way. If we could make the disease principle disappear from crown-gall cells by forcing them to divide rapidly, we could conclude with reasonable certainty that the change was not genetic.

It is a common cliché that tumor cells grow much faster than normal cells. This is true, of course, if tumor cells are compared with the resting cells from which they usually derive. But active normal cells often grow at a far faster rate than do tumor cells. Regenerating cells grow very rapidly: if, for example, three-fourths of the human liver is removed, the remainder may regenerate the complete organ in about two weeks. Tumors of the liver seldom achieve this rate of growth. Shoots of certain plants may grow two feet or more in a month, while rapidly growing crown-gall tumors on such shoots seldom reach a diameter of more than one inch in this time.

The problem, then, was to find some way to speed up the growth of crown-gall tumor cells. This might be done if we could get tumor cells to form buds and young shoots, which then could be forced to grow very rapidly. Crown-gall cells of the commonly found type have never been known to organize buds or other differentiated organs. Very early in the study of the crown-gall disease, however, Smith and the German botanist W. Magnus had found independent-

TYPICAL CROWN GALL tumor grows on a sugar-beet after puncture with a needle bearing bacteria.

COMPLEX TUMOR called a teratoma, unlike other crown gall tumors, is composed of tissues and organs in various stages of development. Crown-gall tumors are usually made up of unorganized and undifferentiated cells.



WOUNDING OF PLANT at the time of inoculation may release a substance which causes the cells to divide after three days (*green area on diagram*). Up to three days the substance multiplies; after that it is diluted. The drawings at the top show the tumors that would result from active infection at that point on the curve.

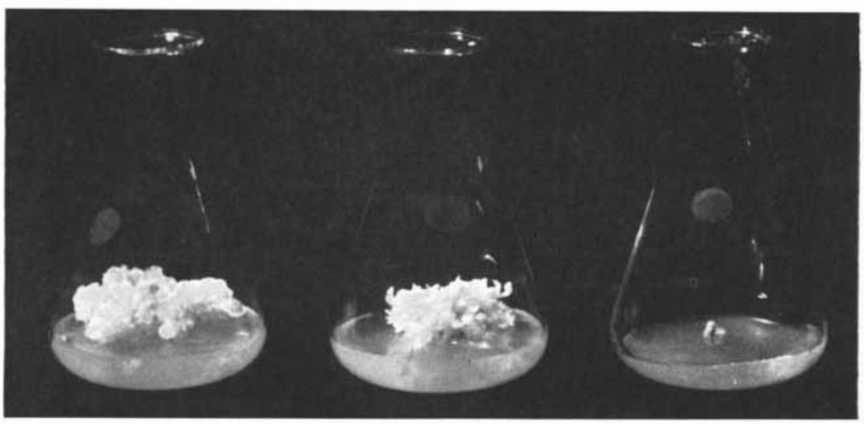
ly that there is a complex species of plant tumor which does sometimes organize leaves and buds, though small and distorted. Such tumors occur in certain plants which have what are known as pluripotent cells, meaning that they have the capacity to develop in many ways. When pluripotent cells are made tumorous, the tumor cells retain indefinitely the ability to organize small, distorted buds and leaves.

We inoculated pluripotent tissue with crown-gall bacteria and obtained tumor buds and shoots. As soon as the shoots were sufficiently developed they were removed and grafted to healthy plants. The diseased shoots grew rapidly, becoming more and more normal in appearance. After these tumor shoots had reached a length of somewhat more than one foot, their tips were again removed and transplanted to healthy plants. The new transplants continued in rapid growth, and eventually flowered and set seed. Examination showed that the cells of the shoots had become completely normal. In other words, by rapid multiplication and successive dilution of the tumor-generating factor in the cells, they had got rid of the disease. This showed that the abnormal growth of crown-gall tumor cells probably results not from a genetic mutation, but from a factor in the cytoplasm of the cell.

THE NEXT question was whether the unknown factor is a virus or an altered component of the cell, that is, a component modified in some way by the bacterium which initiates crown gall. A few cancers are known definitely to be caused by viruses. The Rous agent, which causes malignant tumors in chickens, is the best-known cancer virus. When these tumors are thoroughly ground up and a cell-free extract from the tissue is injected into a healthy chicken, new tumors of exactly the same type begin to grow almost at once. Extracts from these will in turn produce the disease in another animal, and the process can be repeated indefinitely, with the specific infective agent continually producing its characteristic tumors. We found, however, that cell-free extracts from ground-up crown-gall tumors do not transmit the disease to a healthy plant. This suggests that the crown-gall factor is not a virus. But it is not conclusive evidence, because the virus involved might be difficult or even impossible to transmit mechanically.

There is, however, some further experimental evidence that crown gall may not be a virus disease. It has to do with the tumor-initiating activity of the bacteria. We had found that the bacteria induce tumors most readily when kept at a temperature of about 77 degrees Fahrenheit. At 115 degrees the bacteria are killed and cannot initiate tumors. By utilizing these facts we were able to investigate the time required for the bacteria to change normal cells into tumor cells. We inoculated plants with bacteria and then destroyed the bacteria by heat after varying lengths of time. These experiments showed that the bacteria needed at least 34 hours to initiate the tumor process in the plant cells. When they were allowed to act on the plant for only 34 hours before being destroyed, small, slow-growing tumors were produced. But after three to four days of exposure to the bacteria, the plants formed large tumors which grew rapidly.

Apparently the change from a normal cell to a rapidly growing crown-gall cell takes place gradually over a three-to-four-day period. The progressive alterations that take place at each stage are permanent; for instance, the tendency to form slow-growing crown-gall cells, acquired after 34 hours of exposure to bacteria, is transmitted by a tumor cell to its descendants. It appears then that the concentration of the factor that causes crown-gall tumor cells to grow abnormally is maintained indefinitely in the dividing cells at the level present in those cells at the time of their alteration. Now this behavior is not at all what we would expect of a virus disease. Once



TISSUE CULTURE shows differences in the behavior of normal and abnormal cells. At left is crown-gall tumor tissue of the unorganized and undifferentiated type; in center is a teratoma; at right is normal tissue.

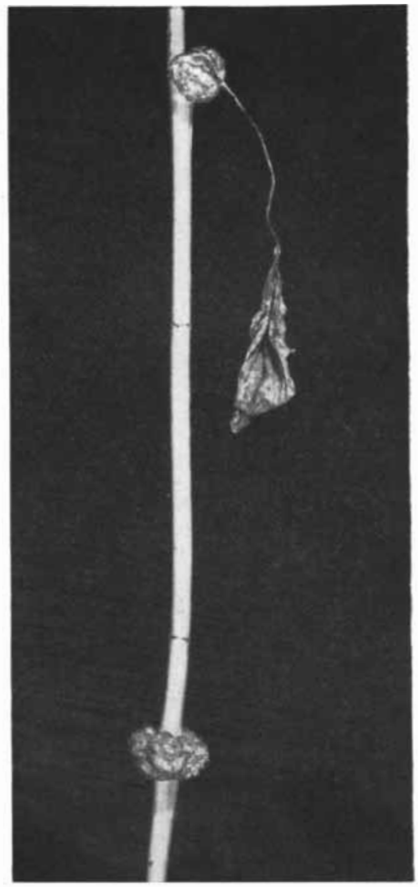
a virus gets into a cell it sets its own rate of growth and development.

A more delicate means of temperature control which we tried next gave further insight into the alteration process. We learned that it was not necessary to kill the bacteria in order to inactivate their tumor-inducing property. They are powerless to produce tumors if the temperature is kept at 89 degrees, though they are alive and thriving in the plant. Moreover, after the tumor-inducing change in the cell has been started, at the optimum temperature of 77 degrees, the process of cell alteration can be stopped abruptly at any point by raising the temperature to 89 degrees. This and other evidence suggests that it is the tumor-inducing factor itself, rather than the bacteria, that is affected by the rise in temperature. Although a temperature of 89 degrees stops completely the transformation of normal cells to tumor cells, exposure of the plant to that temperature after the cellular alteration has occurred does not interfere with the growth of the tumor cells. The tumors developed equally well at 77 and 89 degrees.

The critical period for the initiation of tumors of the largest, most rapidly growing type is between 60 and 72 hours after the plant is inoculated with bacteria. We performed a reversed experiment in which the bacteria and plant were kept at 89 degrees for various periods from the beginning and the temperature was then reduced to 77 degrees. As the delay in exposure to the optimum temperature increased, after the third day the tendency to form tumors fell off. When the temperature was held at 89 degrees for five days, and the inoculated plants were then placed at 77 degrees no tumors formed at all, although many virulent bacteria were in intimate contact with the plant cells.

These results reinforce the impression that crown gall is not caused by a virus. They indicate rather that two different factors are involved in the alteration of normal cells to tumor cells and in the continued abnormal growth of the tumor cells once the cellular change has been accomplished. The first factor appears to be rapidly destroyed at or above 89 degrees. The second factor retains its activity even after exposure to 115 degrees for as long as five days.

WHY DOES it take more than a day for the tumor-inducing action of the bacteria to take effect, and why do the bacteria become powerless to induce tumors after five days? We have a clue in the fact that the wounding of the plant when it is inoculated with bacteria is a necessary condition for the initiation of tumors. When a wound is made in a plant, juices from the ruptured cells bathe the neighboring undamaged cells. The juices activate these resting cells so that between two and three days later



SECONDARY TUMOR (*top*) on a sunflower stem is free of bacteria. Tumor at *bottom* contains bacteria.

they begin to divide, manufacturing new tissue to repair the damage. This conditioning of the cells by the wound stimulus is absolutely essential if normal cells are to be transformed into tumor cells. Presumably the activated normal cells manufacture some component that reaches its maximum concentration between the second and third day after the wound is made and causes them to begin dividing. After a cell starts dividing, it stops producing this component, and the amount of the constituent in the cells declines until by the fifth day it has fallen below the level where it can condition the cells sufficiently to permit cellular alteration to occur.

Thus the initiation of the crown-gall tumor seems to depend on two factors: 1) a normal component produced by the cells during healing, and 2) a tumor-inducing principle produced by the bacteria. Growth substances of the type that stimulate cell division are produced by crown-gall tumor cells. It appears that these altered cells have acquired a capacity for producing large amounts of a growth-promoting substance. The continued and unregulated production of such a substance could and probably does account for the continued and unregulated growth of the tumor cells.

With these facts in mind, it is tempting to speculate on the origin of the

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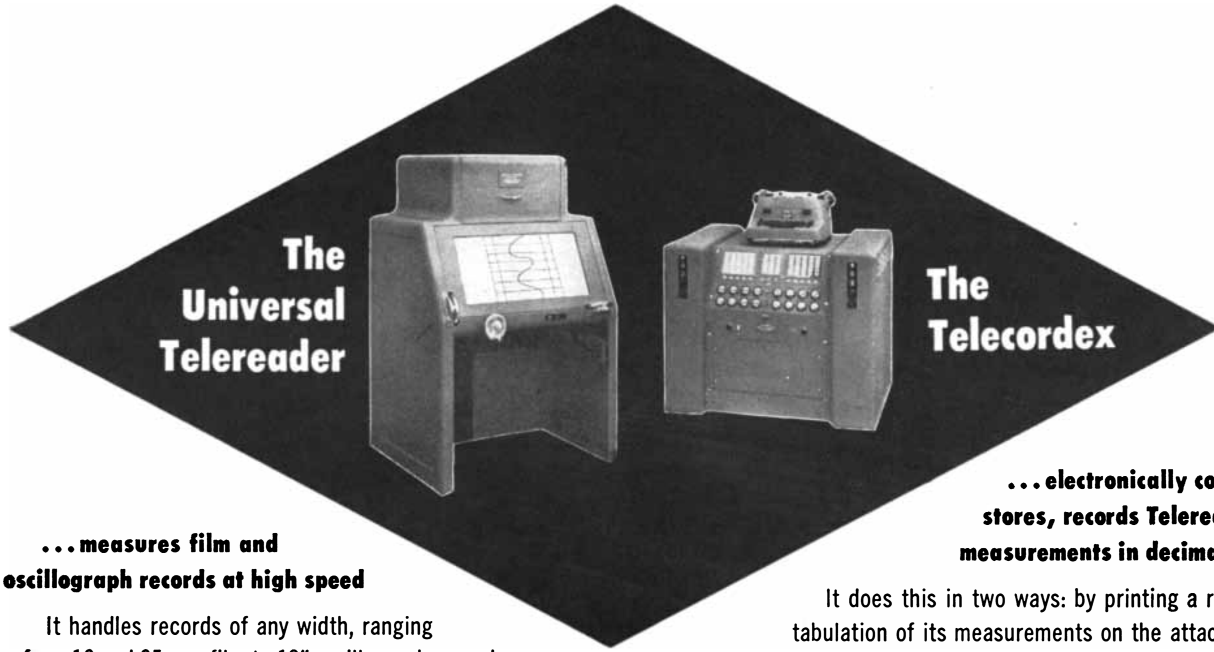

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crown-gall tumor cell. The following interpretation appears to explain the experimental findings quite well: Elements transmitted in the cell cytoplasm, similar to those described by Sol Spiegelman of the University of Illinois in yeast cells, exist in cells of higher plants. The presence of these elements seems to be essential for the production by the cell of those vitally important organic catalysts known as enzymes, on which, in turn, depends the production of growth substances. We believe that the tumor-inducing principle produced by the bacteria may act in such a way as to fix permanently the number of these cytoplasmic elements present in the normal cell at the time of its alteration. This number remains constant in the tumor cells as they grow and divide. Cells altered by bacteria in the first 34 hours would have fewer of these cytoplasmic elements than those altered in 60 hours; hence they would produce less growth substance and grow more slowly.

If, however, the rate of tumor-cell division is increased many times by forcing the growth of a tumor bud, the cytoplasmic factors concerned with growth-substance production do not keep pace with the rapidly dividing cells and are gradually lost. When these components are sufficiently diluted, the cell again becomes normal.

The growth of tumor cells and the very rapid growth of forced tumor buds involve two quite different growth-substance systems. The alteration of normal cells to tumor cells is probably concerned with the wound-healing growth-substance system of the cell. It is the excessive production of this growth substance that keeps the tumor cells growing abnormally. The unusually rapid development obtained by forcing the growth of a tumor bud, on the other hand, is concerned with the auxin-producing mechanism of the cell. The production of this growth substance is carefully regulated by the cell, although large amounts are always found in rapidly growing bud tissues. Thus normal cytoplasmic components concerned with the production of the wound hormone could be eliminated from cells that were forced to grow very rapidly as a result of the presence of large amounts of auxin in the tumor buds. Needless to say, this interpretation remains for the present only a working hypothesis. It does appear to explain the experimental findings very well.

Although the underlying cause of plant-tumor growth is still unknown, we have reason to hope that as this study progresses new facts will emerge to help us understand basic principles applying to the origin of tumors generally.

Armin C. Braun is an associate member of the Rockefeller Institute for Medical Research.

When radar intelligence reports approaching enemy bombers,
the carrier-based Douglas Skyray streaks up
to intercept

New jet interceptor—the Douglas Skyray

A new concept in fighter planes, the Douglas F4D Skyray—when operating from carriers—will let fleet units move deep into enemy waters, protected against sudden attack. When shipboard radar shows enemy bombers approaching, the Douglas Skyray streaks up and hovers—to keep them from hitting vital targets. On spotting the enemy, Skyray slashes down at terrific speed—spitting a stream of bullets, and rockets. Yet, despite its tremendous speed, Skyray's radical swept-back wings can bring it in *slow*, for easier landings on aircraft carriers.

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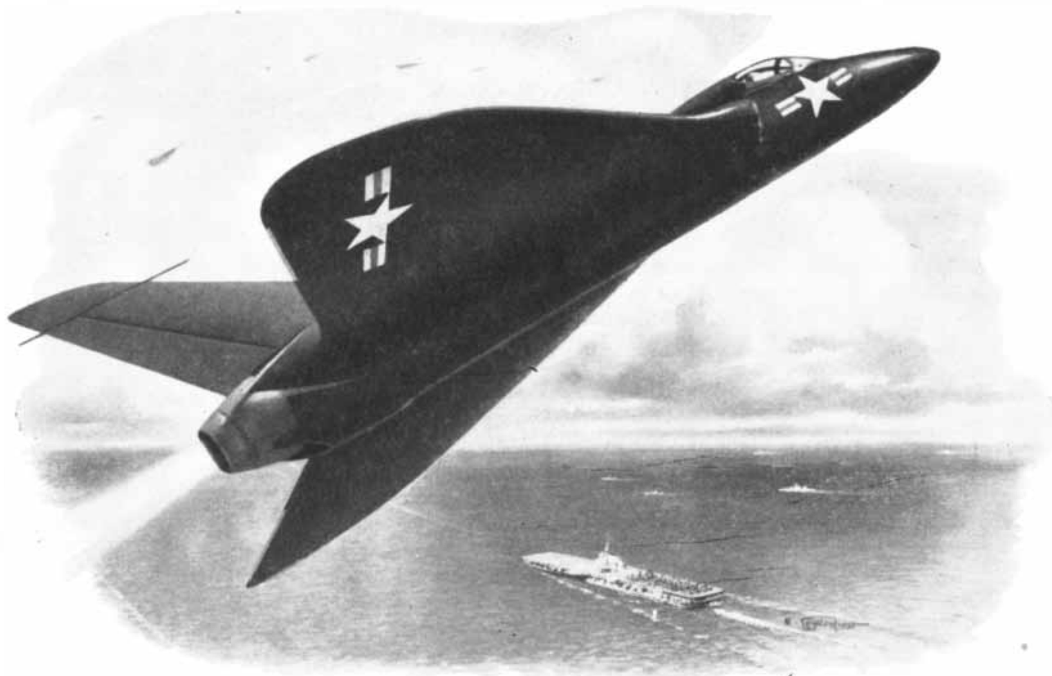

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The History of a River

The Ohio is comparatively young. The course of its predecessor, mightier than the Mississippi, has now been traced by the work of many geologists and even exploited for the benefit of man

by Raymond E. Janssen

TO THOSE who live along its banks the mighty Ohio River is a symbol of power and permanence. It has carved itself deep into the bedrock of the ancient Appalachian hills and into the Middle Western landscape. Yet the present Ohio is not as ancient as it may seem, and as for its place in the American scene, it is but a stunted descendant of a mightier river that once dominated the mid-continent. The predecessor of the Ohio, which many millions of years ago surged across the length and breadth of the Middle West, was greater than the Mississippi, which indeed was then only one of its tributaries. Geologists call the ancient river the Teays. The Teays, rather than the Mississippi, was really the great "father of waters" in North America.

The story of the Teays, as pieced together by many geologists, is a chronicle of how rivers come and go and how the land shifts and changes countenance in the long stretch of time. It is also a story with a practical ending, for the tracing of this ancient river course has turned up an unexpected addition to our vital national resources.

Nearly 50 years ago the Ohio-born geologist William G. Tight made a study of certain signs of comparatively recent shifts in the Ohio River's bed. He decided that the river had once followed a somewhat different course from its present one, and that the changes were due to the Ice Age glaciers. Tight's study was confined to the upper reaches of the Ohio. Through the years many other geologists have carried the tracing further and pieced together additional parts of the puzzle. It is now recognized that the Teays (a name given by Tight to the Ohio's supposed old course from a hamlet on its ancient banks) was not the Ohio itself but a very different river that largely disappeared before the Ohio was born. Only in one brief stretch does the Ohio run in the same channel as the old Teays.

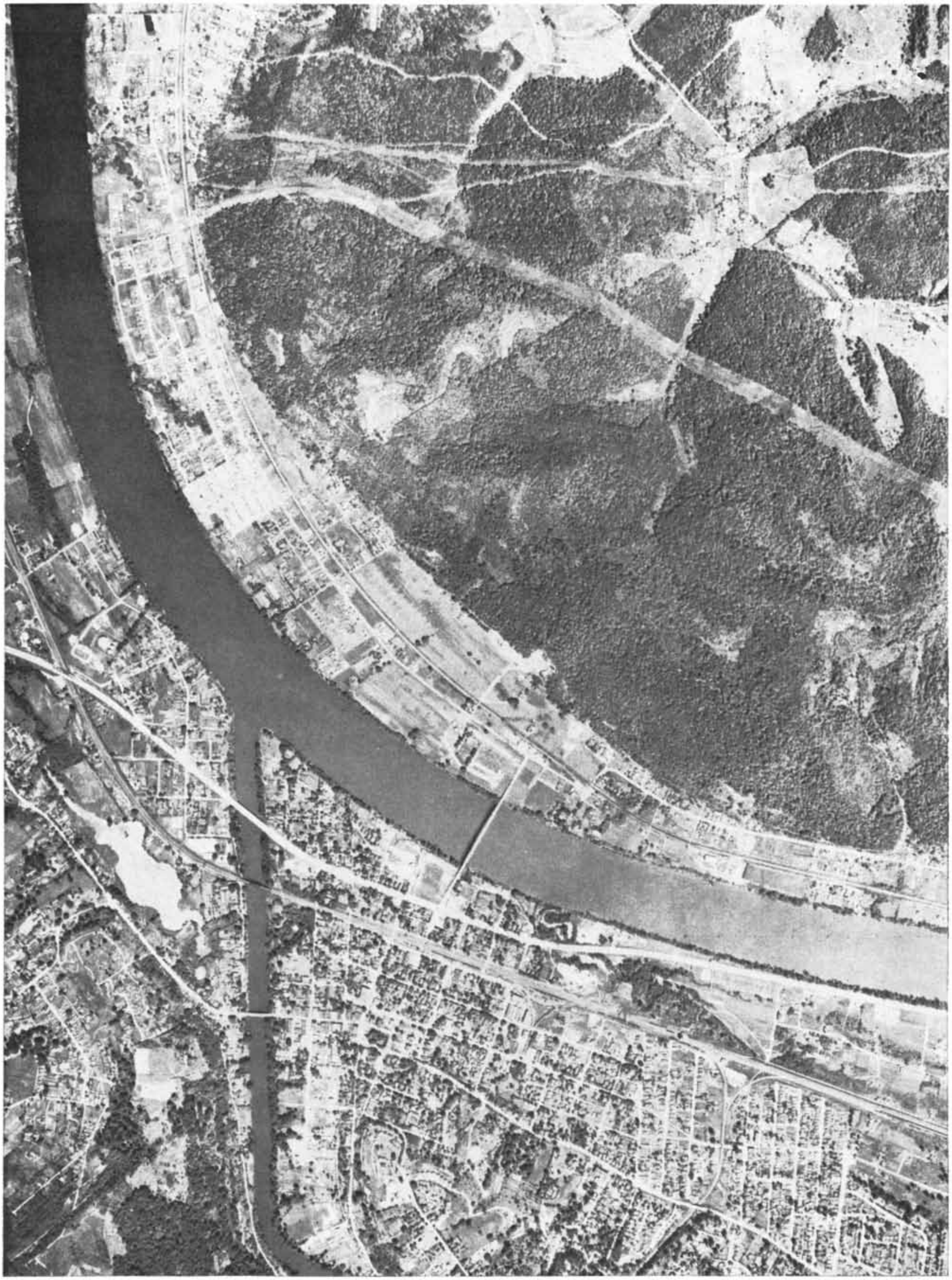
The Ohio has its source in the confluence of the Allegheny and Monongahela Rivers at Pittsburgh and follows a southerly and westerly route to join the Mississippi at Cairo, Ill. Its predecessor, the Teays, was a considerably longer stream which for approximately two-thirds of its course ran almost at right angles to the direction of the present river. Its source was in North Carolina on the eastern edge of the Appalachian Mountains. From there it flowed roughly northwest to a point beyond Fort Wayne, Ind., thence almost due west to Lincoln, Ill., where it was joined by the Mississippi. It then turned sharply south to empty into a northern embayment of the Gulf of Mexico, which at that time extended to a point near St. Louis, where the Illinois River now meets the Mississippi (*see map on pages 76 and 77*). The only part of the present Ohio that follows the ancient Teays bed is the section from Huntington, W. Va., to Wheelersburg, Ohio.

THE UNRAVELING of the histories of these rivers is an epic of geologic attainment. To understand how it came about that the Ohio supplanted the Teays, one must review first the major developments in the formation of the Appalachian region. Originally the area comprising the Central and Eastern U. S. was beneath the sea. About 200 million years ago the sea bottom was uplifted and the Appalachian Mountains, a range loftier even than the present Rockies, came into being. In time these mountains were worn by erosion to a nearly level surface. The plain was then in turn elevated to become a plateau. This high prairie sloped gently toward the west to merge with the present Mississippi Valley. The ranges we now call the Appalachians are no more than the remnants of that plateau—segments separated from one another by stream excavation of the valleys between. Anyone standing today at the summit of the Skyline Drive and looking out over the Appalachians can see that the tops of all the ranges are nearly flat and at about the same elevation. One has merely to imagine the intervening valleys filled again with the rock that was originally there to reconstruct in his mind's eye a vast rolling plateau that stretches on all sides to the horizon.

The Teays was already flowing when this plateau was lifted; it was one of the streams that had helped to cut away the mountain peaks. As the land rose, the river cut its way down through the rock strata. Evidence of the process can be seen in the present gorge of the New River in West Virginia, which occupies a portion of the upper course of the Teays. When the uplift came, the river cut like thread through cheese, but with this difference: the stream had etched a lazy, meandering course on the flat plain, and it could not later straighten its route. The loops and curves were preserved in the deep, winding pattern of the present gorge. The New River is really one of the oldest streams draining the Appalachians, and the only one that flows across the whole range from east to west. As the headwaters of the Teays, it had the advantage of being there before the mountains.

The Teays was not the only river draining the western slopes of the Appalachians at that time. Precursors of the Monongahela, the Allegheny and other rivers were also present, but they flowed northwest to the upper St. Lawrence River Basin, which then extended into the region later occupied by the Great Lakes. A divide between these north-flowing streams and the Teays system ran roughly across northern West Virginia and northeastern Ohio.

THIS STREAM system apparently prevailed for many millions of years. Within the last million years, when the continental glaciers of the Pleistocene pressed as far south as northern Kentucky, the advancing ice overrode and obliterated the lower Teays Valley from Chillicothe, Ohio, to the river mouth. For a considerable time the upper basin of the Teays was dammed by the ice, and one or more large lakes formed over southeastern Ohio and western West Virginia, where they can be identified today by the extensive silt beds in the



KANAWHA RIVER, a tributary of the Ohio, follows the course of the extinct Teays for part of its length. This aerial photograph shows the river at St. Albans, W. Va., where it begins to depart from the course of the Teays. Photograph by the Production and Marketing Administration of the Department of Agriculture.

TEAYS RIVER arose in what is now North Carolina and emptied into the Gulf of Mexico, which then extended much farther north. The Mississippi was a tributary of the Teays; the Monongahela and the Allegheny flowed north toward the region now covered by Lake Erie. After the ice sheet had moved across the lower Teays and retreated, the waters of the Monongahela and the Allegheny were joined to form the Ohio and flowed southwest. The edge of the ice sheet and the

area. When at last the glaciers began to melt northward, the tremendous volume of water from the waning ice sheets joined the lake water and poured west to form the course of what became the Ohio, or at least its lower portion from Wheelersburg to the Mississippi. Upstream from Wheelersburg, where the land was not covered by ice, the Ohio occupied the old channel of the Teays as far as Huntington, but above this region another set of circumstances provided the Ohio with its own source and upper reaches.

The glaciers which erased the lower Teays and formed the lakes also blocked the northward flow of the Allegheny and Monongahela systems. These streams were thus forced to reverse direction. Before the Ice Age there had been two small streams in the New Martinsville area of West Virginia, one of them a south-flowing tributary of the Teays, the other a north-flowing tributary of the Monongahela. Their sources were within a few miles of each other but separated by the divide. When the blocked Monongahela and Allegheny reversed themselves by overflowing their basins to the south, the barrier was apparently broken through and the rivers poured down into the old tributary of the Teays. Thus what had previously been two minor streams flowing in opposite directions became the upper Ohio from Huntington to Pittsburgh, and water that had once flowed north to the St. Lawrence now found its way to the Gulf of Mexico.

The Ohio we know today was formed of five major links: 1) the headwaters portion, consisting of the Monongahela and the Allegheny; 2) the reversed-flow stretch between Pittsburgh and New Martinsville; 3) the section as far as Huntington, formerly a tributary of the Teays; 4) the bed of the Teays itself from Huntington to Wheelersburg, and

present rivers are shown in blue; the extinct watercourses, in black. Where the blue and black lines run closely parallel, the present and ancient streams occupied the same course.

5) the lower river from Wheelersburg to the Mississippi. If this last section existed at all before the Ice Age, it was as an independent drainage system emptying into the Gulf.

MEANWHILE, what happened to the upper Teays River—the eastern end that cut westward across the Appalachians to Huntington? It is now the bed of two streams—the New River and the Kanawha—which are merely tributary to the new master, the Ohio. This portion of the ancient Teays has its own story to tell. The source of the Teays was somewhat east of Blowing Rock, N. C., where the New River rises today. The part of the old river east of Blowing Rock has been lost, because the crest of the Appalachians has gradually been shifted westward by the erosion of the range's steep Atlantic slopes. From Blowing Rock west the New River occupies the bed of the Teays as far as Gauley Bridge, W. Va. There it joins the Gauley River and the two become the Kanawha. The latter river follows the ancient Teays course as far as Charleston, W. Va. Just below Charleston it makes an abrupt turn out of the old Teays Valley, passes through a deep cut in the hills and joins the Ohio at Point Pleasant. The Teays Valley between Charleston and Huntington, a stretch where it is from a mile to a mile and a half wide, is now dry except for minor streams that drain the immediate neighborhood.

How did it happen that the Kanawha, having started off in the bed of the Teays, suddenly abandoned the valley to pursue a long and seemingly more difficult route to the Ohio? Again the answer is to be found in the glaciers. This section of the valley was one of the lake sites produced by the ice jam. There are deep layers of silt overlying the old Teays bed, which indicates that the ponded water remained there a long while. During the lifetime of this lake a small stream having its source near the upper shore gradually ate back to the lake's rim and permitted the dammed water to escape toward the northwest. By the time the glacier was in retreat and the Ohio had begun to flow, this new stream had cut itself lower than the silt-filled bed of the old Teays, and the

NEW RIVER above Gauley Bridge, W. Va., follows the course of the Teays in cutting a steep valley in an ancient plateau that was lifted upward. The nearly level skyline marks the original surface of the plateau.

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My City and State ______________________ released waters from the Appalachian highlands established themselves in the new course, instead of reverting to their former route.

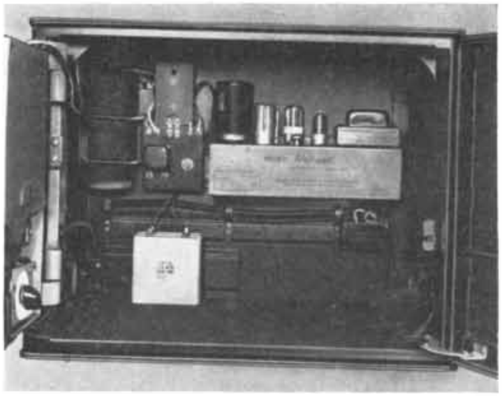
Numerous local and minor changes also occurred in these huge drainage areas to blot out the old Teays system and establish the Ohio system in its place. Almost all the tributaries of the Teays were affected in one way or another, and many new tributaries came into existence. Some of these retrace, others cut across, old stream beds now filled with glacial sands and gravels. The Mississippi, which originally reached the Teays near Lincoln, Ill., established a new and longer course farther west. The lowest reaches of the Teays became the Illinois River. Meanwhile the northern embayment of the Gulf of Mexico in southern Illinois, into which the Teays discharged, gradually filled with sediment until the shoreline of the Gulf was pushed south to its present location near New Orleans. We speak of the river valley from Cairo to the Gulf as the delta of the Mississippi; it would perhaps be more accurate to call it the delta of the Teays.

THE DISCOVERY of the lost Teays and the reconstruction of the birth of the Ohio has primarily been the work of geologists, but drillers of water wells have also played a part. When the mighty Teays disappeared, it did not wholly die: parts of it merely went underground! Water still flows along sections of its bed, long since buried by the glaciers. Where its surface waters once poured down to the Gulf of Mexico, underground streams now follow the old channels, filled with the loose sands and gravels of the glaciers. The course of the ancient river, and of many of its extinct tributaries, has been traced in large part by map plots of thousands of water wells that now tap these underground watercourses. The old Teays system today supplies water to countless towns, villages and farms in the Ohio Basin!

Since the uncovering of adequate water supplies is an increasingly urgent problem in this country, the tracing of the great buried river system of the Teays is not only an adventure in historical geology but a prospecting venture of the greatest utilitarian concern. It has opened a whole new field for geological exploration: the locating of buried river channels that can add to our water resources. Geologists of the future will search for buried rivers as today they hunt for hidden pools of oil.

Raymond E. Janssen, professor of geology at Marshall College in Huntington, W. Va., was the author of "The Beginnings of Coal," which appeared in the July, 1948, issue of this magazine.

Important to Engineering, Research & Testing



Internal view showing amplifier and damping circuit components.

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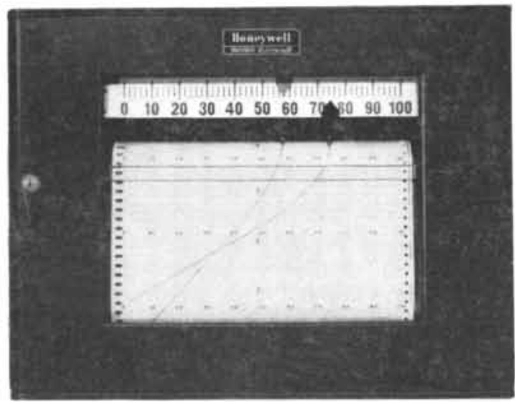

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SERVO MECHANISMS IN THE POWER INDUSTRY: Today the average worker has available for his use more than four times as much power as he had thirty years ago, and twice as much as the average worker in any other comparable country.

But, with the increased use of power have come complex problems of control—particularly automatic control. There would be little advantage in having more power available if all of the workers that would be saved in a particular operation were required to control the power used in this operation. We have developed a wide variety of automatic and semi-automatic control systems. But we have only scratched the surface in this field.

The magnetic amplifier or amplistat was developed in elementary form as early as 1916 when General Electric's Dr. E. F. W. Alexanderson brought out his 50 KW high-frequency alternator for transoceanic radio telephone. Here the problem was to maintain constant the speed and hence frequency of the alternator regardless of the demand placed upon it. Alexanderson developed a magnetic amplifier for his control system and obtained a patent for his design. It had a gain of approximately 400 to 1. This was the first commercial application of magnetic amplifiers in the U.S.

The servo amplifier must be a faithful servant that requires little or no maintenance and will stand ready to perform its task at all times. This is particularly true in the power industry where uninterrupted service must be maintained and failure in service results in large operating losses. The amplistat is a servo amplifier that meets these requirements.

Because the amplistat meets all the requirements of a satisfactory industrial servo amplifier it is being used to perform a wide variety of control functions. The task of opening and closing remotely located valves, regulating the speed of motors or the voltage and current of generators are typical examples.

It is evident that a new tool of great usefulness has been made available. It is simple, sturdy and versatile. Together with electronic and amplidyne amplifiers it is performing a vital function in power control.

American Power Conference
Chicago, Illinois
March 27, 1952

★

C. W. LA PIERRE

Aircraft Gas Turbine Division

FASTEST 10 YEARS IN HISTORY: While military progress is of necessity shrouded in secrecy, the progress in civil air transport is indicative of the potential growth yet untapped. To take speed as one indicator—in 1940 a good accepted speed was 150 miles per hour; in 1950 the accepted speed was 300 miles per hour. Already the planes are taking form to transport people in 1960 at 600 miles per hour.

Corresponding progress is in prospect for efficiency, comfort and reliability of civil transport and the over-all effectiveness of military aviation.

The Aircraft Gas Turbine Division recognizes its obligations to the nation and to its Company. The people you see working here are determined to live up to their obligations. The Division will aim always toward leadership in meeting the performance requirements established by the aircraft makers, the military agencies, the airlines, and the others who together create the tools of aviation.

To a major extent the facilities you see today are aimed toward the inevitable developments which constantly surround a new industry—developments in efficiency and other performance values, so vital to the progress of aviation. These facilities here, in being and under construction, combined with the Lynn and Everett, Massachusetts, plants and the one at Ludlow, Vermont, are evidence of our sincere intention to carry on the leadership inherited from our General Electric steam and gas turbine predecessors.

Dedication, G-E Jet Center
Lockland, Ohio
March 19, 1952

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J. P. DITCHMAN

Lamp Division

INFRARED BROODING: Radiation, applied through the use of lamps to problems of the farm, is on the threshold of great things. Recent announcements in other fields of science add new dimensions to the service radiation will be called on to supply. Thus, new chemicals which promise to save vast acreage for cultivation, and techniques for producing larger food animals in shorter time by use of antibiotics in the diet, are examples of what I have in mind. The implications in these announcements are tremendous. When we consider them in connection with the prospects for using radiation in the control and timing of growth processes, the problem of food supply must be reconsidered.

As we improve our techniques of applying radiation to the control of plant and animal growth, the variety and number of lamps required make us hesitant to speculate. But against the darker portents of the times, this offers a bright contrast. Wherever hunger threatens peace, we now have some wonderfully promising new antidotes.

Public Service Company
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BOOKS

A summer survey of recently published books about nature

by James R. Newman

NATURE BOOKS are of many species. Some are intended to serve as outdoor Baedekers, others are meant for continuous reading; some are for the specialist's shelf, some purely ornamental. The pocket field guide, the learned monograph, the noble folio of color plates, the comprehensive handbook, the grab-bag of odd (and, as the author hopes, diverting) facts, the chronicle of a collecting expedition, the naturalist's personal journey or diary, the volume of intimate essays or philosophical reflections, the fictionalized account of the adventures of a beaver or of the migration cycle of a pair of wild ducks—these are among the leading examples. Flowers and animals are hard things to write about, at least for the writer who strives to be clear, accurate and interesting without indulging in animism or sentimentality. Theodore Roosevelt roared against the "nature-fakers"—naturalists who passed off their fancies in the guise of actual observations of animal behavior. These mischievous fellows are still with us, though their numbers and influence have diminished. Enough is known about animal psychology to make it plain that it is altogether unlikely their mental life resembles ours.

Few of the books reviewed below are of exceptional merit. No near-Audubon or Gould delights the eye; no recent W. H. Hudson or Gilbert White captivates the mind. There are, however, entertaining volumes and useful ones, some of sound scholarship, two or three of distinction. Here is something for everyone who, with an innocent and wondering eye, takes his pleasure at the seashore, in the fields and forests, on the hills, by the river.

Exploration

KARÁNKAWAY COUNTRY, by Roy Bedichek. Doubleday and Company, Inc. ($3.50). Karánkaway Country, named after an Indian tribe that once inhabited it, is a section of marshland along the Gulf Coast of Texas, between Padre Island and Galveston. Well watered, remote and rich in vegetation, it is an ideal area for many forms of wildlife. Its attractions for the naturalist are further enhanced by the establishment of the Aransas National Wildlife Refuge, comprising 47,000 acres of "marsh, salt- and fresh-water lakes, brush-covered sand dunes, savanna and coastal prairie." Mr. Bedichek, a sensitive observer, presents a group of essays and anecdotes about the natural history of this strange and beautiful region. Among his topics are the birds of the Karánkaway Country, the remarkable behavior and character of coons, the destructive effects of dust storms, the deer of Aransas, the successful mating of a pair of the almost extinct species of whooping cranes. He writes with humor, with gentle wisdom and in a richly allusive vein. Nature stories are no good unless they are very good; these are very good.

ELEPHANT BILL, by Lt.-Col. J. H. Williams. Doubleday and Company, Inc. ($3.00). For 22 years Col. Williams, an Englishman, worked in Burma as forest manager for the Bombay Burma Trading Corporation supervising large herds of trained elephants in the hauling of teakwood. This experience was capped by three years' service as "elephant-director" with the British Army in the Burma campaign. It is doubtful that anyone possesses a more intimate and practical knowledge of the characteristics, habits, diseases, foibles and lovable qualities of these wonderful beasts—not even the Burmese oozies, each of whom rides an elephant, guides it in its work, feeds it and may in fact spend every day of a lifetime with it as friend and working companion. (Williams reports the existence of such relationships over periods of 60 years.) *Elephant Bill* recounts how elephants are trained and do their work, their mating habits, their capacity for learning, their memory (good, but not as good as folklore asserts), the care of their health, various surgical operations on elephants (they suffer most from indigestion!), where elephants go when they sense the approach of death (not to a graveyard), their occasional—and dangerous—fits of snappishness or temper, their fears (mostly rational, and *not* of mice), their heroic exploits in the Burmese war. An entertaining book, recommended for all ages. Photographs.

EDGE OF THE JUNGLE, by William Beebe. Duell, Sloan and Pearce ($3.00). This is one of the earliest, and still one of the best, of Dr. Beebe's many books on natural history, brought back into print with minor revisions. The scene is laid 30 years ago in the hinterland of British Guiana, and the subjects range from the giant catfish to the bubble bug.

WHERE WINTER NEVER COMES, by Marston Bates. Charles Scribner's Sons ($3.50). Dr. Bates, a field biologist with the Rockefeller Foundation, writes in defense of the Tropics: its weather, wildlife, forests, culture, food, resources, contributions to civilization. He has done research in Central America, Albania, Egypt and Colombia; in the latter country he directed for eight years the Foundation's yellow-fever laboratory. He dispels a good bit of nonsense about tropical terrors and hardships and makes out a readable, if occasionally meandering, case for the advantages of living somewhere between Cancer and Capricorn. It must be said, however, that Bates has advantages over most of us as regards adaptability to the Tropics: he *likes* hot weather (the hotter, as I understand it, the better), he is almost "immune" to insects, and he would be satisfied, he says, to eat nothing but rice —with a suitable variety of gravies.

THE NATIONAL PARKS: WHAT THEY MEAN TO YOU AND ME, by Freeman Tilden. Alfred A. Knopf ($5.00). An intelligent and informal account of the

national parks and national monuments, describing the history, purpose and principal features of each area, and providing also a most useful tabular guide of essential information for tourists. There are 28 parks and 86 monuments—the designation has no reference to size but depends upon whether the area has been set aside by Congress (park) or by the President (monument). Altogether they comprise an area of 21 million acres, which sounds pretty big but represents only three-quarters of one per cent of the land area of the U. S. The preservation of the parks and monuments is the responsibility of the National Park Service, which handles the job ably and conscientiously in the face not only of normal difficulties but of attempts by various private groups to force the opening of the parks for exploitation of their lumber and other resources.

Up the Missouri with Audubon: The Journal of Edward Harris, edited by John Francis McDermott. The University of Oklahoma Press ($3.75). Edward Harris, a New Jersey gentleman-farmer, sportsman and naturalist, accompanied Audubon in 1843 on an expedition up the Missouri River to its junction with the Yellowstone. Harris kept a diary, reproduced here for the first time, describing the journey on the river steamer *Omega*, the months spent at Fort Union, the buffalo hunts, encounters with Indians and other experiences and adventures of the Audubon party. Harris was interested mainly in shooting wild game; Audubon, in collecting new specimens and sketching. Harris was a capable observer of the flora, fauna and geological features of the neighborhood, and his diary is well worth reading. An ably edited, handsomely illustrated book.

Search for the Spiny Babbler, by S. Dillon Ripley. Houghton Mifflin Company ($4.00). An informal chronicle of an ornithological expedition into Nepal, Buddha's native country and the home of Mount Everest. Nepal, like Tibet, was until recently a "forbidden" land and has been seen by few Americans or Europeans. Mr. Ripley was given special permission for a wide-ranging survey, in the course of which he collected hundreds of bird specimens, some hitherto unknown, and a considerable number of small mammals. He also went through various amusing and exciting adventures.

A Naturalist in the Gran Chaco, by Sir John Graham Kerr. Cambridge University Press ($4.50). A superb account of two expeditions to the great estuarine plain of South America known in its northern part as the Gran Chaco. The first expedition (1889-91) followed the course of the shallow, hazardous, barely navigable Pilcomayo River flowing through Paraguay into Bolivia, and afforded an opportunity for study not only of the natural history of the region but of the Natokoi Indians. The Indians befriended the staff, lived with its members for many months and saw them through perilous adventures, including the threat of attack by surrounding hostile tribes of aborigines such as the Tobas. The second expedition, which Sir John undertook in search of information about that astonishing evolutionary anachronism the lungfish, led him and his companion, J. S. Budgett, farther north in the Chaco to a mission station on the River Paraguay. The story of the journeys (written in 1949, when Kerr was over 80) is based on his diaries, which he reread "during recent troublous years." They enabled him for the time being, as he says, to find "comfort . . . by escaping into what seemed a different

world." It is a comfort which, happily, others now can enjoy; there is not a dull or prolix passage to mar this wonderfully lively, colorful and sympathetic chronicle. To a remarkable degree Kerr combines the rare skills of knowing how to look at nature and how to write about what he sees. His descriptions of birds, fish, reptiles, mammals, insects and plants and his survey of the life and habits of the local Indian tribes, with several of whose members he achieved an unusually intimate relationship, make as absorbing reading as the many tales of the hardship, intrigue and danger to which the expeditions were exposed. Kerr writes with humor and disinterestedness, qualities which served him well in his experiences in the Chaco. His book clearly earns a place among the classics of this genre of literature.

Union Bay: The Life of a City Marsh, by Harry W. Higman and Earl J. Larrison. The University of Washington Press ($4.00). Next to the University of Washington campus in the city of Seattle lies a marsh that was formed by the lowering of the water of Union Bay after the building of a ship canal which flows into Puget Sound. The authors here record their observations of the plants, birds, insects and small mammals for which this tiny wildlife enclave furnishes either a transient or permanent home. The stories are honestly told and make enjoyable reading, but the special merit of this book lies in its portrayal of the interplay between the city and the marsh. It describes the unconscious yet unceasing competition between the two communities—how each group helps and hinders the other's way of life.

General

American Wildlife and Plants, by Alexander C. Martin, Herbert S. Zim, Arnold L. Nelson. McGraw-Hill Book Company, Inc. ($7.50). The subject of this exhaustive guide is: What animals eat what plants? Wildlife food habits are of utmost concern to scientists and practical men, to biologists, foresters, ecologists, farmers and fruitgrowers. Since the latter part of the last century many investigators have studied this phase of animal behavior on behalf of the U. S. Fish and Wildlife Service, under whose direction this book has been prepared. Their findings are here conveniently summarized. For hundreds of birds and mammals information is provided as to general habits, habitat and diet (animal as well as plant food). Plants are listed in a separate section, details being given on their appearance, where they grow, what animals eat them. Among other features adding to the value of this compendium are distribution maps and line drawings of almost every species, tables ranking plants according to their value and references to pertinent books, articles and reports. It is a reliable work which should answer diverse special needs, and it effectively exhibits the cooperative aspect of scientific research.

Animals and their Behavior, by Maurice Burton. Longmans, Green and Co., Inc. (60 cents). Dr. Burton, a naturalist on the staff of the British Museum, discusses such topics as the moth and the candle (a complex business, since moths in fact *shun* the light); animals that live alone and those that like company; automatic guides to behavior; the importance of play among animals; courtship; animal camouflage. He writes clearly, and his little book is a highly satisfactory introduction to an intriguing subject. For teen-agers as well as adults. Illustrations.

Fieldbook of Natural History, by E. Laurence Palmer. McGraw-Hill Book Company, Inc. ($7.00). Mr. Palmer, professor of nature and science education at Cornell University, has managed to cram an immense amount of information into a single volume—too much, in fact. His large book not only treats of plants and animals but attempts to cover rocks, minerals and stars as well. It would have been better to dispense with the 39 pages allotted to the constellations, the solar system, the atmosphere and everything from the phosphates to kaolinite. Neither the illustrations nor the text of this section of the book are worth bothering with. Fortunately the major portion of the volume is well done. Under each of 2,000 illustrations of organic species appears a lucid and concise summary of important facts as to appearance, habitat, behavior. It is remarkable how much information Palmer conveys in his briefs, and how he even succeeds in enlivening them by skillfully selected, out-of-the-way details. Subject to certain obvious limitations, this is a very satisfactory nature guide for home use.

This Fascinating Animal World, by Alan Devoe. McGraw-Hill Book Company, Inc. ($3.75). Here are literate, sensible and often surprising answers to a thousand questions about insects, birds, snakes, fish and mammals. Falling cats do not always land on their feet; the male platypus is as venomous as a poisonous snake; toads *can* give you warts but only because you think they can; beavers do not, alas, use their tails as trowels; pigs can swim; ostriches weigh up to 300 pounds; the hummingbird can fly backward as well as hover; the mongoose—gallant fellow—is *not* immune to the venom of the cobra it fights; snakes have tails, which is not to say they are all tail; snake-bites can be fatal even with a full kit of instruments and antivenins handy (for that matter, antivenins can, and have been, fatal, and whiskey, note well, is "worse than worthless" as a remedy); the smallest fish is a goby (less than a quarter-inch long, transparent, but fully equipped with backbone and all); centipedes have between 30 and 200 legs and millipedes have 60; a pelican's beak *does* hold more than its belly can.

Wildlife in Color, by Roger Tory Peterson. Houghton Mifflin Company ($3.00). A brief popular survey of representative American wildlife, embellished by 450 colored miniatures painted for the National Wildlife Federation and used as poster stamps by the Federation to support its work. The text is by Mr. Peterson. The illustrations, occasionally gay, are suitable for posters and for posters only. An undistinguished effort.

John Ray, Naturalist: His Life and Works, by Charles E. Raven. Cambridge University Press ($7.00). This is a second edition of Canon Raven's erudite and well-praised biography of the famous 17th-century English naturalist, whose monumental and pioneering works in botany and zoology (not to speak of his writings on fossils and insects) have led to his being ranked with Linnaeus as chief founder of "systematic biology."

HOW TO KNOW THE AMERICAN MAMMALS, by Ivan T. Sanderson. Little, Brown and Company ($2.50). How to tell Western from Mountain Cottontails, Common from Bog Lemmings, Pocket-Mice from Jumping-Mice, New York from California Weasels, Bobcats from Canadian Lynxes, Blue from Right Whales, Sea Elephants from Crested Seals, Mountain from Dall's Sheep, and, if need be, the Caa'ing from the Sewellel. To each species Sanderson allots a descriptive half-page or so, with a few words about habits and habitat. There are 183 black-and-white illustrations, 25 color plates and 10 pages of animal tracks. An unpretentious, serviceable little volume.

AMPHIBIANS OF WESTERN NORTH AMERICA, by Robert C. Stebbins. University of California Press ($7.50). This is a comprehensive, scholarly account of all known species and subspecies, giving information on form, coloration, habits and distribution, by the Curator of Herpetology at the University of California Museum of Vertebrate Zoology. Excellent black-and-white illustrations, color plates, distribution maps, bibliography. A solid contribution to natural history.

Birds

AUDUBON WATER BIRD GUIDE, by Richard H. Pough. Doubleday and Company, Inc. ($3.50). This useful, sturdy field companion by the Curator of Conservation of the American Museum of Natural History describes the water, game and large land-birds of Eastern and Central North America from Southern Texas to Central Greenland, reciting details of identification, habits, voice, nest, range of 258 species. It has more than 600 illustrations, three-quarters of them in color. The color pictures are by Don Eckelberry, the line drawings by Earl L. Poole.

A GUIDE TO BIRD FINDING EAST OF THE MISSISSIPPI, by Olin Sewall Pettingill, Jr. Oxford University Press ($5.00). Dr. Pettingill, an instructor at Carleton College, Minnesota, attempts to cover all species of birds occurring in 26 states lying entirely east of the Mississippi River, and in Canadian areas adjacent to Maine and New York. A chapter is devoted to each state, and information is furnished on the location of representative types of bird habitats, breeding colonies and wintering aggregations. It includes the birds to be found not only in remote rural areas, on beaches and on mountaintops, but also in the vicinity of large cities and vacation centers. There are sensible instructions on how to get to each of the places described. The 72 pen-and-ink sketches by George Miksch Sutton are neither especially helpful nor apt to produce a new crop of bird-finding addicts.

BIRD GUIDE: LAND BIRDS EAST OF THE ROCKIES, by Chester A. Reed. Doubleday and Company, Inc. ($1.95). Here is an enlarged and revised edition of a small fabrikoid-bound pocket book, setting forth the principal features of 222 species, with the aid of 300 color illustrations of moderate quality. Mr. Reed's book will serve its purpose, though it is doubtful that a bird-walker will derive much enlightenment from such intelligence as that the Eastern meadowlark's song is "a flutelike *tseeu-tseer,* a rapid stuttering alarm note."

HANDBOOK OF ATTRACTING BIRDS, by Thomas P. McElroy, Jr. Alfred A. Knopf ($2.75). This attractive and practical manual tells you how to bring birds to your garden (providing them with the hospitality of food, water and cover will turn the trick if there are any birds around), how to feed them, build shelters for them, help them at nesting time and protect them from predators. The working drawings by Lambert Guenther are praiseworthy.

A GUIDE TO BIRD SONGS, by Aretas A. Saunders. Doubleday and Company, Inc. ($3.00). Mr. Saunders, who for more than 35 years has studied and recorded the songs and calls of birds, presents a revised and enlarged edition of his labor of science and of love. He has devised an ingenious diagrammatic system of representation, not too simple yet not beyond the average reader's grasp, and undoubtedly far superior to ordinary phonetic reproductions. Saunders' shorthand for tempo, pitch and pattern can be learned with a little effort, and it should then prove invaluable, especially when used as a memory aid by those who have heard actual recordings of the songs in question. As an example of Saunders' meticulous observations it may be remarked that his collection of meadowlark songs alone numbers "about one thousand that are all different," and that in this book, in which the songs of 200 different species are given, with many variations, there are 11 diagrams portraying the songs of the Eastern meadowlark. Not one of these in its accompanying phonetic representations even remotely resembles *"tseeu-tseer."*

MIGRATION OF BIRDS, by Frederick C. Lincoln. Doubleday and Company, Inc. ($1.00). This interesting monograph on the migratory habits of North American birds is based on a publication of the U. S. Fish and Wildlife Service and is written by a biologist serving that organization. Mr. Lincoln discusses the several theories of migration: the Northern and

Southern "ancestral home" theory, theories of photoperiodism and of continental drift. He tells when various species move to warmer regions; why the majority travel at night; the speeds and altitudes of flight; the speeds of migration. Ducks and geese commonly fly at 40 to 50 miles per hour, but smaller birds are much slower. Nonstop flights of 400 to 500 miles by birds have been recorded. The average migrating altitude is 3,000 feet, but storks and cranes have been observed flying in the Himalayas at 20,000 feet above sea level. Mr. Lincoln also relates how birds find their way and tells about their migration routes, their flight hazards (*e.g.*, the torch on the Statue of Liberty, when it was kept lighted, caused enormous destruction of bird life), the influence of

weather on migration, and other problems. A useful and readable survey.

LIFE HISTORIES OF NORTH AMERICAN WILD FOWL: DUCKS, GEESE AND SWANS, by Arthur Cleveland Bent. Dover Publications, Inc. (2 vols., $8.00). This is a reprint of a noted contribution to ornithology, for some time out of print. Bent describes the plumage, eggs, nesting habits, food, behavior and distribution of these birds. Besides quoting from the works of other leading specialists, he adds valuable information drawn from his own extensive observations. More than 100 photographs accompany the text.

A BOOK OF DUCKS, by Phyllis Barclay-Smith. Penguin Books (95 cents). Shelducks, mallards, gadwalls, teals, garganeys, widgeons, pintails, shovelers, common pochards, tufted ducks, scaupducks, goldeneyes, common eiders, goosanders, red-breasted mergansers, smews: a concise biography of each species, accompanied by a line drawing and color plate (by Peter Shepheard). There is also a pleasantly informative introductory essay on ducks in general. One of the delightful King Penguin Books.

A BIRD PHOTOGRAPHER IN INDIA, by E. H. N. Lowther. Oxford University Press ($5.50). "Until 1906 I was an ardent egg collector, but on the last day of the Easter term of that year Richard Kearton lectured at my school and persuaded me to give up egg-drill and blowpipe and photograph birds instead. This I have done for the past 40 years." Thirty of the years, at least, were spent by Mr. Lowther as a railroad official in India, where the many striking photographs in this volume were taken. There is an agreeable, unassuming text describing various episodes of this gentle pastime and proving the author an unusually perceptive naturalist. But the photographs are the thing. The frontispiece, showing a crested swift jauntily perched on its nest, is surely one of the handsomest and most exciting wildlife photographs ever taken.

MEXICAN BIRDS, by George Miksch Sutton. The University of Oklahoma Press ($10.00). This book records an ornithological expedition to Tamaulipas, Nuevo Leon and Coahuila. It is supplemented by an appendix containing short descriptions of all Mexican birds. Mr. Sutton is not a stimulating narrator, but a number of his drawings and water colors are first rate. He characterizes his illustrations as "first impressions" of the birds he found. They possess, in truth, the freshness of a first encounter, and the birds of some of Sutton's best water colors—of the flaming-topped flint-billed woodpecker, for example—look as wonderfully surprised, if not as delighted, as Sutton must have been when he had his first glimpse of them.

Insects

A FIELD GUIDE TO THE BUTTERFLIES OF NORTH AMERICA, EAST OF THE GREAT PLAINS, by Alexander B. Klots. Houghton, Mifflin Company ($3.75). Descriptions of adults and larvae; details on food, range, subspecies, behavior; instructions on equipment, collecting, spreading. The book has a chapter on principles of classification, bibliographies and photographs of 417 species, 247 in color. A dependable book in a dependable series (Peterson Field Guides).

THE HOUSEFLY: ITS NATURAL HISTORY, MEDICAL IMPORTANCE AND CONTROL, by Luther S. West. Comstock Publishing Company, Inc. ($7.50). Here is a thorough, clearly written, authoritative, up-to-date treatise on that wretch *Musca domestica,* whose menace to man, though often and widely demonstrated, is still only imperfectly understood in many parts of the world. From the earliest times (see, for example, *Exodus* 8:24) it was known that flies "corrupted" the land; Sir John Lubbock in the 19th century aptly described houseflies as "winged sponges spreading hither and thither to carry out the foul behests of contagion." Yet the period of "friendly tolerance," as Dr. West points out, has never really terminated. This excellent scientific work, while primarily intended for physicians, biologists, public health officers and those in related fields, is not too difficult for the general reader, and it should contribute therefore to the spread of essential knowledge upon which the elimination of this insect—"responsible for more human misery than any other"—ultimately depends. Photographs, maps, diagrams, bibliographies.

AMERICAN SOCIAL INSECTS, by Charles D. Michener and Mary H. Michener. D. Van Nostrand Company, Inc. ($6.00). This volume in The New Illustrated Naturalist Series is an interesting, popular account of the life and habits of insects living in communities—bees, wasps, ants, hornets, termites and the like. The black-and-white pictures, taken by some of the country's leading nature photographers, are excellent; the colored photographs are generally less successful, being either posed or cast in the slick, unreal brilliance of food advertisements.

BEES: THEIR VISION, CHEMICAL SENSES, AND LANGUAGE, by Karl von Frisch. Cornell University Press ($3.00). This book consists of three lectures by the noted Austrian zoologist whose lifework has been the study of the sensory capacity and behavior of bees and other lower animals. Professor von Frisch describes a number of ingenious experiments to determine whether bees can distinguish colors (they can, including ultraviolet), the acuteness of their senses of taste and smell, their ability to discriminate between various shapes and forms, their method of communication. The last lecture deals with Frisch's brilliant discovery of the dance of the bees, whereby scouts are able to inform other workers in the hive of the location of food, thus enabling them to find the "exact spot" as far as three miles away. An exceptionally interesting book. Illustrations.

Plants

THE MOLDS AND MAN: AN INTRODUCTION TO THE FUNGI, by Clyde M. Christensen. University of Minnesota Press ($4.00). Fungi are simple in structure and hold a lowly place on the evolutionary ladder. Yet they are of enormous importance to man and to almost all other forms of life, not only because of their destructive effects but also because some of them are highly beneficial, indeed indispensable, to the existence of plants and animals. Fungi cause a great variety of diseases in plants and animals; they attack everything from girdles and bread to lenses and electrical insulation; they are responsible for the soil exhaustion ensuing on the raising of many kinds of crops. Yet the products of fungous decay are essential to the survival of most green plants. The spore production and rate of growth of fungi must astound even the most sophisticated imagination. In 24 hours a small fungus colony can produce a total length of over one-half mile of mycelium, and in 48 hours a total length of "hundreds of miles of cells." An average-sized gall of the fungus causing smut of corn holds 25 billion spores; a single fruit body of *Fomes applanatus*, a common wood-rotting fungus, liberates 350,000 spores a second, day in and day out for six months of the year. Professor Christensen's fascinating survey discusses the reproduction and dissemination of fungi, their partnership with plants and animals, their destructive parasitic effects, their growing industrial and medical use. He has written a popular science book of exceptional interest and educational value.

BEGINNER'S GUIDE TO WILD FLOWERS, by Ethel Hinckley Hausman. G. P. Putnam's Sons ($3.50). More than 1,000

species arranged in color groups for quick identification, with brief descriptive notes, distribution data and black-and-white illustrations. Not a glamorous book, but it may serve a limited purpose.

FLORA OF THE BRITISH ISLES, by A. R. Clapham, T. G. Tutin, and E. F. Warburg. Cambridge University Press ($9.50). This is a Flora for students and serious amateurs. Nothing nearly as thorough or systematic in its coverage has appeared for more than half a century. During that time a great deal has been learned about new plant forms—species, subspecies, varieties—in the British Isles, and in the sciences of ecology and genetics. The authors give detailed descriptions of each species and information about flowering, pollination, seed dispersal, chromosome number. A distinguished addition to the great clan of botanical handbooks.

THE NATURAL PHILOSOPHY OF PLANT FORM, by Agnes Arber. Cambridge University Press ($6.00). A somewhat specialized but extremely interesting study of plant morphology by an outstanding British expert. Mrs. Arber describes her book as an "attempt to review the relation of parts in the flowering plants in the light of those more universal, and also more stringent, modes of thought, which are characteristic of philosophy rather than of biology. There are indications that, when morphology is subjected to this discipline, its contents may be unified by the synthesis of various theories that are, from the standpoint of analytical science, irreconcilable." Illustrations.

THE AURICULA, by Rowland H. Biffen. Cambridge University Press ($3.00). The late Sir Rowland Biffen, a noted plant breeder and botanist, throughout his life had a special affection for this beautiful flower. He discusses the group of auriculas, their origin, history, cultivation and breeding. Photographs and line drawings.

The Sea

THE SEA AROUND US, by Rachel L. Carson. Oxford University Press ($3.50). Miss Carson's celebrated book, which has led the nonfiction sales lists for many months, hardly needs further recommendation. Literate, entertaining and informative, it is an outstanding job of popularization, though its mannered word-painting and insistence on the Beauty and Mystery of the subject sometimes grows a trifle wearisome.

UNDER THE SEA-WIND, by Rachel L. Carson. Oxford University Press ($3.50). This is a reissue of Miss Carson's first book, published in 1941, dealing with the birds and fishes inhabiting the Eastern rim of the U. S. What sets this book apart from others of its kind is not only the quality of its prose, rich-textured and firm, but Miss Carson's self-discipline in refusing to yield to the temptations of sentimentality. Her story does not lack for sympathy, yet she conveys to the reader, as only rarely in other naturalists' writings, the authentic, almost overwhelming sense of the ferocity of the struggle to avert being devoured, to eat and to reproduce before being eaten. A very good book.

HALF MILE DOWN, by William Beebe. Duell, Sloan and Pearce ($6.00). Dr. Beebe's exciting story of his and Otis Barton's remarkable adventures in the bathysphere first appeared in 1934. It is here reissued (at what one would judge an excessive price) with a new introduction noting briefly later advances in "abyssal oceanography," deep-sea photography and kindred activities. Beebe tells of an important find in 1938 when a fisherman's net hauled up from a considerable depth off South Africa a bright-blue fish with a large head and "strangely primitive fins and tails" whose closest relative became extinct in the Cretaceous. This creature he labels a "living fossil," since "in the depths it had persisted unchanged for the past 60 or 75 millions of years." Photographs and color plates.

THE AMATEUR SCIENTIST

Mountain geology and an amateur contribution to a new ruling engine

Conducted by Albert G. Ingalls

THE photographs on the opposite page tell the story of an amateur's investigation of mountain geology. They were taken by Carol De Decker, who lives in the Owens Valley of California and snapped the pictures practically in her own back yard. Carol is only 17, but she is already a veteran of nine years of research on the Sierra Nevada mountain range. Last year a paper she wrote about it won her a top award in the Westinghouse Science Talent Search, and she is now at Pomona College preparing for a career in science.

Besides making her mark in geology, Carol is also an amateur astronomer and has found time to master horsemanship, win letters in tennis and basketball, serve as vice president of her high school's student body and graduate at the head of her class.

From her pigtail days Carol wondered about the forces that built the Sierra. It seemed evident to her that the Sierra Nevadas, with their slender peaks and knifelike ridges, must be young mountains, since she had learned in books that old mountains were worn down in time to gently rolling contours. Yet here and there in the Sierras are stretches of smooth terrain, sometimes on the floors of valleys, sometimes on the summits of peaks. Could the Sierra be both young and old?

As soon as she was old enough to go hiking, Carol began to spend part of every summer tramping and camping the range. She questioned geologists and learned to read their journals. She made lengthy field notes and supplemented them with photographs. Finally her assorted data began to form an orderly pattern. She could answer part of the riddle out of her own experience.

"To the casual observer," she wrote, "the Sierra appears to be a jumbled mass of steep canyons and jagged pinnacles—a landscape devoid of all order. Everywhere, it seems, patches of ancient terrain mingle with the new features of today. Yet with enough care and study the old topography, now glacially carved, assumes a clear and logical pattern, and thus gradually the mystery of the Sierra, like its ancient glaciers, melts away."

Carol's prize-winning paper presents a concise geological outline of the range. Essentially the Sierra Nevada is a single block of granite 400 miles long and 40 to 80 miles wide, now badly cracked by the processes of its formation and partly eroded by time. It was thrust up and tilted to the west some 110 million years ago. Thereafter the range was successively elevated and eroded until it reached its present height about a million years ago. Throughout its length the eastern edge descends in steep and irregular cliffs, while on the western side the broad back of the range slopes more gently, finally disappearing under a deposit of alluvial debris. Along the base of the range on the eastern side is a series of faults, some of them geologically recent, indicating that the range is still being elevated.

The seeming age differences in sections of the Sierra's terrain are explained by the fact that the range has undergone four major uplifts, each followed by a period of erosion. Thus it has four distinct types of surfaces, known to geologists as summit upland, subsummit plateau, high valley and canyon. A typical example of each is shown in Carol's photographs. She took these in the Kings-Kern Divide region, an area 150 miles north of Los Angeles and about 50 miles west of Death Valley.

Kings-Kern Divide marks the approximate southern limit of the Ice Age glaciers on the Pacific Coast. The Sierra Nevada owes much of its distinctive appearance to the work of the glaciers. At least three periods of glaciation left their marks on the northern portion of the range, and Carol has recorded evidence of two glacial excursions that reached as far south as Kings-Kern Divide. Here she found a great pile of small rocks mixed with earth and other debris, the deposit of an early glacier. This moraine is partially buried under a thick layer of lava, laid down by the subsequent eruption of an ancient volcano. Over the lava a still more recent glacier deposited another moraine—positive evidence of at least two glacial periods. The comparatively uneroded condition of the topmost moraine indicates that it was deposited recently, perhaps as late as 10,000 years ago.

"The main canyons which open into Owens Valley," Carol reported, "are all alike, in that at about the same elevation each changes from the characteristic form of glacial erosion to that caused by the action of streams. Georges Creek Canyon, which is situated near my home, is typical. In the canyon's upper portion you find rocks with rounded surfaces, and there the valley is littered with assorted moraines. At its highest elevation the canyon is broad and open. But lower down, at about 9,000 feet, its whole character changes. The sides narrow into a sharp V. The moraines disappear, and even to the unpracticed eye it is clear that here the rock has been eaten away by the action of running water.

"There are many glacial cirques to be seen throughout the Sierra. These are semi-circular recesses, usually situated at the head of a canyon or basin. In some instances it is evident that two glaciers ate into opposite sides of the same mountain and came so close to uniting at their heads that only a narrow, steep ridge connects the peak with the divide of which it was once a major part.

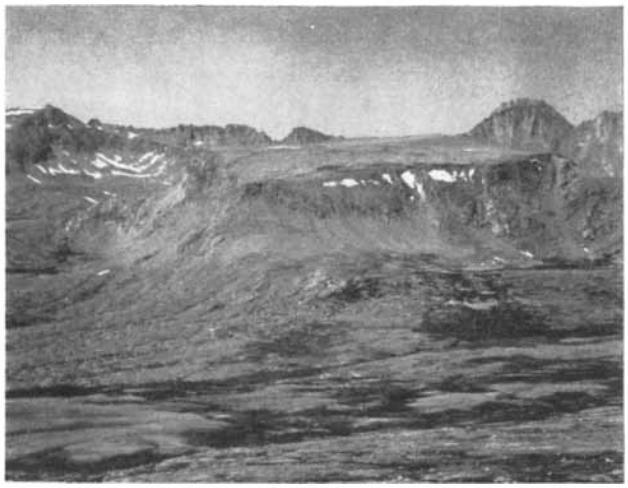
"From University Peak, a few miles north of Mt. Whitney, one can get an excellent view of several hanging valleys. These are valleys whose floors are considerably higher than the main valley into which they drain. The tributary glaciers once occupying them did not dig as deeply into their beds as did the main glacier, hence the difference in levels when the ice melted.

"I have found few moraines on the western slope of the Sierra. Perhaps the glaciers carried the products of erosion to the western base of the range before depositing them."

THIS MONTH and next the space in this department that is usually devoted to amateur telescope-making is given to another aspect of optics: the ruling engine that makes diffraction gratings. At mention of the ruling engine the average amateur optical worker assumes an attitude of extreme respect, for this tricky machine is an even higher example of controlled ultraprecision than telescope mirror-making. In precision optics the standard tolerance of error is one-500,000th of an inch; in diffraction gratings it is one-millionth of an inch.

It is not a coincidence that three men

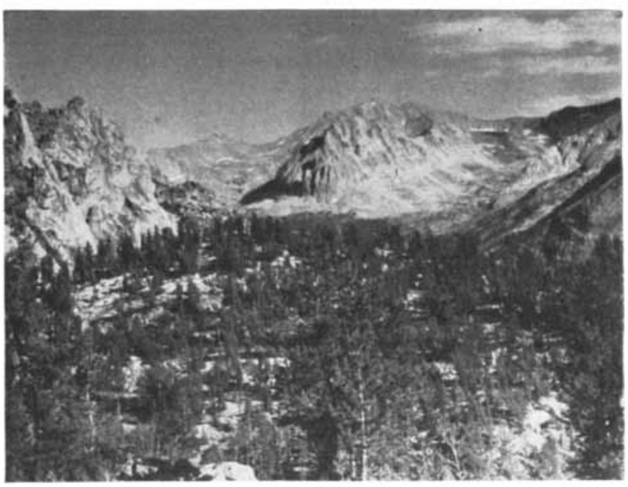
CREST of the Sierra Nevada, seen from the north, shows how the range was elevated and tilted westward near the close of the Jurassic Period some 110 million years ago.



MESA is the largest remaining fragment of subsummit plateau, an ancient landscape formed during the second of the four major uplifts that raised the Sierra Nevada.

MORAINE litters the base of Mount Tyndall, a remnant of the summit upland. Such deposits are composed of debris left behind by a glacier as it melts and retreats.

CIRQUE, the steep-walled, semicircular recess surrounding the lake in the middle distance, was carved out of the upland by the upper end of an extinct glacier.



TWIN CIRQUES occur when the heads of two glaciers are so close that only a narrow ridge separates them. Here the ridge connects Center Peak to the main divide.

EROSION by glacier gave way to stream erosion in Georges Creek Canyon. Above 9,000 feet canyon has flat glacial floor; below, stream has cut it in a sharp V.

who have been close to precision optics or in it—John Strong, Wilbur Perry and Dave Broadhead—have had much to do with the advanced ruling-engine described elsewhere in this issue. Strong's researches in experimental physics were performed for several years in the optical shop at the California Institute of Technology only a few feet from where the 200-inch Hale telescope mirror was being made; indeed, it was Strong who aluminized this mirror. Perry and Broadhead were members of the team that Strong later assembled at the Johns Hopkins University to build his ruling engine. Perry had been the chief technician at the Johns Hopkins ruling-engine laboratory since 1930, and both he and Broadhead have long been telescope makers.

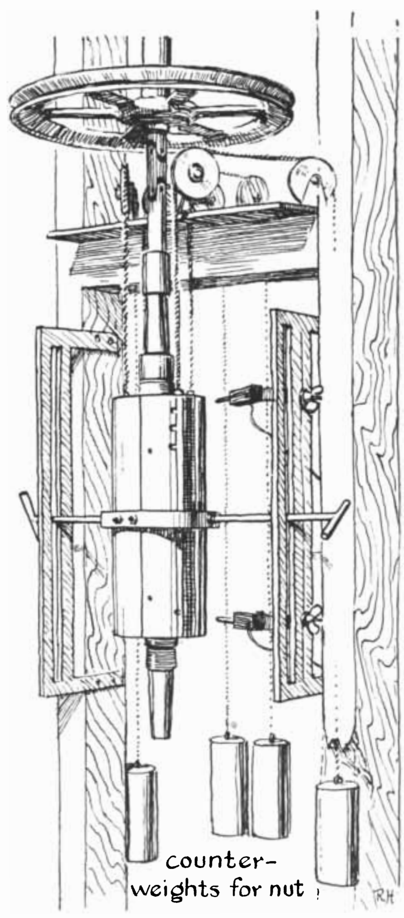
Perry was born in 1905 in Vermont. Before entering the Worcester Polytechnic Institute he spent a year with Russell Porter in Springfield, Vt., making the six-inch mirrors for 100 of the Porter garden telescopes which were marketed by the Jones and Lamson Machine Company. Perry worked two years as a toolmaker. He was an early member of the Telescope Makers of Springfield, and his portrait, done by Porter, may still be seen at Stellafane, their clubhouse.

In 1930 Perry became technician for the physicist R. W. Wood, long in charge of the Rowland engines. Since then Perry has ruled on these engines about half of the total number of gratings that have been made by the machines since the first one was built in 1882. A pleasant, calm, poised and always deliberate man, Perry is the exact opposite of the tense, hurried, mercurial "slambanger" type who would be a bull in any ruling-engine china shop. His hands have four special qualifications for ruling-engine work: 1) they are dry—damp hands corrode gratings; 2) they are both "right" hands—an ambidextrous technician is two men; 3) they are sensitive, and 4) they are sure-fingered—in 22 years he has never dropped as much as a feather on the delicate ruling engine. Habitually "pessimistic" (as the realist's viewpoint appears to the optimist), he gets results where chronic optimists only "op." Throughout the ruling-engine world Perry is a legend. As an avocation he still makes telescope mirrors.

Broadhead became ensnared in amateur optics in 1936. As his first adventure he made three 4-inch optical flats and an objective lens, then a 6-inch Newtonian telescope, an 8-inch Dall-Kirkham and a 10-inch Maksutov. In 1941 he joined Scientific American's wartime roof-prism group on learning that roof-prism-making called for "men who get results despite all obstacles." The first prism he made was so good that Frankford Arsenal asked for 50 more, 47 of which proved acceptable. In spare hours while doing other work he then made 2,850 roof prisms in the cellar shop of his home in Wellsville, N. Y. Government inspectors accepted more than 98 per cent of them.

After the war Strong selected Broadhead to make a pair of matched 36-inch plate-glass paraboloids for research in infrared spectroscopy and asked for them in 90 days. Broadhead extemporized equipment and, working alone, delivered them in 60 days. This showed Strong where to look for a resourceful builder for the vital parts of his ruling engine. Without ever having seen a ruling engine, Broadhead made these parts working alone in his shop, with a lathe, shaper, grinder and drill press. He cut the threads and pivots of the screws for the Strong engine, built the lapping machine shown in the drawing below, lapped the threads and lapped their axis into coincidence with that of the pivots, cut and lapped the end-thrust bearings and built and fitted the working nuts. At Baltimore Perry helped with the design and assembled the parts: the dividing wheels on the ends of the screws, the cross ways, the connector bar and the diamond mounting.

A high-precision screw can only be roughed out on a lathe, because even in the best possible lathe the gears and lead-screw are less precise than the thing we are going to make. After the first roughing out we cannot borrow preci-



Lapping a precision screw

sion from any machine; we must generate it by some primitive (*i.e.*, prime) method. To make a "perfect" screw (in mechanics perfect means good enough) Henry A. Rowland of Johns Hopkins invented a method so simple in principle, though not in application, that Robinson Crusoe could have made one with the iron crowbars, scrap metal, lead and grindstone that he had—if Robinson had needed a screw and had been a mechanic.

The Rowland method was to make a nut almost the length of the screw out of softer metal, split it lengthwise and equip the halves with tightening clamps. One half of a typical lapping nut for this work, Broadhead's first, is shown in the drawing. It consists of a thick and rigid steel backing into which thin half-ring sectors of bronze are screwed and soldered. The sectors are separated by about an eighth of an inch for cleanliness, for even distribution of the abrasive and to minimize flexure from differential expansion. The nut is then threaded as a whole, and is equipped with six push-pull clamps. This lapping nut is run up and down the screw for weeks in emery and oil. The emery grains embed themselves in the softer nut and precision-shape the screw by refined, slow abrasion. This is lapping.

Rowland explained the screw-perfecting principle in negative form: "A long solid nut, tightly fitting in one position, cannot be moved freely to another position unless the screw is very accurate. If grinding material is applied and the nut is constantly tightened, it will grind out all errors of run, drunkenness, crookedness, and irregularity of size. . . . The condition is that the nut must be long, rigid and capable of being tightened as the grinding proceeds." A short nut would lap only locally, failing to integrate the screw as a whole. A flexible lap would condone the errors. A nut that could not be tightened would soon cease to lap because of wear.

The entire literature on the art of screw-making consists of Rowland's 1,400-word article in the ninth edition of the *Encyclopaedia Britannica*, George F. Ballou's fascinating but technically unrewarding account of the five-year task of making a ruling-engine screw in an 1895 issue of *American Machinist*, Edward K. Hammond's article on making screws for scientific instruments in a 1917 issue of *Machinery*, and J. A. Anderson's short article in Richard Glazebrook's *Dictionary of Applied Physics*, Volume 4. None of this literature is detailed. Broadhead made his apprenticeship screw without seeing even these articles; sometimes it is more profitable not to read up on an art. Instead he worked and thought—a method of demonstrated value in mirror-making. His first screw came out uniform in diameter over substantially all its length within one-eighth of a wavelength of light (one-400,000th of an inch). A common machine screw of equal diameter has a diameter tolerance 15,000 times as great.

For several years this department received progress reports in an informal correspondence with Broadhead as he wrestled with the screws. The resulting fat file of interlineated scraps of paper would equal a book in length if fit to print. From them the following narrative, with sidelights on precision screw-making, is abstracted. This account, to be continued in the next issue, should make future precision screw-makers Broadhead's debtors for hundreds of hours of time.

Broadhead's apprenticeship screw, begun early in 1947, was made from a bar of dead soft steel two inches in diameter and 16 inches long. Nine inches of its length was threaded with 20 threads per inch at a 45-degree thread angle. This angle gives better positional stability than the standard 60-degree thread angle, but the steeper angle makes the work much more difficult at the root. Broadhead had to work for an angle accuracy within two or three minutes of arc, and a root-radius accuracy within one-thousandth of an inch.

In roughing (a relative term, since the "rough" screw is rough only under the microscope) the threads were given 10 passes, each .002 inch deep, and then five passes, each .0005 inch deep, with a carbide tool in the lathe. "This is only an approximation," Broadhead says, "since you reduce the cuts progressively by feel, to avoid tearing." Finally came enough passes at .0001 inch each to reach the desired depth. All the cuts were made on one side of the thread and then the screw was reversed. In finishing, each pass advanced .0005 inch or less for a total of .002 or .003 inch, with guided 1,200-grit diamond honing at each pass.

This was as far as the lathe could carry the precision. The "figuring" by lapping was done with the counterweighted split lapping-nut with bronze sectors, shown in the drawing, anointed with oil and emery (at the start, 303½ emery in white lead and olive oil, later 303½ emery alone, then 1200 emery). The nut was constantly run up and down the screw by an electric motor reversed every five minutes by the automatic switches shown. But only the drive is automatic; Broadhead had to make frequent adjustments in tightness. The rub is in deciding which changes to make; the screw is made by the man rather than by the machine.

Broadhead had become pessimistic by autumn and wrote that "the work has progressed like a dumb amateur's first telescope mirror." He found that precision screw-making "parallels mirror-making in a general way but goes at snail's pace because it requires a day to do appreciable lapping in order to test a change in technique, and the possible changes are countless. The screw improves rapidly at first and you celebrate, perhaps prematurely. Progress stops beyond the goal if the technique is good enough, otherwise you have failed. I am one of the Strong team and have the screwy end."

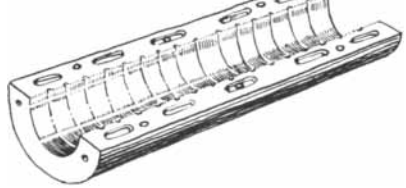
Interferometric tests showed the following deviations (or non-deviations) from the desired diameter at 19 stations along the screw-threads: zero, zero, 1/500,000 inch, 1/1,000,000 inch, zero, 1/1,000,000 inch, zero, zero, zero, 1/2,000,000 inch, 1/2,000,000 inch, zero, zero, zero, 1/500,000 inch, 1/1,000-000 inch, 1/500,000 inch, minus 1/1,-000,000 inch, zero.

The experimental screw successful, the screws for the Strong engine came next. These are an inch and a quarter in diameter, threaded on 10 inches of their length, with 45-degree threads at 40 per inch instead of 20. Before beginning, Broadhead made a precision tool of his old $500 South Bend lathe, scraping its ways straight within .0001 inch with the aid of a cast-iron straightedge and Prussian blue, and making them parallel. "That's the catch: parallel," he wrote. He fitted the lathe with new gears, lapped a new lead-screw (no problem for him now), took periodic errors out of its thrust bearing, fitted the headstock and tailstock bearings with high precision to the bed and brought the carriage-travel errors down to .0001 inch in 10 inches. "It's an old lathe," he explained, "but instrument makers use such lathes for centuries, just scraping 'em over—which they'd have to do even with new ones, for this work."

In summer Strong arrived and "for two days," Broadhead wrote, "we worked like beavers. He brought two garbage cans with inner cells, one for electric heat, the other with dry ice, so I could artificially age the screws before the finish cuts were made." After roughing out the screws and thus setting up internal stresses in the metal, Broadhead spent a week relieving them of stress by dipping them in what he called "tincture of skunk cabbage" (overheated vegetable oil, Mazola) at 400 degrees F., then at 100 degrees, and next in "hobo cocktails" (dry ice and alcohol) at 10 degrees, minus 60 degrees, 10 again and again 100. He repeated the whole process for 50 cycles.

Early in 1949 I found work well started on the Strong engine at Baltimore, while the veteran Rowland engines, hovered over by the always careful Perry, plodded along, falling more and more behind the growing backlog of orders for gratings. A little later Strong, Perry and John F. McClellan of Strong's team drove to Broadhead's house in Wellsville to coordinate the work and try to consume a side of Broadhead's venison.

In the spring Broadhead philoso-



Inside of the lapping nut

phized: "My experience with ruling engines has tempered my amateur eagerness. I agree with R. W. Wood that making gratings is not a project for amateurs in the sense that mirrors are. It also takes cooperative effort. I think I could build an engine in about five years, but prefer participation in this team. Working all alone, a rabid, egotistical amateur could easily kill himself if egged on, so don't commit manslaughter. Some guys might think that because they hit millionth-inch accuracy on a mirror they could as easily do so on ruling engines. They might be surprised. A mechanic working to .0001 inch is as good as a telescope maker working to .00001 inch."

Strong praised the upgraded Broadhead lathe: "On the screws Dave can take a cut as small as .00004 inch thick and hold it over the length of the thread, or turn a cylinder 10 inches long accurate to .00005 inch diameter."

I journeyed to Wellsville and found Broadhead peering downward through a 50-power toolmaker's microscope attached to the lathe. The tool was smoothly peeling off a shaving only one micron thick. Without the microscope it seemed to be cutting nothing. As he worked he discussed the philosophy of screws and telescope mirrors.

"A long lapping nut corresponds in theory to a mirror lap. A 'full-size' nut, 10 inches in this instance, would run out over the ends of the 10-inch screw and affect the screw as a full-diameter lap affects a mirror: the screw would become barrel-shaped. On a mirror an 83-per-cent-diameter (neutral) lap on top will hold the curve, neither deepening nor shallowing. On the screw I use a neutral lap of about 90 per cent length, mirrors and screws not being wholly alike."

That summer he finished the threads and began work on the mounting of the screw—several times more difficult than the screw itself. "Progress is slow and what is learned is mainly what not to do. I feel like a sapper crawling in a mine field." And in November: "Anyone who schedules a ruling-engine job by advance dates is my idea of an *optimist*." When he was asked "What's wrong?" the answer came: "How do I know? Trouble is, there's no Foucault test for screws. A mirror can be tested with great precision throughout the process of making, and the test takes only a few moments, but on a screw the use of the interferometer, nut tension scales, recorders, feel, appearance, all add up to little, and the first real test is the cross-rulings made with the assembled engine. With the screw it takes weeks to evaluate each change in technique. I am now working on getting the pivots concentric with the helix of threads, as mean a job as Anderson said, and on eliminating periodic end-thrust errors, an awful job, far more nerve-wracking than making the screw." ("Mean" and "awful" were not the actual adjectives Broadhead used.) The factors involved are pressure distribution, "stroke" length, oil viscosity, types and sizes of abrasive, speed, tooling method. Nobody seems ever to have made systematic records of these, or perhaps they hid them.

Rowland depended largely on feel as a test for constancy of screw diameter and progressive error; the two are mixed, or additive, not separately identifiable because of the shape of a screw-thread. Broadhead states that if the diameter, as given by the three-wire method, is good to .0001 inch, the error may be attributed to lead. "If the nut moves from end to end without friction," Rowland wrote, "the screw is uniform in diameter." To Rowland's method of testing, Anderson added a lever and spring balance, and Broadhead, with a background in electronics, devised electrical recording apparatus, with an Esterline-Angus tape recorder that makes a continuous ink record of the torque of the nut as it keeps changing while the screw is lapped. The change of torque, Broadhead said, is due mainly to temperature changes in the work, to variations in the lead and diameter of the screw, to the additions of fresh grit and to overhang. With this recorder the trends can be watched and the lap adjusted often to prevent seizing. The recorder indicates when fresh abrasive is needed, when a bit of steel has got in, and so on. Even with the recorder it still amounts to making a whole engine to test its screws.

A few days later McClellan arrived at Wellsville with a truck, and the parts of the engine that Broadhead had made were taken to Baltimore.

In January, 1950, Broadhead was queried as he hung at home on tenterhooks, awaiting reports on the newly assembled engine. "Dave," I wrote, "knowing mechanism as you do, did you really expect it to go together and start right off working satisfactorily?" No answer came for several days, and then: "No. But it *did*. It DID! Strong, Perry and I got on the long-distance phone and celebrated. First grating came off today; only 56 hours to rule it. I just wander around in a daze. Can't think, plan or do anything, except drum on piano."

Since that was written, Broadhead has all but completed the important parts for the engine's duplicate, for gratings with 28,800 grooves per inch.

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