SCIENTIFIC AMERICAN

EMBRYOS

FIFTY CENTS

February 1950

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Through IBM research and development, the remarkable abilities of electron tubes have been put to work in business machines.

Electron tubes—fast, versatile, accurate—are used in the IBM Machines pictured here to calculate at extraordinary speeds, to "remember" the answers to intricate computations, to follow long series of instructions, to control the flow of electricity with amazing precision.

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The IBM machines illustrated use electronic principles. Clockwise from the top, they are: Electric Time System, with Electronic Self-regulation; Alphabetical Collator; Statistical Machine; Card-programmed Calculator, including Calculating Punch; Punched Card Sorter.

For descriptive literature, write to Dept. W.

IBM

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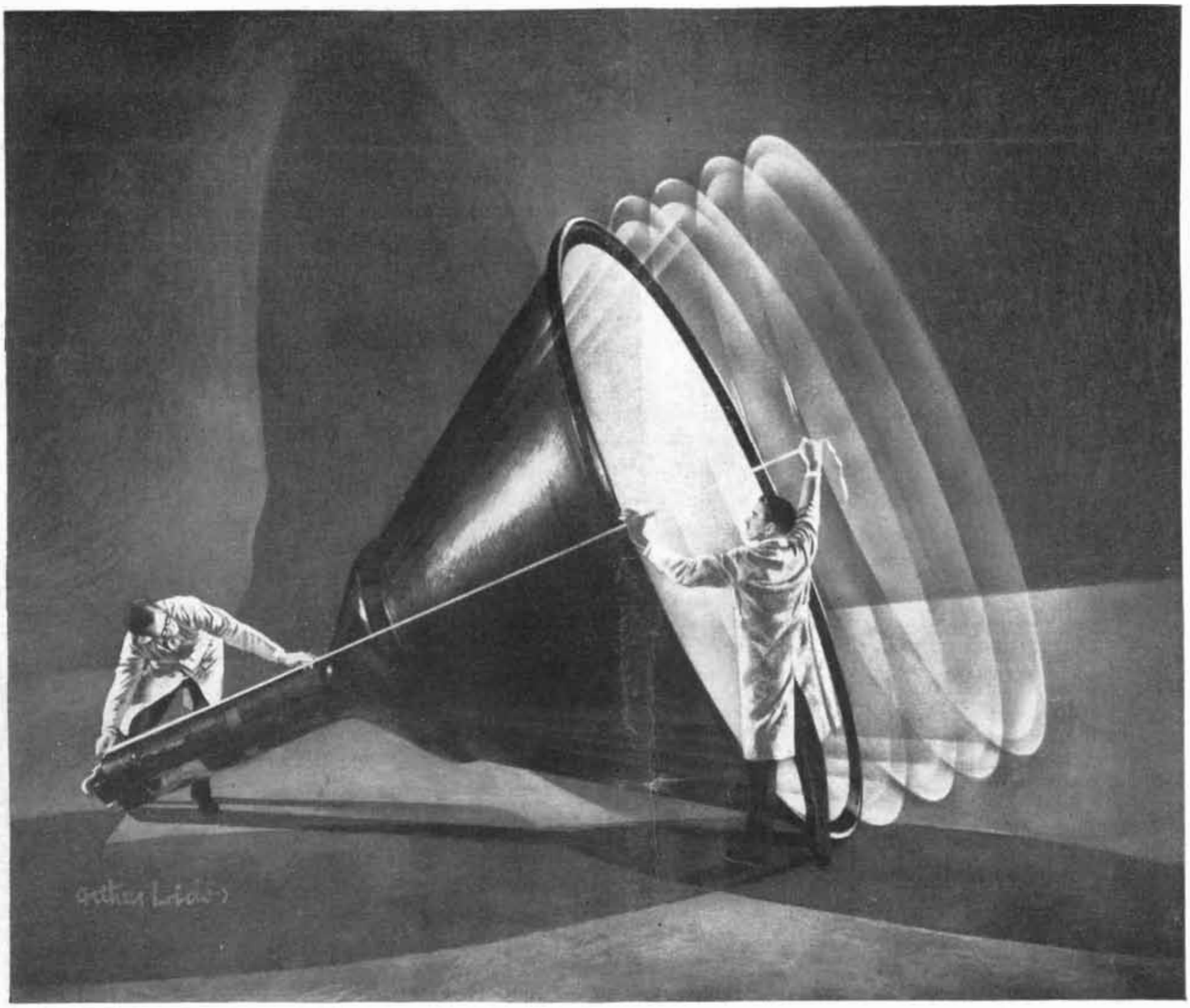

New and shorter big screen 16-inch kinescope developed by RCA scientists.

Problem: shrink the television tube, but keep the picture ***big!***

Some rooms accommodate grand pianos, a small spinet is right for others. Until *recently,* much the same rule held true for television receivers. Your choice was governed by room space.

Now the space problem has been whipped by RCA scientists, who have *shortened the length of 16-inch television "picture tubes" more than 20%!* All the complex inner works—such as the sensitive electron gun that "paints" pictures on the screen—have been redesigned to operate at shorter focus, wider angle. Even a new type of faceplate glass, Filterglass, has been developed for RCA's 16-inch picture tubes—on principles first investigated for television by RCA.

Filterglass, incorporating a light-absorbing material, improves picture quality by cutting down reflected room light . . . and by reducing reflections inside the glass faceplate of the kinescope tube itself. Result: richer, deeper black areas and greater contrast in the television picture!

See the newest advances in radio, television, and electronics at RCA Exhibition Hall, 36 W. 49th St., New York. Admission is free. Radio Corporation of America, Radio City, N. Y.

New RCA Victor home television receiver, with big 16-inch screen—now *more than 20% shorter* in depth.

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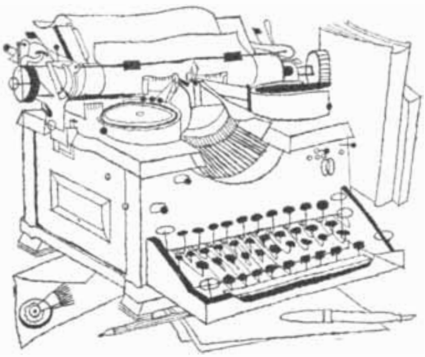
LETTERS



Sirs:

The note in your department "Science and the Citizen" for December, "Refined Pi," on its computation by the ENIAC at the Ballistic Research Laboratories, may be somewhat misleading with regard to the implied complacency of later mathematicians to accept as correct and adequate Shanks' early 19th-century approximation of *pi* to 707 decimal places by Machin's formula. In 1854 the calculation to 500 decimal places was verified, and in 1945 Mr. D. F. Ferguson, of the Royal Naval College and the University of Manchester, by use of Loney's formula verified Shanks' approximation to 527 places, but found the rest of Shanks' result incorrect. Then Dr. J. W. Wrench, Jr., and Mr. L. B. Smith, by Machin's formula, substantiated Ferguson's finding of Shanks' errors. Suffice it to say that at present Ferguson, Smith and Wrench are in agreement on the value of *pi* through their computations to 808 places and that the checked ENIAC determination, based on Machin's formula, confirms their work and extends the value to 2,035 certain figures, and 2,037 probable.

It may be worth-while to say that the ENIAC computers undertook their task on their own time, with a view toward obtaining a statistical measure of the randomness of distribution of the digits in *pi* (and *e* as well), following a suggestion of Professor J. von Neumann, who as a rule has a dependable sense of the cogent. A group of four ENIAC operators spent Labor Day week end on the project and required actual machine-running time of about 70 hours. As a warm-up job *e* had been computed over the July 4 week end to a total of 2,012 places. Mr. George W. Reitwiesner has submitted an account of this latter work to *Mathematical Tables and Aids to Computation.*

I suspect that Mr. Ferguson, who computed some 500-odd places by hand over a few years before he resorted to a machine for the final 300, will not be disheartened by the ENIAC competition, but instead will rejoice in the knowledge that a computation of *pi* has sufficient interest to keep four youthful mathematicians in Aberdeen over two summer holiday week ends.

D. J. X. MONTGOMERY

Ballistic Research Laboratories
Aberdeen Proving Ground, Md.

Sirs:

Dr. Infeld's remarks in his "Visit to England" (*Scientific American,* November) about Blackett's new theory to explain terrestrial magnetism bring to mind an idea expounded by William Gilbert of Colchester in his book *De Magnete.*

Gilbert (1544-1603), a graduate of Cambridge University, was a wealthy physician who happened to have an amateur's passion for physics. In the pursuit of his hobby he founded the sciences of magnetism, electrostatics and terrestrial magnetism. He was also the first Englishman to give a published literary defense of the idea that the earth rotates. His laboratory technique was the modern experimental inductive method.

One of Gilbert's achievements was to classify the kinds of magnetic movement into five categories. Four of these are acceptable without question: (1) attraction, (2) polarity, (3) declination, (4) inclination. But his fifth class, rotation, seems somewhat of an anomaly; and it is this unexpected idea that Blackett's new theory brings to mind.

How Gilbert happened to include this fifth class is a mystery, for his generalization was based on experiments with spherical lodestones or *terrellae* (earthlets). Doubtless he never saw a lodestone spin on the strength of its being a magnet. But the conception of rotation as a type of magnetic motion crops up every now and then in *De Magnete.* He associated the earth's whirling with its magnetism. He was convinced that every planet and star spins on a private axis, and in each case he attributed the rotary movement to magnetism. Like Blackett he supposed that the magnetic poles lie along the axis of rotation. Again like Blackett he believed that the relation between magnetism and rotation is explicable only in terms of a basic property of matter. In Gilbert's Renaissance jargon he picturesquely called it "form" or "soul."

The chief point of difference between Gilbert and Blackett is that the one conceived of magnetism as the cause of rotation, while the other thinks of the relation in the reverse.

RUFUS SUTER

Army Map Service
Washington, D. C.

Sirs:

Re your December "Science and the Citizen" item "Hereditary Schizophrenia?" you may be interested to know that Dr. Franz J. Kallman of the New York Psychiatric Institute published in the *American Journal of Psychiatry* his account of schizophrenia in 174 pairs of identical twins and 517 pairs of ordinary twins. If one of a pair of identical twins developed this disease, the other developed it in 85.8 per cent of the cases. If the twins were ordinary twins and one member of the pair developed the disease, the other developed it in only 14.7 per cent of the cases. This is the same as its frequency in other members of a family in which one member develops the disease. An account has been published, also I think by Kallman, of identical twins, one of whom came to America while the other remained in Europe. Both of the identical twins developed the disease.

H. D. GOODALE

Williamstown, Mass.

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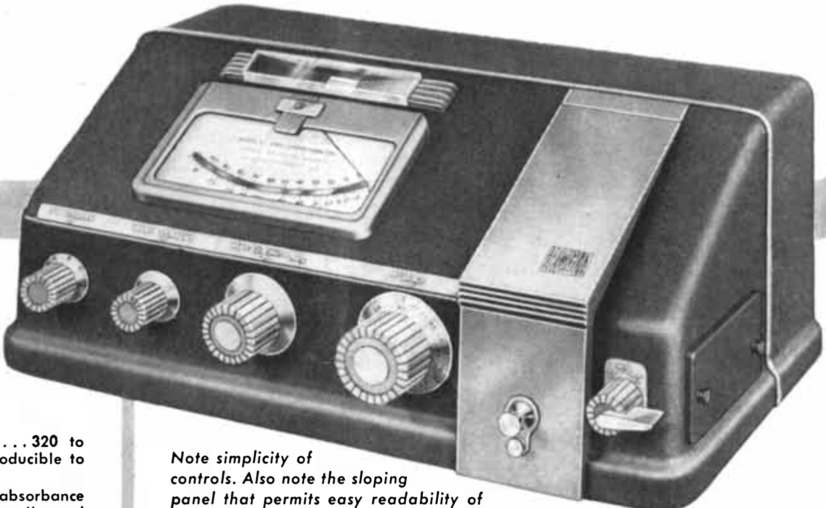

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50 AND 100 YEARS AGO

FEBRUARY 1900. "Candidates for the Nobel prize for scientific achievements are being considered by the Swedish Academy of Science, at Stockholm, which must award the prize this year for the first time. Among the names already proposed are Prof. Roentgen, Marconi, Baron Nordenskjold, and Henri Dunant, the founder of the Red Cross Society."

"M. E. Becquerel has presented at the last meeting of the Academie des Sciences an account of a new series of experiments which he has made upon the action of radio-active matter in a magnetic field. In the experiments previously described, the active matter contained a large proportion of the newly discovered element radium; in continuing his experiments with matter containing the other new element, polonium, discovered by M. and Mme. Curie, which possesses properties analogous to the former, he finds that the action is entirely different; the radiations from this body, while showing in other respects nearly the same activity as those of radium, are not appreciably affected by the magnetic field. It has been observed also that these rays are very unequally absorbed by different substances. To these observations should be added those made by M. and Mme. Curie upon the compounds of uranium, which are found to be unaffected by the magnetic field."

"The United States Bureau of Labor has been investigating the effect of displacement of hand labor by machinery in the iron and steel trade. It was found that in 1857 a rifle barrel took 98 hours to make by hand. It is now made in 3 hours and 40 minutes. Half-inch bolts 6 inches long with nuts were made by hand at the rate of 500 in 43 hours, while by machinery the same product is turned out with only 8 hours' labor. In 1835, 100 feet of 4-inch lap-welded pipe required over 84 hours of labor, while in 1895 the same product was turned out in 5 hours."

"Dr. Ludwig Mach discovered that alloys of magnesium and aluminium possess properties not found in either of the two components. For ordinary uses, where small weight, great tenacity, and strength are required, these alloys containing small percentages of magnesium are evidently extremely serviceable. At present the cost of these alloys is considerably greater than that of pure aluminium, owing to the higher price of magnesium. But magnesium is so expensive chiefly because it has been used only in small quantities and produced only on a small scale. When the metal will be more widely employed in the arts, it will probably become cheaper than aluminium. We may, therefore, hope that Mach's alloy—'magnalium,' as it has been called—will become one of the cheapest metals which we can use. The strength of the compound is extraordinary. Tests made by the inventor show that magnalium is stronger than cast iron and less brittle."

"The Roentgen rays are proving their value in field surgery in South Africa. A fresh equipment of apparatus has been ordered, and skilled operators are being sent to the front."

"It is probable that barbed wire will become classed as war material, as it was largely used by the Spanish army in Cuba, and it is now doing excellent service for the Boers, and probably nothing tends to demoralize an assault more than strong barbed wire."

"At a meeting of the Royal Institution, Lord Rayleigh delivered a most interesting discourse on flight. A bird did not use a revolving mechanism like a screw to propel itself, but he had no doubt that a revolving mechanism was the most suitable for artificial flying machines. He did not think flight would ever be a safe mode of conveyance for those who were desirous of going out for a day's shopping. But, as Mr. Maxim once remarked, the first use of flying machines would be for military purposes, and they had not yet succeeded in making war quite safe."

FEBRUARY 1850. "A French savant, M. Fiqueau, has just discovered a method of measuring the speed with which light travels, without any resort to the regions of astronomy. Two glasses are fixed opposite each other, so that the focus of the one (having a mirror) reflects a ray of light, starting from the focus of the other back to that focus again. A disc is provided to revolve at this point; and the eye, observing whether the ray appears, or is eclipsed, knows whether it has encountered a tooth of the disc, or one of the vacant spaces between the teeth; and thus elements are found for a calculation which shows the speed of light to be very nearly the same as that arrived at by the astronomical calculation of Bradley or Roemer."

"In a recent lecture delivered before the American Institute, by the celebrated Professor Agassiz, he stated some curious facts respecting insects. He said more than a lifetime would be necessary to enumerate the various species and describe their appearances. There are numerous species collected in the museums of Europe, but they form only a small part of the whole number; and even of these, the habits and metamorphoses are almost entirely unknown."

"A letter has been received from the American Charge d'Affaires, John P. Brown, Esq., at Constantinople, by Mr. Samuel Colt, the inventor of the firearm which bears his name, announcing that the next European steamer would bring out an elegant snuff box, set in diamonds, of the value of $1,300, designed as an evidence of the very high appreciation of his weapon entertained by Mehemet Ali Pacha, Serosbi of the Army."

"According to the late accounts from California, it appears that the miners make very little money compared with what the speculators are doing."

"M. Grange read a paper on that terrible disease in the Swiss valleys, named the Goitre. He stated that the cause of it was magnesia in the waters, and that it could be cured by minute doses of iodine salts."

"M. M. Malaguti Durocher and Sarzeaud announce that they have detected in the waters of the ocean the presence of copper, lead and silver. The water examined appears to have been taken some leagues off the coast of St. Malo, and the fucoidal plants of that district are also found to contain silver. Beyond this, pursuing their researches on terrestrial plants, they have obtained such indications as leave no doubt of the existence of silver in vegetable tissues. Lead is said to be always found in the ashes of marine plants, and invariably a trace of copper."

Above is the Bell System's new "musical keyboard." Insert shows the digits of telephone numbers in musical notation, just as they are sent across country.

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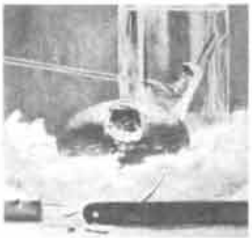

THE COVER

The speckled brown chicken's egg on this month's cover has been cut open to permit observation of the developing embryo inside (*see page 52*). The missing piece of shell lies in front of the saw with which it was cut out. A small watch glass covers the hole in the shell. The glass rod above the egg has enclosed in its tip a loop of hair with which delicate operations can be performed on the embryo. To the left of the saw is a yellow-handled Spemann pipette, used to lift and carry bits of embryo removed by the experimenters. It is named after its inventor, Hans Spemann, a German biologist who was one of the fathers of experimental embryology. In front of the pipette are three tiny fertilized frog's eggs. The eggs of frogs and other amphibians, used by Spemann in his investigations, are exceptionally easy to observe under the microscope. In the background of the painting is a bottle containing a six-day-old chick fetus that has been stained, preserved, and mounted on a glass slide. The prismatic effect around the slide is caused by the combined optical properties of the glass and the preservative. The scene of this painting is the Laboratory of Experimental Embryology at Washington University.

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Cover by Stanley Meltzoff

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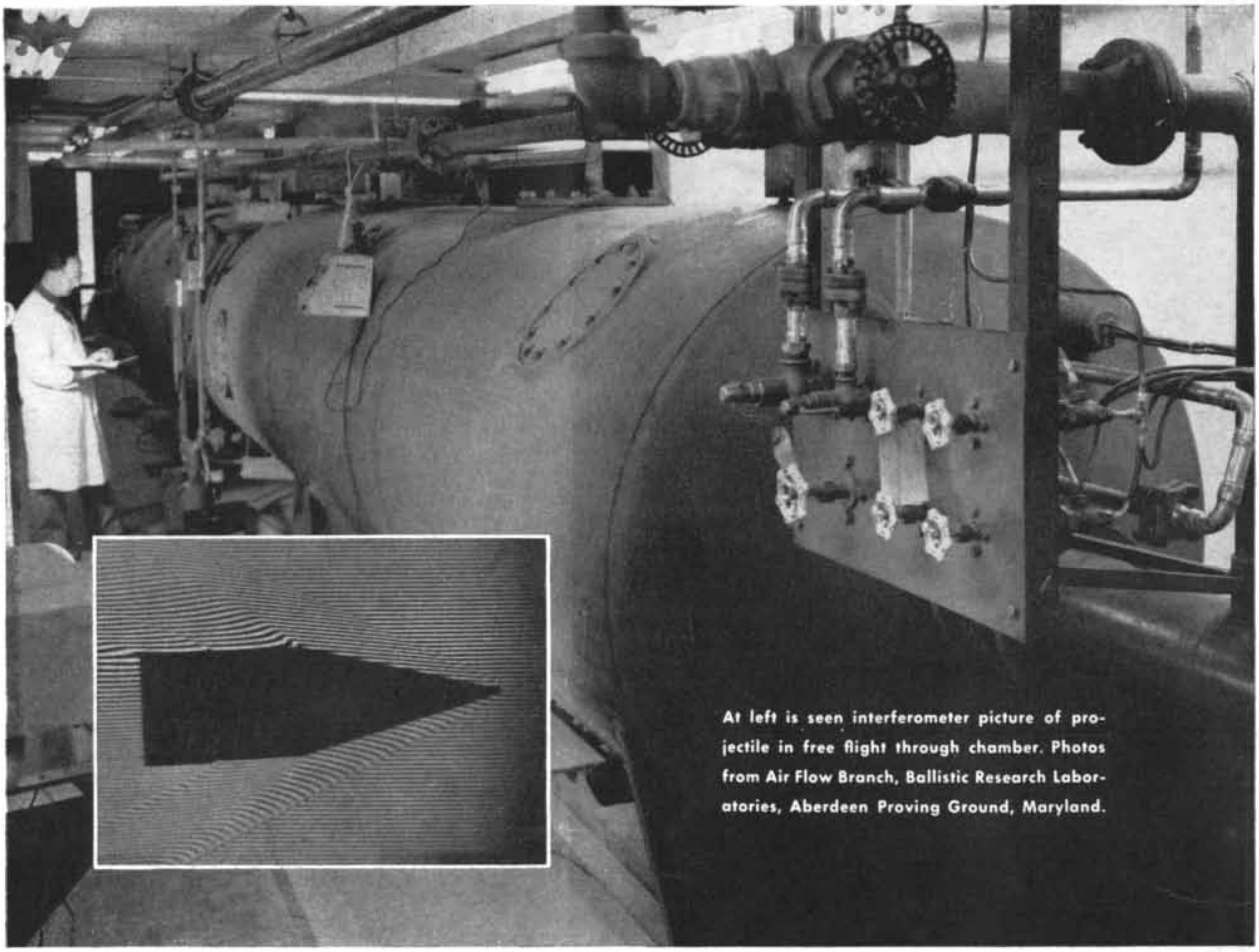

At left is seen interferometer picture of projectile in free flight through chamber. Photos from Air Flow Branch, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.

Shooting Gallery in a DPi Vacuum Bottle

The Army Ordnance men of the Ballistic Research Laboratories at Aberdeen Proving Ground knew that by setting up proper combinations of temperature and pressure they could duplicate any of the conditions that determine turbulence, Mach number, and other factors in the air around a flying projectile. But their demands were extreme.

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VOLUME 182, NUMBER 2

ARTICLES

DEPARTMENTS

SCIENTIFIC AMERICAN

FEBRUARY 1950 VOL. 182, NO. 2

POPULATION

Is civilization endangered by the probability of a rapid Malthusian growth of the peoples in Asia and Latin America during the next five decades?

by Warren S. Thompson

TO appreciate what has happened in the growth of the world's population in the past 250 years, we must place the situation in a longer perspective. For purposes of illustration let us consider the 10,000-year period prior to 1700 A.D. The best available estimate is that the population of the world in 1700 was in the neighborhood of 600 million, and we may certainly assume that 10,000 years earlier there were at least one million human beings on earth. On these assumptions, the average rate of increase throughout the 10,000 years would have been only .64 of a person per 1,000 per year. Of course in short time intervals and in local communities there must have been much sharper increases or decreases. But taking the period as a whole, any observer might well have agreed with the general conclusion expressed by the 18th- and 19th-century English economist Thomas Malthus, that over long periods population remained almost stationary, and that the chief reason for this was that the positive checks of hunger, disease and war kept man's death rate on the average at about the same high level as his birth rate.

In the 250 years since 1700, however, the number of human beings has abruptly shot upward with almost explosive force. In a period only a fortieth as long as the 10,000 years preceding 1700, the population of the world probably has almost quadrupled, rising from 600 million to more than two and a quarter billion. Over the past 250 years the average annual increase for the planet as a whole has been 5.5 persons per 1,000. Even this average rate of increase in another 250 years would raise the world's population to over nine billion. In some productive areas of the world the rise has been much greater than the average; for example, in the U. S. between 1790 and 1860 the rate of natural increase, excluding immigration, was nearly 33 per 1,000 per year.

The factor principally responsible for the great increase of the past 250 years is a sharp relative drop in the death rate. As to the reasons for this drop, we can find some clues in an analysis of the fluctuations of particular populations. Consider, for instance, the variations in growth from year to year in Sweden between 1751 and 1850. During that century Sweden's population almost doubled, growing from 1,772,701 to 3,461,914. The rate of increase averages out to 6.7 persons per 1,000 per year. Actually the annual fluctuations departed widely from this average; they varied from a natural increase (excess of births over deaths) of 15.95 per 1,000 in 1825 to a decrease of 26.93 per 1,000 in 1773.

The significant fact for our purposes is that there were only six years during this century in which deaths were more numerous than births, and only eight others when the natural increase was less than three per 1,000. In every one of those 14 years the death rate was abnormally high. And in each case the high death rate was preceded by a period of scarcity of food, generally accompanied by an increase in epidemic disease. Abundance or scarcity of subsistence also had an effect on the birth rate: a good harvest generally was followed by an increase in marriages and, in due course, an increase in births, while scarcity was followed by fewer marriages and a lower birth rate. But during this century death rates in Sweden varied much more than birth rates; thus the yearly variations in the death rate during this period clearly were more important in accounting for the variations in natural increase, although later the variations in the birth rate became about equally important. The same general pattern prevailed in Finland during the century we have been considering. There is also much evidence that even today death rates in the less industrialized nations are still highly variable and are more important than birth rates in determining the variations in population growth from year to year.

Thus it appears that the principal restriction on population growth has been the scarcity of food. To be sure, there have occasionally been devastating epidemics that did not seem to be directly related to such a scarcity, but over long periods it is highly probable that epidemics connected with scarcity have been more important in reducing population growth than those not so connected. There can be no reasonable doubt that the amount of subsistence is still the chief factor in determining the level of the death rate in such countries as China and India.

In the long view, Malthus was fundamentally correct when he said that man's growth in numbers was largely dependent on the supply of subsistence. He did not live long enough to be certain of any significant decline in the birth rate, except possibly in France. Nor did he witness any significant advance in public health, although he mentioned vaccination as probably a factor in the decline of France's death rate. He remained convinced to the end of his life that the supply of food was and would remain the overriding factor in determining population growth.

MANY unexpected things have happened since Malthus made this diagnosis. In the writer's opinion the fundamental factors in bringing about the unprecedented growth of population in the last two and a half centuries have been the development of science, *i.e.*, knowledge, and the application of this knowledge to the practical problems of production and health. Of the first importance, both in time and in its effect on the death rate, is the increase in production which has come to be associated with the Industrial Revolution beginning about the middle of the 18th century. Of course this revolution took some time to make its effects felt even in Western Europe, and many parts of the world have still not been much influenced by it. The essential fact, however, is that prior to about 1750 there was very little difference in the manner of life of all civilized peoples, whereas now there are great differences, affecting their birth rates and their death rates.

I remember walking down a street in Nanking, China, one afternoon nearly 20 years ago with the eminent English economic historian R. H. Tawney, and remarking to him that Chinese cities often reminded me of his description of early 18th-century English economic life. He replied in effect: "I was just thinking that the English workman of that age would have been very much at home in the economy as well as in the living conditions we have just been observing, but so also would the Frenchman from Paris or the Italian from Florence. The farmers would have wondered at some of the crops raised here, but they would have understood the Chinese methods of cultivation and the care given the soil."

In 1700 it took the labor of about four European peasant families to produce enough food and fiber for five families. So it did in Russia until within the last 20 or 30 years and so it does in China and Java today. The yields of most crops per acre were low (in this respect much of China was probably well in advance of Europe in 1800), the methods of cultivation were primitive and the livestock was of extremely poor quality. Production of nonagricultural commodities was of the same low estate. Almost the only power man knew, either for agriculture or industry, was his own muscle power.

Into this situation improved varieties of staple crops, new crops, better farming methods and better-bred livestock were introduced slowly. Compared, however, with the changes during the preceding 2,000 years, the revolution in agricultural practices after about 1700 was indeed rapid. Contrary to the common belief, an Agricultural Revolution got under way before the Industrial Revolution, and it was primarily responsible for launching the huge increase of population that we are considering.

The improvement in crops and livestock in Europe not only made it possible for people to eat better, but was also instrumental in making it possible to accumulate capital faster. Soon industry joined agriculture in the revolution, and each made possible further advances in the other. Farmers could clear and drain land faster, and otherwise improve the management of soil so that it would produce still better crops. From the latter part of the 17th century to the present, agriculture has undergone changes fully as spectacular, though not as widely realized, as those in industry. Today in the U. S. only about 16 to 18 per cent of our workers are engaged directly in agriculture; in other words, one farm family produces enough for six families, and at a vastly superior level of consumption. It is probable that the average American farmer today produces as much as 10 non-farm families consumed in 1700.

The improvements in agriculture not only proved to be good economics; they also had exactly the effect that Malthus had predicted the provision of more ample subsistence would have on population growth. They reduced the death rate, *i.e.*, rendered the positive checks less severe, and population grew more rapidly and more steadily.

WHEN man began to harness water to run his machines, to burn coal to generate steam and to produce an increasing variety of goods of better quality, he was well on the way to the development of a new pattern of production which soon exceeded his wildest dreams of efficiency. For a time it appeared that in the Western world we no longer needed to give serious attention to the ideas of Malthus, that we had learned how to produce at a rate in excess of any possible rate of population growth, and that we could look forward to an easier life no matter how high our birth rate or how low our death rate. This view was further strengthened when the rate of natural increase in population began to fall, due to the fact that the birth rate began to decline faster than the death rate. The result was a further general rise in the standard of living.

Two other factors played an important role in the West. The first was the abundance of new land to which Western Europeans began to migrate on a large scale after 1800. Millions of acres of rich agricultural soil and incalculable mineral wealth were opened up in the U. S., Canada, Argentina, Brazil and Australia. Coupled with the application of power, these riches gave Europeans an opportunity to expand unique in human history, permitting an increase of hundreds of millions in population with a better level of living.

The second factor was the application of science to produce great advances in public health facilities—good medical schools, medical research, sewage disposal systems, water works, hospitals. These health works, by preventing the perennial epidemics of typhoid, dysentery, smallpox, diphtheria, and so on, sharply reduced the death rates in the West. They may also reduce them even more rapidly in those parts of the world where rates are still high. In Japan during the Occupation, for example, the vigorous application of health knowledge has reduced the death rate from an estimated 32 per 1,000 in the last five months of 1945 to 12 per 1,000 in 1948, about a third below the prewar rate. This unprecedented achievement is all the more remarkable because the level of living is far lower in Japan than in Western nations. This experience in Japan gives tangible support to the belief of demographers that the industrially backward areas of the world are likely to grow rapidly in population during the next century as they industrialize.

YET most Americans and Europeans are much less conscious of this possibility of vast increases in population than they are of the possibility of further large increases in production. Hence it is not surprising that there is a rather widespread feeling in the West that the application of science to agriculture and industry will provide improving standards of living for any population the world is likely to have in the foreseeable future. This seems all the more probable to us in the Americas and Australia because of the widespread talk of agricultural surpluses. It is natural, therefore, to find many people asking why anyone should be concerned over the possibility of the world's population growing faster than the world's supply of subsistence. Put in this form, however, the problem is meaningless. To consider the problems of population growth realistically we must examine the different situations that exist among the peoples of the world.

Anyone even moderately familiar with the conditions of population growth will readily recognize several different situations. On the basis of characteristic patterns of birth rates, death rates and conditions that determine these rates, the writer classifies the populations of the world in three groups.

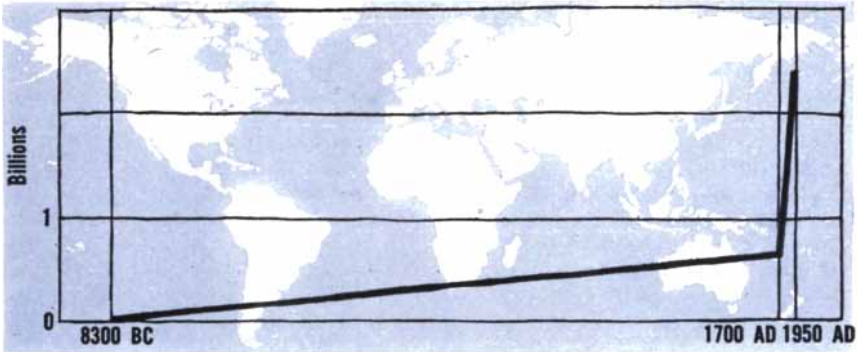
Group A consists of most of the peoples of Western Europe and of the lands, such as the Americas, that they have chiefly settled. This category, comprising about a fifth of the world's population, is characterized by low birth rates, low death rates and low rates of natural increase. In general, except for war there is little reason to be concerned over the ability of these peoples to produce the goods essential to decent living.

Group B consists of the peoples of Eastern and Southeastern Europe, Japan, Spain and perhaps two or three South American countries. These peoples, also comprising about a fifth of the world's population, are characterized by moderate death rates and birth rates high enough to yield a rather high rate of natural increase, which seems likely to continue for several decades. They have as yet only a moderate measure of voluntary control over births, and death rates which are decreasing about as fast as, and perhaps faster than, their birth rates. They will almost certainly become an increasing proportion of the world's population during the next half or three quarters of a century.

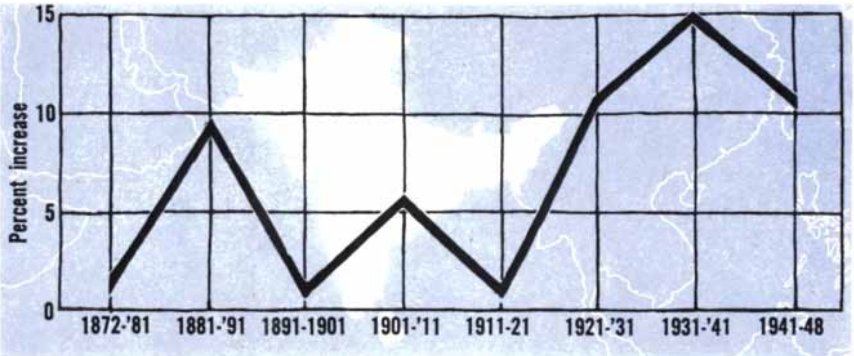
Group C, making up the remaining three fifths of the world's population, lives chiefly in Asia and its large adjacent islands, in Africa and in those parts of South and Central America not included in the second group. They may be called the Malthusian countries. They have very high birth rates and death rates, but chiefly because of the great variability of their death rates their rates of natural increase are also highly variable. Thus India in the decade from 1931 to 1941 was able to hold her death rate nearly 15 points below her birth rate and grew by about 50 millions. However, in this group the control over death rates, such as it is, is highly precarious, and there is no evidence anywhere of any significant decline in the birth rate. The population seems to grow whenever subsistence increases and to stop or even decline at times of scarcity and great epidemics.

THESE three categories of peoples also have distinguishing economic characteristics. Group A in general has a highly productive economy in which efficiency is increasing rapidly. Since families are small and population is growing slowly, the level of living is high, and if it had not been for the two world wars, all of these peoples would probably have enjoyed rising levels of living. In Group B the economy is less productive, but machine industry is spreading and agriculture is improving. There is reason to believe that in some of the Group B countries productivity will increase faster than population even in the immediate future. Apparently this was beginning to take place in Poland, Hungary and Czechoslovakia before the war, and it may be now occurring in the U.S.S.R., although demographic data from that country are so scanty as to permit of only the most tentative conclusions.

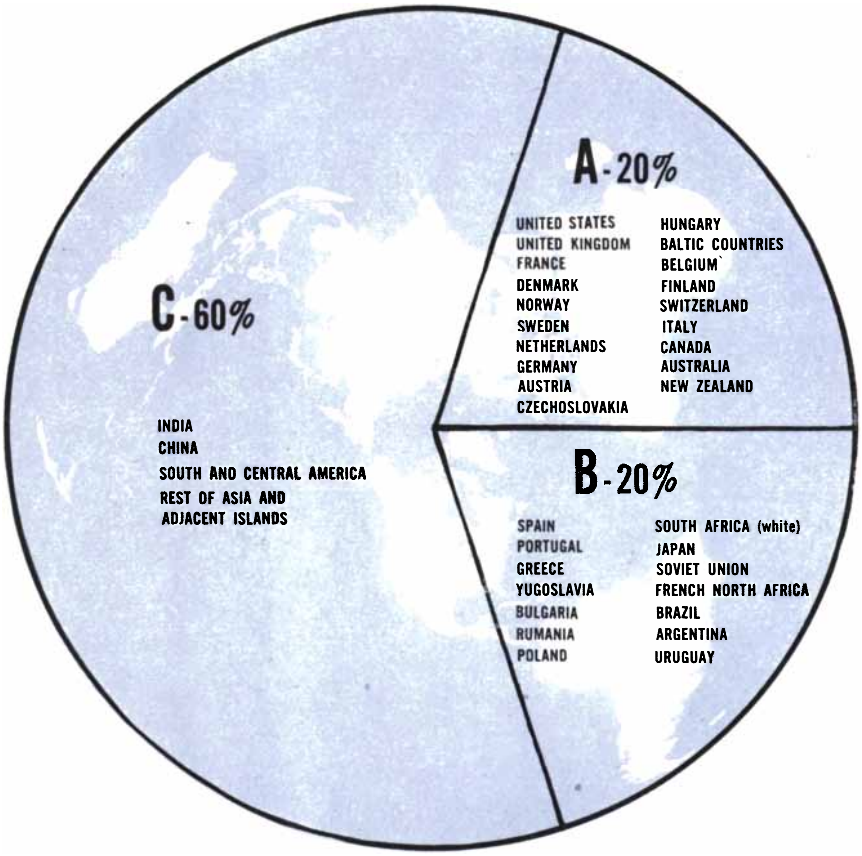
In Group C the low level of productivity is the basic factor in keeping the death rate very high, although it gets an occasional assist from an epidemic not due primarily to scarcity, like the 1918



JUMP IN POPULATION of the world during the past 250 years is dramatically shown by chart comparing it with slow growth in preceding 10,000 years.



FLUCTUATIONS IN GROWTH of India, a typical Malthusian country, illustrate the dependence of population increases on supply of subsistence.



WORLD'S PEOPLES are divided into three categories based on relation of births to deaths. Countries with high rates in both have three fifths of people.

influenza outbreak in India that killed many millions. Group C now has 10 or more times as many people as the whole of Europe in 1700. It has little machine-powered industry. The yields of rice in many parts of South and East Asia, however, are well above grain yields in most of the West today. So far this relatively high per acre production of rice has only served to increase the density of population, and not to raise the level of living. Here is a population at least twice as large as the population of the entire world in 1700, with birth rates and death rates which are probably higher than those of most countries in Europe at that time.

What are the prospects that the growth in agricultural and industrial production among the peoples of Group C will exceed the growth in population enough to raise levels of living? What will be the consequences to these peoples and the rest of the world if this fails to happen? Even these questions are of too general a character to have much meaning, but they are much more realistic than one which gives the impression that there is but one vital question regarding the relation of population and subsistence, and that it can be phrased in some such simple manner as: Can the world feed a large increase in population?

TO consider the matter as concretely as possible, let us take a particular country as illustrative of what is likely to happen in the whole of Group C. For the type of analysis which seems to me worth making, India is chosen rather than China because we have much more reliable information about her population and agriculture. Between 1872 and 1941 India's population grew from about 256 million to 389 million, approximately 52 per cent. In three of those seven decades her growth was less than one per cent. In those three decades famine and disease were rampant. Only from 1921 to 1941 did India have two consecutive decades of significant growth.

There can be no reasonable doubt that during the 70 years in question India's birth rate varied much less than its death rate. Although no precise figures can be given, both are known to have been very high; the birth rate probably varied from 40 to 50 per 1,000. In periods when there was no real famine but only the usual inadequate nourishment, and when there were also no widespread epidemics, the death rate fell by several points and population grew fairly rapidly. There is as yet no evidence of any long-term downward trend in the birth rate. Since about 1920 the increasing security of subsistence, due in part to the extension of irrigation and in part to the ability to organize famine relief, and the development of public health work, though still very modest by Western standards, have kept the death rate consistently below the birth rate. It is very doubtful, however, that comparable gains can be made during the next two or three decades.

In the light of these facts, what is India s population growth likely to be in the future? Official estimates for the decade since 1941 for the Indian Union indicate a growth of seven to eight per 1,000 per year. This is about one half the rate in the preceding decade. The famine in Bengal and neighboring areas in 1943-44 appears to have been an important factor in reducing the rate of increase. The troubles arising out of the withdrawal of the British and the establishment of the Indian Union and Pakistan no doubt also played a part.

Those who give chief attention to the fact that crop yields are much lower in India than in Japan or even in China see possibilities for large increases in the yields and total production of India in coming decades. Hence they have little fear of any danger of overpopulation. I see no reason to doubt that Indian agriculture as well as that of all other Group C countries can be much improved in the course of time, but I seriously question the practicability of obtaining an increase of more than one or two per cent a year over several decades. For the sake of illustration, however, let us assume that an average annual increase of 2.5 per cent is achieved, and that it is maintained for 50 years.

With a steady 2.5 per cent increase in agricultural production there is good reason to believe that the natural increase in population during the next few decades would be well above the 1.5 per cent annual rise in the 1931-41 period, and might almost equal the 2.5 per cent increase in subsistence. If at the same time industry were to develop rapidly, some of the increased production could be used for public health work and for the relief of the local food scarcities common in India, which is so highly dependent on seasonal rainfall. This would almost certainly reduce the death rate still more. But suppose that the population grew by only 1.5 per cent annually. Even on these assumptions there would be a relative rise of subsistence over population of only one per cent a year, out of which must come any improvements in the level of living and any funds for the accumulation of capital, for training men for participation in a more complex economy and for the many other overhead costs made inevitable by the development of modern industry. I am not for a moment insisting that 2.5 per cent per year represents the maximum increase in production that might be attained in India under ideally favorable conditions. I am saying, however, that it is a higher rate of increase than can be safely assumed under the conditions likely to prevail in India during the next half-century. I would also argue that even if the rate of increase in production were raised to 3.5 per cent, the growth in population would follow very close behind for several decades, because the greater the increase in production and the more stable this increase the greater would be the reduction of the death rate. I do not see how anyone can study the facts of India's growth in the past several decades and not conclude that any increased production that may be attained in the next four or five decades will be used largely to support more people at about the existing low level of living rather than to raise this level.

A steady increase of only 1.5 per cent a year would raise India's population to 817 million by 1991. And practically all of the Group C countries would follow much the same pattern. If their populations increased 1.5 per cent a year, the 1.4 billion people in this group today would grow to about three billion in a half-century. Personally I do not believe there will be any such growth, simply because I do not believe that their production can be increased sufficiently to support it. Yet even at a considerably slower rate the growth of the Group C countries in the next half-century obviously will create serious social, economic and political problems for the entire world.

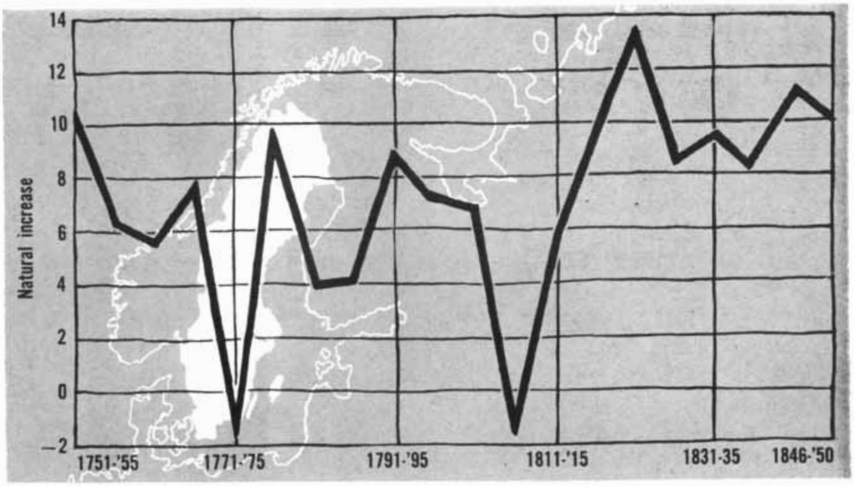
It can be taken for granted that a considerable part of any surplus above subsistence that India or any other industrially undeveloped country may achieve in the next few decades will be spent on education, on health and on the accumulation of capital goods. An increase in literacy will make the people of India far more aware of conditions in the world than they have been hitherto. Another effect, partly of education and partly of the development of modern industry, will be to increase India's realization of the need for minerals and other resources necessary to industry. At the same time industrialization will increase the ability of such a nation to produce the munitions of war. Thus increased knowledge of world conditions will increase the desire of these peoples to share more largely in the world's resources while it increases their power to enforce this desire.

WILL India or any other country forego converting this increasing military potential into actual power, if and when it begins to feel the increasing pressure of population? It should be remembered that it is not poverty alone that leads a people to talk about pressure of population but the growing awareness of relative poverty, and the knowledge that through the exercise of power other peoples have been able to secure a better living. An India of 800 million will be more aware of her relative poverty than she is today and probably better able to muster force to obtain what her people consider a fair share of the world's resources. We have seen in Japan an example of what can happen. A large part of Japan's increase in production obviously went into the support of a large population; her population about doubled between 1872 and 1930. But Japan also raised her level of living significantly above other Asiatic peoples and increased her capital rather rapidly. She developed sufficient industrial strength to support a military organization able to challenge the position of the Western Powers in Asia and the Pacific. Japan's military potential never was large in comparison with our own or that of Europe, but it was large enough to cost us many tens of thousands of lives and many tens of billions of dollars. Furthermore it has forced us to reshape our national and international policies for years to come—and the end is not yet.

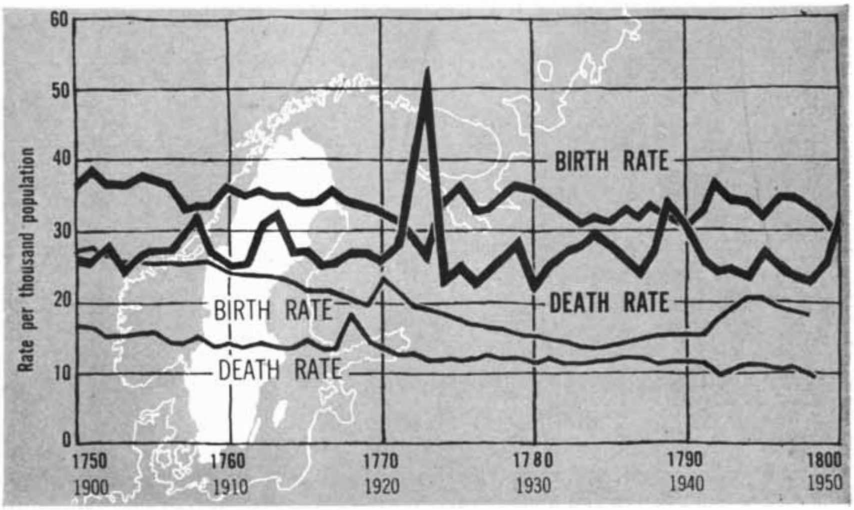
I wish to make it clear that I am not attributing any distinctive warlike tendency to India. I am merely using India to illustrate certain probable population changes among the unindustrialized peoples. I am assuming, however, that all peoples will fight against what they regard as injustice when they have the power to assure a fair chance of success. I believe that the feeling of population pressure will grow among these Group C peoples as they come within the influence of the modern type of economy, and that they will not be more loath to use force to insure their national well-being than other peoples have been. This will also be true of some of the Group B countries, perhaps sooner than for Group C.

If I have given the impression that the Malthusian view is the only aspect of population study worth our attention today, I can only disclaim any such intent. There are many other aspects of population growth and change that are of great importance to man's welfare, such as the distribution of population, the qualities of peoples, migrations, changes in age structure, differential birth rates and the control of death rates. But in my opinion they are secondary in the furthering of human welfare to the economic problems which many nations and peoples face. I also believe that these problems have a very direct relation to the maintenance of peace. In a world which is filling up as ours is, and which is one world whether we like it or not, the urgent questions regarding the livelihood of a growing people soon become a matter of concern to all nations. Hence there is a need to begin to plan for such changes in population growth as will contribute best to human welfare. We cannot ignore population changes in India and China and Japan even if we desire to do so.

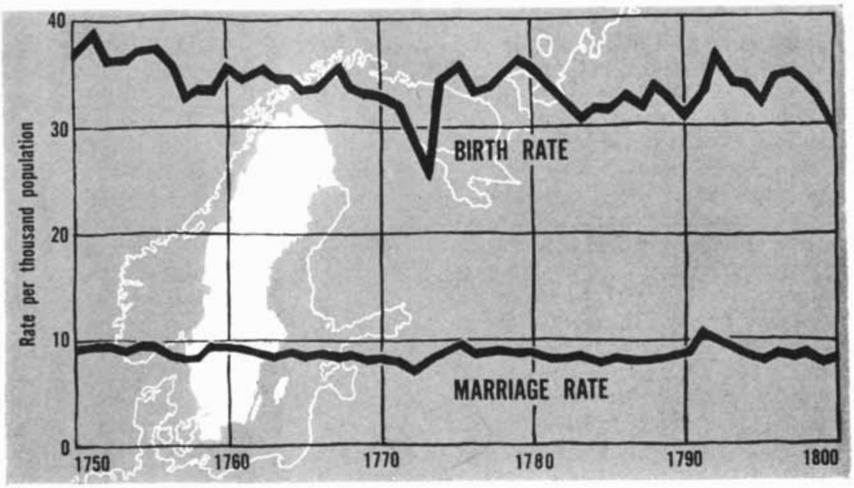
Warren S. Thompson is director of the Scripps Foundation for Research in Population Problems at Miami University.



SWEDISH POPULATION increase in century from 1751 to 1850 showed great variations from one five-year period to next. These fluctuations reflected the effects of famines and the resultant disease epidemics.



ADVANCES IN HEALTH and food production in Sweden smoothed out death rates. The two top curves show the annual variations in birth and death rates from 1750 to 1800; the bottom curves, from 1900 to 1948.



MARRIAGE AND BIRTH rates show fairly close relation, a rise or dip in the former usually being followed by a corresponding change in the latter. In 18th-century Sweden both phenomena reflected the harvests.

High Compression

New auto engines, now in the offing, must get more miles per gallon. But industry is debating whether to count on higher octanes or more ingenious design

by Alex Taub

THE U. S. auto industry, having churned out 15 million new automobiles since the end of the war to catch up with the demand, is turning at last to the more difficult task of designing new engines. The redesign of the traditional auto engine is long overdue. It is a fact, obscured by the vigorous merchandising of new body styles, that all but two of the standard auto makes are powered in 1950 by engines that date back in basic design to the 1920s. That changes in the design are now necessary is generally recognized in the industry. Automotive engineers are already engaged in the preliminary skirmishes of a major controversy as to what those changes shall be.

The industry is here concerned with much more important issues than those involved in the design of the continuous-fender body line. The principal issue is fuel consumption, given force by the fact that the number of automotive units on the road is expected to increase by an estimated 50 per cent in the immediate future and by 150 per cent within the next 30 years, while our foreseeable supplies of liquid fuel decline (SCIENTIFIC AMERICAN, December, 1949).

Clearly the auto industry's new engines must be designed to burn less gasoline per mile. On this objective all participants in the controversy agree. They agree also that the best single way to improve the efficiency of our auto engines is to increase the compression ratio, which means in effect increasing the pressure at which the fuel is burned in the combustion chamber. Increasing the compression ratio raises the temperature of combustion and hence raises the amount of heat energy per unit of fuel that is made available to do work. A step-up in the compression ratio from the present 7-to-1 standard to 12-to-1 would reduce the consumption of fuel per auto by 33 to 40 per cent.

The heart of the issue is how this high compression is to be made feasible—whether it shall be by the use of high-octane fuel or by basic changes in engine design. High compression raises the problem, among others, of what the engineer calls "detonation" and the motorist calls "knock" in the engine. Detonation, resulting from premature ignition of some of the fuel in the cylinder, liberates the energy of this portion of the fuel in a useless and hence wasteful way. The difficulty is that detonation and the wasted proportion of fuel increase with increasing compression ratio.

As every motorist knows, knock can be suppressed by "high-test" or high-octane gasolines. This is the solution to the problem preferred by strong elements in the auto industry. They propose to control detonation in the new high-compression engines by using higher-octane gasolines. This would permit the achievement of high compression with minimum changes in engine design. On the other hand the fuel industry and its engineers, seconded by many automotive engineers including the author of this article, believe that detonation should be controlled by changes in engine design. Detonation control should be built into the combustion chamber of the engine, not into the fuel. High-compression engines not only can be but have been built to operate successfully on standard octane rating fuels. In Europe, where fuel is less abundant and less cheap than in the U. S., this is the accepted approach to the control of detonation. Non-detonating engines would place far less demand upon our fuel resources than non-detonating fuels, and would yield cheaper as well as more miles per gallon.

The U. S. auto industry historically has resisted change in its engines. The first of the new postwar engines to arrive on the market, those of the Cadillac and Oldsmobile, admirably demonstrate the industry's approach to high compression. They are the logical product of the automotive engineering traditions established in the early 1920s. A decisive influence was the work of the General Motors fuel chemist Thomas Midgley, Jr., who with his staff developed tetraethyl lead to suppress knock. Fuel today is properly regarded as an integral component of the engine: its molecular structure is carefully built up to fit the engine, and the engine, in turn, is built to extract dependable performance from the available fuel. The new General Motors engines are designed to take advantage of the high-octane fuels developed for military aviation during World War II. The first production models raise the compression ratio only to 7.5-to-1, so they can operate on the present 83-octane premium fuel, but the engine can be advanced to a 12-to-1 ratio with a minimum of tooling changes as soon as 99-octane fuel becomes available for autos.

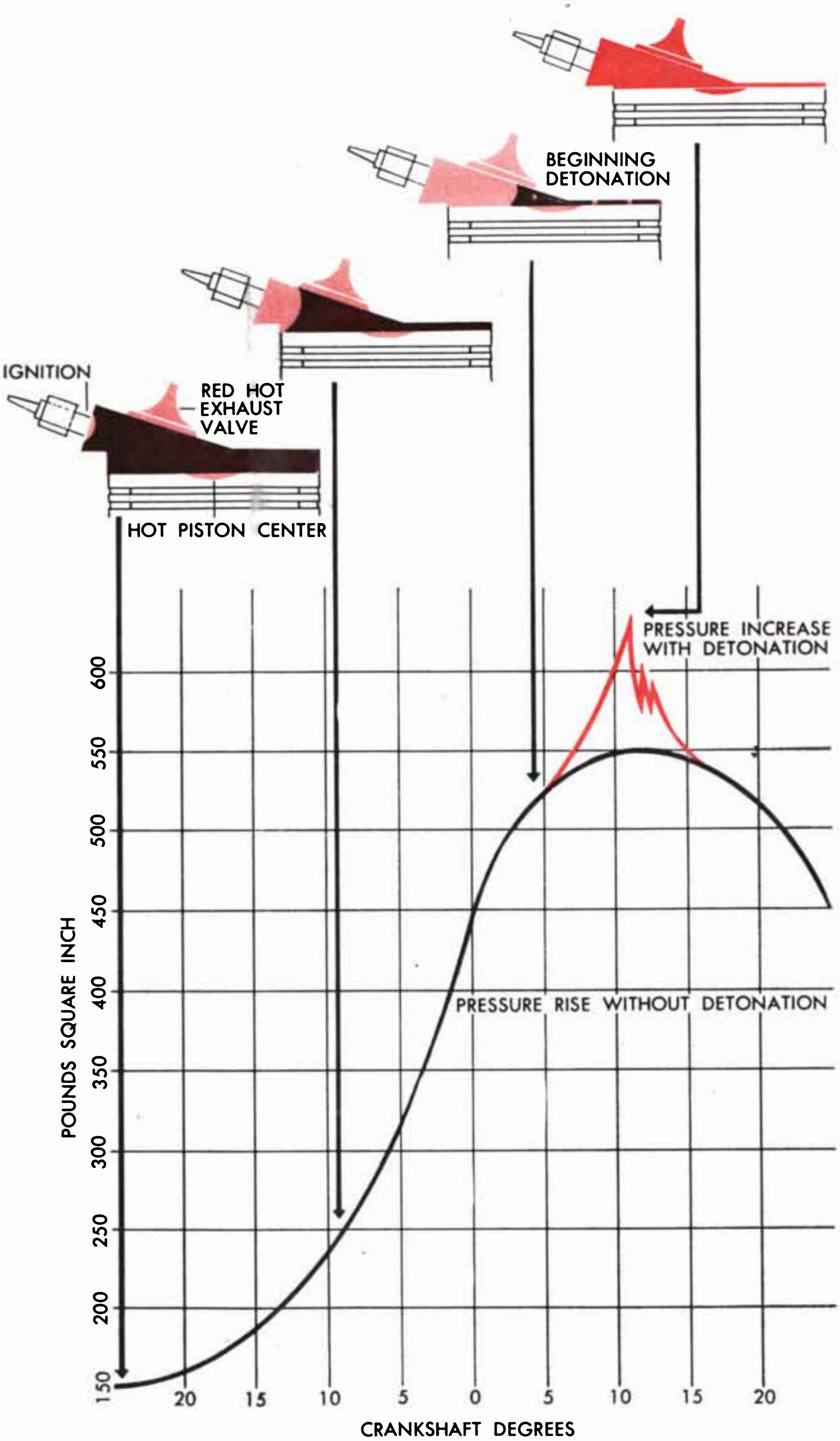
The fuel makers are doing their best to discourage this expectation. Their position has the most compelling economic motives. Since a 12-to-1 compression ratio offers the motorist a 33 per cent saving in miles per gallon, he could pay a third more per gallon for fuel without increasing his cost per mile. On the basis of the present price of around 21 cents for 83-octane premium gasoline, this means he could pay a 7-cent premium for 99-octane. But seven cents would fall far short of the refiner's extra cost. A plant to produce 100,000 barrels per day of 83-octane gasoline costs $25 to $30 million to build; a plant of the same capacity to produce 99-octane costs more than $65 million. It is reliably estimated that for our total national output of gasoline each increase of one octane number would require an investment of $270 to $300 million in refining and cracking facilities, to say nothing of the higher operating costs. The increase of 10 to 15 octane numbers for which many in the auto industry are now pressing would require a total investment of $2,700 to $4,500 million. On the other hand, it is estimated that a $200 million investment would generously cover the cost of retooling our entire auto industry to produce the new engines that would make it possible to have high compression with present fuels.

These economic facts explain why the refining industry takes a poor view of the program of the "riders of the purple blends." And beyond these costs is a question of much broader public interest —the question of the most efficient use of our remaining petroleum resources. The higher we go in the octane scale, the smaller is the yield of gasoline per barrel of crude petroleum. To make the best use of our available crude, we must take the bulk of our gasoline from the "middle barrel," where the yield is highest. The aviation industry fortunately has already begun to shift to the lower-octane range; the continuous-combustion jet engine operates satisfactorily on low-octane fuels of vintage 1937, or even kerosene. This is no time, therefore, for the auto industry to increase its octane standards. Such an increase would cancel the very savings that are sought in the move to high compression.

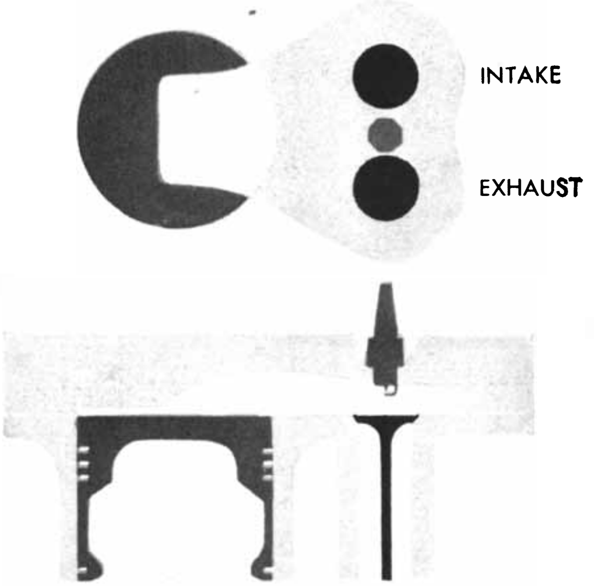
The auto industry today is in an ideal position to meet its responsibilities in the fuel problem. Most of its engines are no longer hostages to the investment in tools. They have been in production for 12 to 15 years, and have long ceased to represent the full capabilities of the industry that produces them. Since retooling is imminent in any event, very little if any extra cost would be involved in tooling up for high-compression engines of basically new design.

What are the problems in the design of such an engine? To understand them we must review briefly the operation of the internal-combustion machine that powers our autos. This engine is built basically on the four-phase Otto cycle, first worked out three quarters of a century ago by the German engineer Nikolaus A. Otto. A piston fits snugly into a cylinder equipped with a fuel intake valve and an exhaust valve. To start the power stroke, the vaporous fuel, compressed in a small space at the top of the cylinder by the upthrust piston, is ignited by the spark plug. The explosion of the fuel gives the piston a sharp push downward. On the piston's return stroke, the exhaust valve opens to permit the piston to drive the spent gases from the cylinder. In the third phase, the intake valve opens and the descending piston sucks in a new charge of fuel. The fourth phase, the compression stroke, brings the piston up again to compress the fuel and thereby raise the temperature and pressure at which the fuel is to be ignited for the next power stroke.

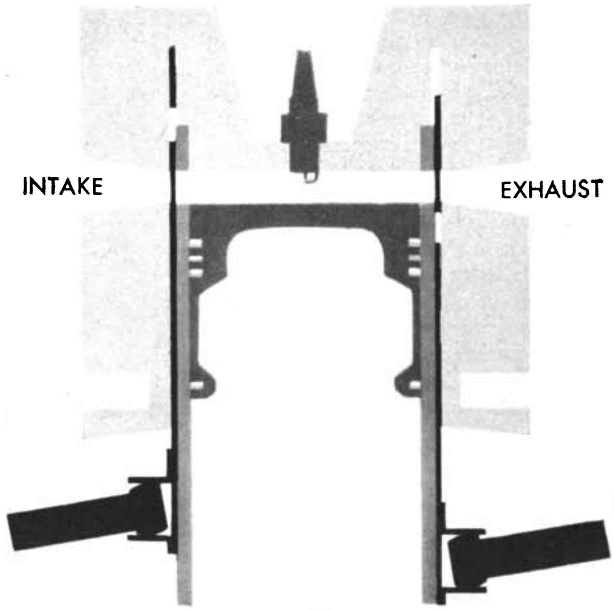
The timing of the ignition is an essential feature of the process. The firing of the spark plug must catch the piston at a precisely measured point in the last instant of its upward travel on the compression stroke. As the fuel burns outward on a spherical front from the ignition point, the pressure must reach its peak immediately after the top of the piston's stroke and then drop slowly and smoothly as the piston moves downward. It is easy to see that the smoothness of the power stroke depends a great deal



INCREASE OF PRESSURE during combustion in auto engine cylinder is plotted against crankshaft rotation (or piston travel) to show effect of unwanted detonation. At top are shown four stages in burning of fuel in cylinder-head. As the rapidly moving flame front of the burning fuel, shown in pink, advances in the cylinder, premature ignition of the unburned fuel (*black*) by pressure and the exhaust-valve hot spot causes a detonation of unburned fuel which yields no useful energy. This explosion is heard as knock. The red line showing a sharp rise in the pressure curve indicates the break in the smooth application of power to the piston. Waste of fuel due to detonation increases when the compression ratio in the cylinder is increased. Methods of controlling knock by modification of conventional design and by new designs are shown in the drawings on the next two pages.



CONVENTIONAL combustion chamber, here shown in plan (*top*) and in profile (*bottom*), provides a narrow "quench area" at left to cool the last portion of the fuel to burn, thus preventing its detonation. Spark plug is placed close to hot exhaust valve.



SPLIT-SLEEVE VALVE type of cylinder, shown in profile, has two outer sleeves with openings (*white sections*) that are alternately pushed up and down past intake and exhaust ports. Thus the exhaust-valve hot spot that causes detonation is eliminated from combustion chamber.

upon the shape of the pressure curve (*see chart on page 17*).

Now there are several things besides detonation that can disrupt the process. The worst thing that can happen is self-ignition of the fuel before the spark plug has fired. In a gasoline system this condition is a symptom of a very sick engine. The Diesel engine employs self-ignition and, as a result, is not as efficient as it might be. At a compression ratio of 16-to-1 it delivers only 75 per cent of the power developed at a 7-to-1 compression ratio by the controlled-ignition gasoline engine.

The explosive release of energy at the moment of ignition creates another problem—the shock to the engine parts, particularly the crankshaft. Early in the development of the engine, when compression ratios and pressure rises were smaller than now, designers learned to offset the shock force by increasing the rigidity of the engine. At each successive increase in compression ratio, this has meant more precise balance and distribution of weight in all moving parts, shortening the piston stroke relative to the bore of the cylinder and increasing the rigidity of the crankshaft. Between 1912 and 1920, designers achieved further control over shock by modifications in the shape of the combustion chamber. The profile of the "L"-head engine at left at the top of this page reflects this development. The slipper-shaped combustion chamber in this engine gives the flame front a relatively large area for its rapid initial spread and progressively reduces the frontal area as the gas is burned. The effect of this progressive reduction in fuel mixture available to the advancing flame front is to slow down the acceleration of the pressure rise.

In the case of a 12-to-1 compression ratio the shock factor for a given shape of chamber will be much higher, probably more than five times as high as in present engines. However, even an increase of this size can be largely offset by combustion-chamber design, and any residue of shock can be controlled by such measures as increasing the rigidity of the engine, shortening the stroke and providing the maximum number of main bearings.

With these problems disposed of, we come up against knock as the most troublesome factor to be solved. For the beginning of our knowledge about knock we are indebted to the British engineer Sir Harry Ricardo, who in 1919 defined it as follows: "An explosive wave or almost instantaneous pressure rise, caused by the supercompression of the unburned portion of the charge after ignition by a very rapid pressure rise in the burning portion, to a point where temperature rise in the unburned portion, due to radiation and pressure, is faster than the heat can be transferred. At this point the unburned portion explodes or ignites at one time, increasing the pressure rise in the whole burning charge, springing the walls of the combustion chamber."

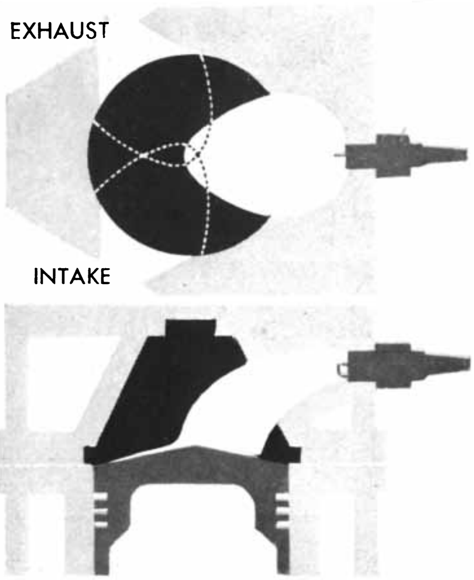
This was a fine statement, although in detail it is somewhat inaccurate. The percentage of the total charge involved in detonation is usually less than five per cent, and this relatively small explosion, being instantaneous, allows no time for springing the walls of the chamber.

To eliminate knock in his engines, Ricardo narrowed the combustion chamber at the side farthest from the ignition point to provide a "quench area." Here the surface-to-volume ratio of the combustion chamber was greatly increased. As a result, the temperature of the last gas to burn was stabilized, despite the compression and radiant heat of the advancing flame front.

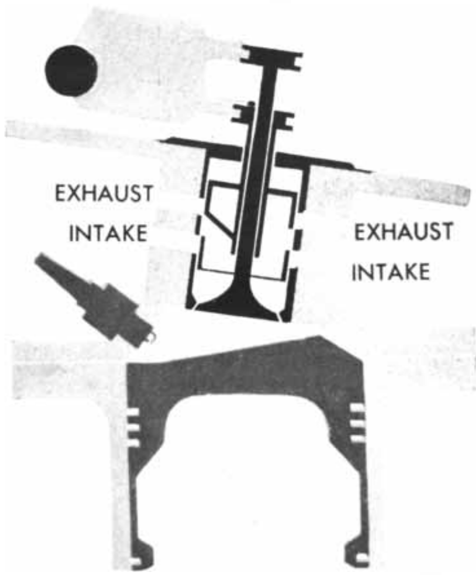
We owe our present understanding of knock to Robert Janeway, a distinguished U. S. designer, now with the Chrysler Corporation, who combines a rare gift in mathematics with engineering skill. He laid down the four fundamental rules for control of detonation: 1) a minimum initial temperature for the charge before ignition; 2) maximum cooling of the last gas to burn; 3) location of the spark plug at the hottest area of the chamber and farthest away from the quench area; 4) elimination of hot spots in the combustion chamber.

The most sensitive of the Janeway anti-detonation rules is the first, having to do with "minimum initial temperature." The initial temperature of the charge before ignition is largely determined by the heat it absorbs from hot areas in the cylinder. When the fuel mixture sweeps into the cylinder, it picks up heat as it cools the existing hot spots. By far the worst hot spot is the exhaust valve, which in many engines operates at the cherry-red temperature of 1,700 degrees F. The best auto designs locate the exhaust valve as far as possible from the last gas to burn.

But when we come to the high compression ratios toward which we are now striving, we cannot solve the problem with such temporizing measures. Increased compression will raise the criti-



ROTATING-CHAMBER design, shown in plan and profile, turns the cone-shaped combustion chamber inside the engine head. Oval opening in chamber meshes successively with intake port, spark plug recess and exhaust port, closing off two openings as it registers with third.



SINGLE-VALVE ENGINE has a sleeve mechanism sliding up and down behind (here above) valve. It opens and shuts exhaust and intake ports. Incoming fuel cools the valve; sleeve insulates the valve from hot exhaust ports. This design permits higher compression ratio.

cal initial temperature of the charge too close to the danger point to permit further compromise with the exhaust valve. The time has come to remove this 5 to 7 square inches of red-hot metal entirely from the combustion chamber. This objective has been achieved in four tested and successful engines.

The most familiar of these is the single-sleeve valve design, used in the Argyle or Burt automotive engines and in the Centaurus, Rolls Royce Eagle and Napier Sabre aircraft engines that powered many Royal Air Force planes of World War II. In this design a sleeve that spirals up and down around the cylinder serves to valve the cylinder for both the intake and the exhaust.

In the second design, exemplified by the Skinner split-sleeve valve engine, valving is provided separately for the exhaust and the intake by two separate sleeves on the outside of the cylinder (*see drawing at right on the opposite page*). There has been no extensive production experience on this design, but it has mechanical simplicities that recommend it over the single-sleeve engine.

In the third design, advanced by the British engineer Frank Aspin in 1936, the combustion chamber, a hollow conical plug, rotates in the head of the engine at half of engine speed. It registers successively with the intake port, with an area in which the spark plug is seated and with the exhaust port, blocking off each of the other two as it registers at each port. Thus the exhaust system is shut off entirely from the combustion chamber during ignition. As a result the Aspin engine will operate on a given octane fuel at higher compression ratios than any other engine; it has achieved a 14-to-1 ratio on 80-octane gasoline.

All three of these designs, however, are too radical by Detroit standards, and too costly to provide an early solution for our problems. We should like to have an engine closer to familiar designs and more immediately within the range of present manufacturing costs. This brings us to the fourth type, the single-valve engine proposed by Rollin Abell of Boston in 1914.

In this design, the single valve opens the combustion chamber to both the intake and the exhaust manifolds. The manifolds in turn are opened separately by a sleeve which is concentric with the valve stem but is driven by an eccentric cam, different from the cam that drives the valve (*see diagram at right at top of this page*). The sleeve does not require snug fitting; it need fit no closer than .006 of an inch. During the crankshaft's two complete rotations in each cycle, the single valve is heated by the exhaust for 220 degrees of rotation, is cooled for 220 degrees by the inflowing fuel, and for the remaining 280 degrees is on its seat, cut off from the exhaust manifold by the sleeve for most of this time. Thus with the single-valve engine we have the advantages of direct cooling by the fuel and a minimum flow-back of heat from the exhaust manifold.

Here we have a simple and effective way to get rid of the red-hot exhaust valve and thereby to achieve mechanical control of detonation at high compression ratios. Exhaustive study indicates that the lowered temperature of the single valve represents a gain in anti-detonation value equivalent to 25 to 30 octane. Assuming the gain to be only 20 octane, this means that the engine would perform as well on 65-octane as present engines do on 85-octane fuels. We could be certain of a 10-to-1 compression ratio with 78- to 84-octane fuel. With a 92-octane fuel we could expect this engine to climb to a 14-to-1 compression ratio.

The single-valve design has other advantages that promise economies over and above those obtained by the high compression. In any engine the lowest consumption of fuel is determined by the leanest mixture that will burn. The single-valve engine will operate on very lean mixtures without missing. Moreover, at full throttle present engines depend upon increased wetness of the fuel to provide internal cooling, particularly of such hot spots as the exhaust valve. The single-valve engine operates on a leaner full-throttle mixture and thus eliminates the use of fuel as an internal fire extinguisher. These economies, plus the savings inherent in high compression, indicate an over-all reduction of 50 per cent in the consumption of fuel per automotive unit. Multiplied by the number of vehicles on the road, they equal a saving of 400 million barrels of fuel per year. Converted into dollars at present wholesale gasoline prices, this comes to $1 billion per year. In other words, the fuel saving that can be achieved in a single year by newly designed non-detonating engines is five times the cost of completely retooling our engine lines.

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INFANT VISION

Babies grasp the world first with their eyes and then with their hands. Vision is therefore a prime constituent in the development of the total child

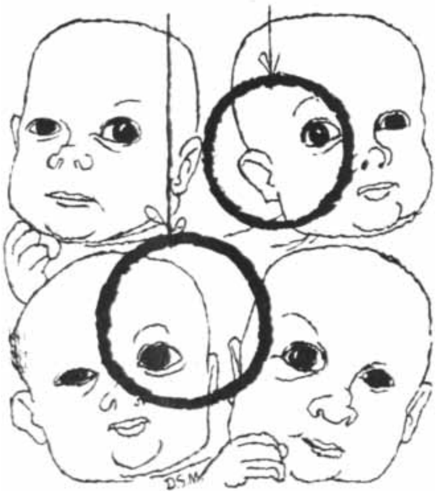
by Arnold Gesell

MAN is but a modified fish. Like the fish, he has a pair of eyes, and even his pair of hands is foreshadowed in the forward fins of the fish. But to understand the unique characteristics of human vision, we must at once emphasize the remarkable modifications in the vertebrate eye that have taken place since land animals began to evolve from the fish of ancient Devonian days.

The fish eye is equipped with a full set of extrinsic muscles—internal, external and oblique. They are amazingly like our own eye motor muscles in arrangement, but their function in the fish is extremely limited. They simply maintain a constant visual field so the fish may detect the movements that denote danger and food. The fish, not having a neck, turns its whole body in order to keep the object of interest within its very narrow binocular field; its eyes are gyroscopically stabilized. In a human being, on the other hand, the oculomotor muscles play an important role in complex mental acts of fixation, inspection and attention.

The fish's field of vision is narrow because it wears its eyes, as well as its ears, on the side. In the course of evolution the eyes of higher animals have moved forward to a frontal position. It has taken nature a few hundred million years to confer this particular advantage upon the human species. Our ears, however, remain in a lateral position, which places some limitations on the sense of hearing. It is interesting to speculate as to what would have happened to the architecture of the human mind if nature had placed the hearing receptors in our present eye sockets and compelled us to wear our eyes in the ancient lateral position. Such a transposition would have produced profound alterations, not only in the mechanisms of vision but also in the construction of the total action system of the body. For it is clear that the evolution of vision has been inseparably bound up with the evolution of the whole motor system, including the trunk, arms and legs. As the vertebrate eye, which originated in water, became adapted to new terrestrial and arboreal modes of life, other organs were modified with it. The sense of smell declined in importance; the sense of sight assumed increasing status. In due course the snout diminished; the neck became mobile; the forelimbs were freed for manipulation; and finally the human species acquired a pair of feet as arch platforms that enabled man to maintain an erect posture and to bestride the earth as a master of destiny, eyes front.

In Eocene times, about 50 million years ago, a prehuman primate, comparable to the modern *Tarsius spectrum*, sat upright and in feeding used its hands in a squirrel-like manner. Some seven million years ago a near-human being, *Plesianthropus*, came upon the scene. He walked erect, with frontal eyes under an arching forehead. Presumably the forelimbs of this creature, even though they did not flex freely at the elbow, were sufficiently mobile to release eyes and hands for another evolutionary advance which led to the utilization of tools.



FIRST LOOKS of the infant are monocular. He fixes one eye on an object and closes or relaxes the other.

All these evolutionary gains entailed enormous elaborations in the structure of the brain and of the retina, which is in fact an outpost of the brain cortex. The seat of vision is not in the eyeball but in the multimillion neurones of the central nervous system. The nervous system in turn controls and integrates the entire organism in its motor as well as its sensory aspects. As in fish, so in man vision has a motor basis. It is a complex sensory-motor response to a light stimulus mediated by the eyes but involving the entire action system. The seeing child sees with his whole being.

The development of vision in the individual child is extremely complex, because this development compresses into a short time the countless stages of evolution which brought vision to its present advanced state in the human species. The child's patterns of visual behavior go through progressive stages of maturity correlated with his changing postural control, his manual coordinations, his intelligence and even his personality. Indeed, vision is so completely identified with the whole child that we cannot understand the phenomenon without investigating the whole child.

OUR special researches in the field of child vision grew out of our general interest in the development of the total child. The studies of the Yale Clinic of Child Development, since its founding in 1911, have been mainly concerned with the growth aspects of early human behavior. The Clinic has charted the manifold behavior characteristics of children at 34 age levels, encompassing the first 10 years of life. This has been done by a variety of techniques: observations of the spontaneous behavior of infant and child at advancing ages; the detection of significant behavior patterns through periodic developmental examinations under standard conditions; observations of behavior in experimental situations. Much of the infant behavior was recorded by means of a one-way-vision dome equipped with motion-picture cameras. The films were later analyzed, frame by frame, to define the growth changes in the patterns of behavior. The basic data were amplified by stenographic reporting, interviews and records of home and school behavior.

The children's specific visual functions were investigated by tests of visual skills, reading-readiness and performance tests, and examinations with certain instruments—the phoropter, the stereoscope and the retinoscope. The accumulated evidence from the various studies of development demonstrated that the organization of the child's vision is intimately identified with the growth of his total behavior equipment.

The underlying principles and methods of observation are illustrated in the following outline of a typical examination of a 28-week-old infant. The mother brings the infant to the reception room. She is familiar with the surroundings, and her interest and confidence are bolstered by the fact that she made previous visits when the baby was 16, 20 and 24 weeks of age. The examiner begins an informal conversation with the mother; the baby, hearing their conversational voices, is aided in making an emotional adjustment to the new situation. When rapport is established, the examination begins in an adjoining room.

The mother places the infant in a small Morris chair facing a test table mounted on the side panels of a crib. The mother then withdraws to an inconspicuous location near the head of the crib, and the examiner takes over. He places a red one-inch cube on the test table to elicit a reaction. In a moderate voice he dictates a running description of the baby's behavior to a stenographer concealed behind a one-way-vision screen. A similar procedure is followed in a standardized sequence for a series of test objects, which include two cubes, three cubes, 10 cubes, cup and cubes, pellet, hand bell, ring and string, mirror and so on.

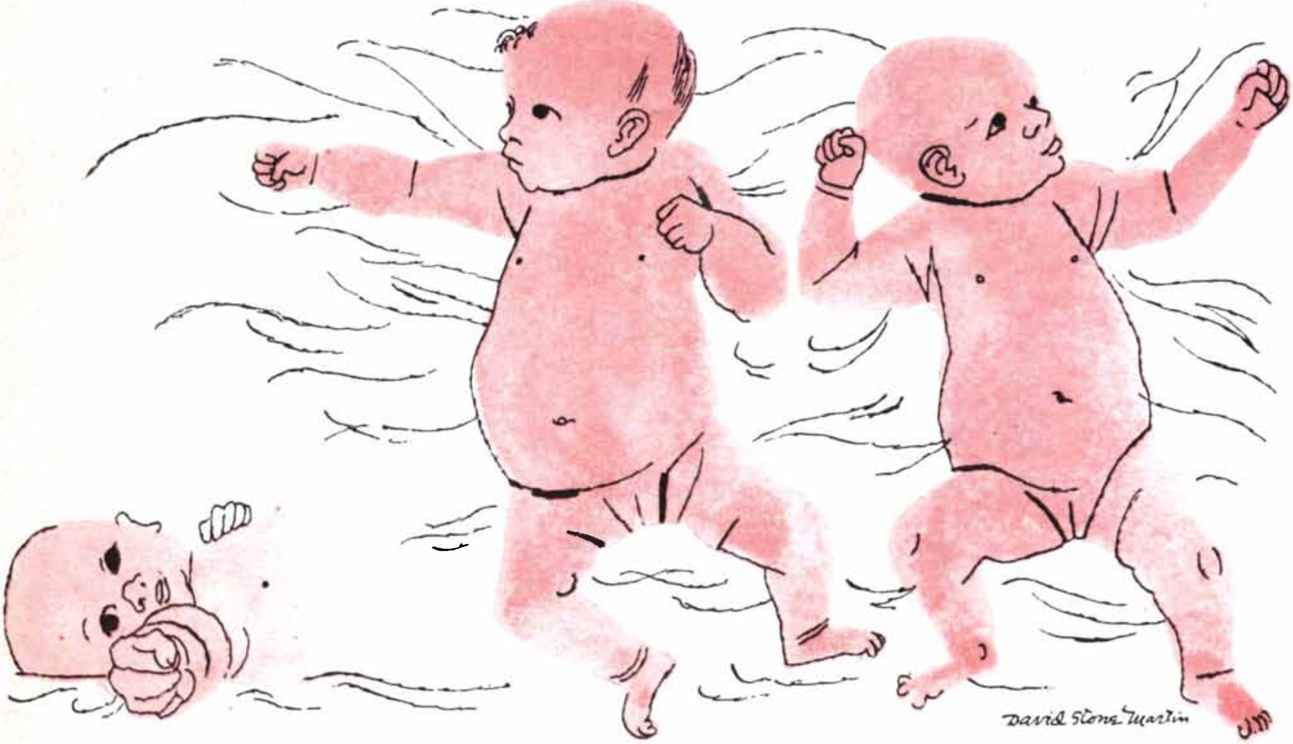
Next the test table is removed and the baby's postural behavior and incidental reactions are observed in various positions: supine, free sitting, prone, and standing with support. Then the infant is restored to the mother and another conference follows. The total session consumes approximately an hour. Four weeks later the infant may be returned for another examination.

WHEN the records for a large series of successive examinations of this kind were compared to define growth trends, they showed that the interaction of eyes and hands plays a master role in the development of the behavior patterns of the individual child, as it did in human evolution. This development begins in the uterus and continues throughout the first 10 years of life and beyond.

Nature has given top priority to the sense of sight. Six months before birth the eyes of the fetus move sketchily and independently beneath their sealed lids. In time the eyes move in unison, so the child is born with two eyes partly yoked in a single organ—"a physiological binoculus." Accordingly the newborn infant is able to move his eyes conjugately, and to fixate momentarily and monocularly. Sustained fixation of a nearby object occurs in the first week, fixation of more distant objects at the end of the first month. Binocular convergence comes later.

The infant takes hold of the world with his eyes long before he does so with his hands—an extremely significant fact. During the first eight weeks of life the hands remain predominantly fisted, while the eyes and brain are busy with looking, staring, seeking and, in a rudimentary manner, apprehending. The young infant when awake lies in an asymmetric attitude simulating a fencing position, with the head averted to one side, the arm on that side extended and the opposite arm flexed at the shoulder. This tonic-neck-reflex posture is fundamental in the patterning of eye-hand behavior.

The first true looking of the infant is monocular. He fixates the near object of interest by aligning the active eye and relaxing or closing the subordinate eye. At a later stage the monocular fixation alternates rapidly between two eyes, with a rhythmic excursion of the head from right to left to right. This eventually leads to teaming of the two eyes, which at about eight weeks of age simultaneously converge upon an object of interest. At 12 weeks we find that the infant still prefers the tonic-neck-reflex attitude and gazes in the direction of his extended arm as though regarding his hand. At 16 weeks his head favors the mid-position and his hands tend to come together at the mid-plane—a symmetro-tonic-reflex pattern. Placed in the examining chair, this 16-week-old infant proves to



EYES AND HANDS are joined in a pattern of behavior during the first eight weeks after birth. At this stage of development the infant keeps its hands clenched and its head to one side. One fisted arm is extended in front of its eyes and the other is bent upward to the shoulder. The position resembles that which is taken in fencing.

HAND GRASP begins to develop at 16 weeks after birth. The infant looks intently at his hands, the table top and the cube. He may even scratch at the table top a little, but he is still unable to grasp and lift the cube.

be avid for visual experience: he looks intently at the table top, then at his own hand, then at the cube, and again at his own hand. He may scratch the surface of the table by flexing his fingers, but he cannot as yet seize the object of interest.

By 28 weeks a dramatic gain in eye-hand coordination is achieved. When a cube is presented on the test table, the infant seizes it almost before it is placed; after a swift glance he brings the cube to his mouth and senses its surfaces orally; speedily he withdraws the cube, rotates it with a twist of the wrist, remarking the motion visually; soon the cube goes to mouth or table top for further exploitation. The cycle of eye-hand behavior repeats with variations. Repeatedly he transfers the cube alternately from one hand to the other—a pattern reminiscent of the eye movements which passed through a similar phase of alternation some five months earlier.

SUCH is the logic of visual development. The basic patterns and sequences are untaught, for they are the functional expression of gene effects operating at appropriate stages of maturity. Ocular prehension precedes manual. A 20-week-old infant at the test table unquestionably can pick up a white pellet, seven millimeters in diameter, with his eyes. He doubles his age before he picks up this pellet with his fingers. At 44 weeks he plucks it with precise finger prehension and neat thumb opposition.

As the child grows older his visual tasks become increasingly symbolic, although they always retain a concrete core. He has to associate visual experiences with words. He "learns," as we say, to build a tower, a wall, a bridge with his blocks. He learns to make vertical, horizontal and curved strokes with a crayon. He identifies pictures, drawings, letters and words. But his ability to handle them does not depend upon mere visual acuity. By the test chart he may show 20/15 acuity, which permits him to identify small type. Nevertheless this same boy may be backward in his reading. All of which reminds us again that the ability to see really depends upon the total behavior equipment.

At birth the visual system of the child is very incomplete; it continues to develop throughout infancy, preschool and school childhood into the adolescent years. The intricacy of this development indicates that the refractive condition of the eyes is only one factor in the total effectiveness of the child's visual behavior. Superimposed upon a basic delimiting refractive state there is a margin of adaptability which is under the dynamic controls of the cerebro-spinal and autonomic nervous systems. The total visual apparatus has three closely interacting components: skeletal, visceral and cortical. The skeletal component comprises the body musculature and the oculomotor muscles; it seeks and holds the visual image. The visceral component comprises the focus mechanism; it discriminates and defines the image. The cortical component comprises the highest nerve centers; it unifies and interprets the image. Nowhere else in human behavior do we see such an intimate linkage between postural, viscero-sympathetic and cerebral reactions. The cortex functions as the master tool of synthesis and integration. It funnels and mediates the electrodynamic forces that culminate in adaptive visual behavior.

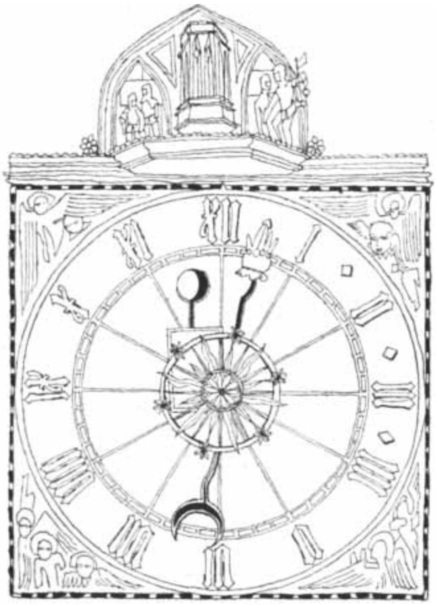
THERE is no device that permits us to observe directly the course of such ultramicroscopic forces. But the retinoscope brings us into the near-presence of these forces and their immediate consequences. The retinoscope projects a beam of light upon the reflecting surface of the retina. In the Yale research it was found that the returning light in the young retina varied significantly in relation to identifiable moments of the visual act. The variations were manifested in the motion, the direction, the speed, the brightness and sometimes the color of the retinal reflex. Characteristically an increase of brightness in the reflex occurs at the moment when the infant identifies an object of interest.

All this becomes somewhat understandable when one thinks of the eye not as a camera but as the most direct corridor to the vast networks of the brain cortex, where billions of neurones engender and organize the energies that issue in vision. The seeing eye is a reaching, groping, grasping organ—a teleceptive prehensory apparatus. In league with the growing brain it manipulates visible objects, cues and symbols. At every stage of growth during infancy, childhood and youth the visual mechanism undergoes changes which serve to reorient the ever-transforming individual. For him the space-world is not a fixed and static absolute. It is a plastic domain which he manipulates in terms of the growing powers of his total behavior equipment.

Our civilization is becoming increasingly eye-minded. The demands upon the eyes of growing children are multiplying and intensifying. The conservation of vision, therefore, has become a task of vast social dimensions. This task includes the care of the visually handicapped and the prevention of industrial, highway and household accidents; but, above all, it concerns the mental health and developmental welfare of school children and preschool children.

Arnold Gesell, retired director of the Yale Clinic of Child Development, is presently in charge of the Yale Child Vision Research project. He is a co-author of the recent book Vision: Its Development in Infant and Child.

SCIENCE AND THE



Einstein

THE announcement of Albert Einstein's new "Generalized Theory of Gravitation," first made in this department last month, stirred the imagination of men more than any event since the fission of uranium. Yet not even physicists knew the full content of the theory; it will be published this month as an appendix to the third edition of Einstein's book *The Meaning of Relativity*. The reaction of non-physicists was expressed in a wonderful cartoon by Herblock in the Washington *Post*. The cartoon showed two average citizens discussing the theory on the surface of a very small Earth. Said one to the other: "It's a little out of my line, but he's a good man."

The new theory reminded a few physicists with good memories of how they felt when Einstein presented his general theory of relativity in 1916. The general theory, like its new extension, resembled a mighty tower without visible means of support. It took a little while for the foundation of the structure to be revealed in the form of three epochal proofs.

The first proof was found in the advancing perihelion of Mercury, a phenomenon that had been known since the 19th century. It did not fit the classical gravitational theory of Newton; it fitted the new gravitational theory of Einstein. The second proof was sought in the deflection of light by a massive body, which was predicted by the general theory. Two British expeditions were dispatched to Africa and South America to observe the eclipse of the sun in 1919; they discovered that light from stars which grazed the occulted limb of the sun was indeed deflected. The third proof was the displacement of lines in the spectrum of the dense companion of Sirius.

Einstein's general theory had not satisfactorily embraced all known physical phenomena. The domain of electromagnetism, then principally formulated in the famous equations of the 19th-century Scotch physicist James Clerk Maxwell, was only very loosely incorporated. Einstein now turned to the work of enlarging his theoretical structure so that electromagnetism would be an integral part of it. The task proved immense, and during the many years that Einstein labored a second structure grew beside his own. It was quantum mechanics, born of the realization that the fundamental units of matter behave both as particles and as waves. Many brilliant minds of the 1920s and 1930s enlarged the quantum mechanics—Werner Heisenberg, Erwin Schrödinger, Paul A. M. Dirac. The approach was powerful; it accomplished such impressive feats as predicting the discovery of the positron and the meson. Where Einstein's theory grasped the macrocosm of the universe, only quantum mechanics provided a useful description of the microcosm of the atom. It appeared, and still appears to most physicists, to be the most promising approach to a unified account of all natural phenomena.

How then has Einstein attempted to extend his general theory to include all natural phenomena? The answer is not a simple one, and no one will pretend that it can be given to laymen until it is better understood by physicists. The heart of the answer, however, lies in one difficult problem that Einstein appears definitely to have solved.

The general theory of 1916 was characterized by the mathematical usage of the tensor. The electromagnetic theory of Maxwell likewise utilized the tensor. In the general theory, however, the tensor was "symmetrical"; in the Maxwell theory it was "antisymmetrical." What Einstein has accomplished during the past three years is to enlarge his mathematical edifice in such a way that it incorporates the antisymmetrical tensor. In other words, he has succeeded in relating more closely the mathematical usages of gravitational and electromagnetic theory.

In the presentation of his new work Einstein says that he finds the formulations "highly convincing" but that he has not "yet found a practicable way to confront the results of the theory with experimental evidence." To find proofs such as those which established his theory of 1916 will require perhaps years of work by Einstein and others. Einstein himself believes the result will show that the structure of quantum mechanics is not separate from his own but part of it; that quantum mechanics can be made a consequence of the general theory rather than a rival of it. Such results, like the proofs, will be a while in coming; perhaps they will never come. Physicists await with deep interest the publication of Einstein's technical paper in the new edition of *The Meaning of Relativity*.

A.A.A.S. Meeting

FROM the standpoint of attendance and the number of papers read, the 116th meeting of the American Association for the Advancement of Science in New York last month was the largest in the organization's history. The Association's Council also made some important decisions in three general areas: 1) renewed support for establishment of a National Science Foundation; 2) increased efforts to preserve civil liberties for scientists; 3) plans for closer cooperation and exchange of ideas between scientists and Congressmen. Kirtley F. Mather, professor of geology at Harvard University, was chosen president-elect of the A.A.A.S. Roger Adams, head of the chemistry department at the University of Illinois, is president for 1950.

About 10,000 scientists attended the six-day convention to hear and read reports on recent research and to participate in more than a dozen symposia on subjects ranging from the Kinsey report to nuclear engineering. A summary of some of the papers that received special attention follows:

Tracy M. Sonneborn, Indiana University geneticist, made a full-length commentary on the torrid Lysenko controversy. Among U. S. geneticists, Sonneborn is the one whose work seemingly comes closest to supporting the theory of inheritance of acquired characteristics championed by the Soviet biologist Trofim D. Lysenko. In his studies of the single-celled animal paramecium, Sonneborn has shown that there are "killer" and "sensitive" types of paramecia, and that one can be transformed into the other by environmental factors, such as heat, limiting the supply of food, and so on. The transformation is hereditary, though it is passed along from generation to generation not by genes in the nucleus of the cell but by "plasmagenes" in the cytoplasm surrounding the nucleus.

Do these experiments prove that acquired traits can be inherited? Yes, said Sonneborn, but only in a limited sense that "does not undermine" Mendelian genetics. He declared that Lysenkoists who have seized upon his results as confirmation of their position have misinterpreted them. The hereditary transformation of paramecia through the cytoplasm, he said, is a special case—an "addition" to Mendelian genetics, not a "replacement" of it. Most traits, particularly in organisms that reproduce sexually, are transmitted exclusively through the nuclear genes, which are only rarely altered by the environment. Moreover, even the plasmagenes in the cytoplasm are controlled by genes; for example, the "killer" plasmagene cannot maintain itself in a paramecium unless certain genes are present in the nucleus of the cell.

Sonneborn concluded: "We do find evidence . . . of a possible mechanism for the inheritance of acquired characters, but only when the characters belong to that very small class which is determined by migratory plasmagenes—the existence of which the Lysenkoists do not admit!"

Phil S. Shurrager of the Illinois Institute of Technology reported some dramatic experiments that led to a startling conclusion: an animal is capable of learning in its spinal cord, even when the cord is severed from the brain. He cut the spinal cord and all interconnecting nerve pathways in a four-week-old kitten. The paraplegic kitten's hind legs were completely paralyzed. Then Shurrager started an intensive training program of the paralyzed legs, including daily massages, electrical stimulation and walking exercises. After four weeks the animal walked short distances, though it moved awkwardly and often fell down. At the end of three months the kitten could walk for ten minutes at a time, crouch, jump and turn sharp corners—using all four legs. Shurrager and a coworker, R. A. Dykman, obtained similar results with six other kittens. They believe that the mass of nerve cells in the lumbar-sacral junction may constitute what is in effect a "lower brain."

Vaden W. Miles of Wayne University wanted to know to what extent the rich folklore about the weather is just superstition and to what extent it is borne out by modern meteorology. He selected 153 weather proverbs from the Bible, ancient Greek writings, Bartlett's *Familiar Quotations* and other sources. Then he picked a jury of three physical-science teachers, including a licensed meteorologist, to rate the accuracy of the proverbs. The judges decided that 56.9 per cent of them were sound and only 15 per cent clearly false. Among the false: "The north wind doth blow and we shall have snow"; "Sunshine and shower, rain again tomorrow." Among the true:

"Rain before seven—lift before eleven."

"Mackerel clouds in the sky—expect more wet than dry."

"Evening red and morning gray will help the traveler on his way."

Norbert Wiener of the Massachusetts Institute of Technology, founder of the new study called cybernetics, reported that he was working on an application of cybernetic principles to the practical problem of aiding the deaf. Together with J. B. Wiesner and Leon Levine of M.I.T.'s electronics laboratory, he is building experimental devices designed to enable deaf persons to "hear" by the sense of touch. One experimental instrument uses a microphone to convert speech into electrical current, which in turn operates five mechanical vibrators, one for each finger. Each sound and syllable of everyday conversation produces a unique pattern of vibrations, which the fingers can be trained to recognize. Wiener reported that normal persons "whose ears were filled with such a jumble of artificial noise that they were quite deaf for the purpose of the experiment" quickly learned to recognize syllables, the best run being a series of 80 trials with only six errors. In one test a deaf mute not only learned to "listen" with his fingers but, by comparing the vibrations of his larynx with those of the instrument, markedly improved his ability to pronounce his name and a few other previously mumbled words. Since the mechanical vibrators are too heavy to carry around, Wiener's group is developing a variation of the device that will stimulate the finger tips electrically instead of mechanically. They hope to make it small enough to be built into a flexible glove, so users will be able to hear and to employ the hand for other purposes at the same time.

Donald H. Menzel, associate director of solar research at the Harvard Observatory, exhibited an extraordinary motion picture of the flares and prominences on the sun. Titled *Action on the Sun,* the 10-minute film was put together from more than 15,000 feet shot at the Observatory's station in Climax, Col. It showed great twisting filaments of luminous gas rising 30,000 miles or more above the surface of the sun, some forming huge arches, others resembling ribbons fluttering in the breeze.

From his studies of the films Menzel derived a new theory of the origin of solar prominences. The sun, he suggested, is enclosed in an invisible shell of crisscrossing lines of magnetic force. When electrified particles from the sun's atmosphere or corona collect on the top of the shell, the lines of force sag "as if a pocket of snow were causing partial collapse of a tent whose roof was made of rubber." Sometimes, the films show, several such pockets overlap; they then form a vast depression shaped somewhat like the Grand Canyon, through which rushes a swift "river" of coronal material which may be more than a million miles long. The sudden emptying of part of the depression relieves the pressure on the magnetic roof. As the roof snaps back it catapults the material remaining in the pocket out into the corona. The catapulted masses are solar prominences.

Douglas Marsland of New York University announced that he had found a method of reversing what has long been considered one of nature's most irreversible processes—the reproductive splitting of a fertilized egg. He accomplished this feat by the use of pressure, applied by means of an automobile-type hydraulic jack modified for the occasion.

The jack served as a piston to press water in a small bronze cylinder containing fertilized frogs' eggs. When the eggs had nearly divided by mitosis, Marsland slowly increased the pressure. The splitting process stopped. Then, as the pressure rose still further to about 6,000 pounds per square inch, the mitotic eggs reverted from their spindle shape to the original spherical form. Marsland explained that the pressure had broken up the jellylike belt that divides an egg by pulling tighter and tighter around its middle. He is now investigating the problem of how the eggs of deep-sea fishes manage to split at pressures of more than 15,000 pounds per square inch.

Armin C. Braun of the Rockefeller Institute for Medical Research was awarded the $1,000 A.A.A.S. prize for the most noteworthy paper presented at the meeting. His paper reported an admirably precise study of crown gall, a cancerous disease of apple trees, raspberries, sugar beets and many other plants. It has long been known that crown gall is caused by a microbe, *Agrobacterium tumefaciens.* Biologists have assumed that multiplication of the bacteria is what keeps the tumor growing. Braun proved that actually the microorganisms only start the process. Once started, the malignant cells, like those in animals, become self-multiplying.

Working mainly with the tropical herb known as Madagascar periwinkle, the Rockefeller Institute physiologist has been able to breed malignant cells for more than five years in tissue cultures completely free of bacteria. He announced that crown gall involves at least two "tumor-inducing principles"—one substance that "triggers" and another that maintains the abnormal cell multiplication. This discovery ties in with similar reports from other laboratories on certain mouse and rabbit tumors which are known to be caused by viruslike proteins. The fact that Braun's "principles" also seem to be proteins indicates a closer relation between plant and animal cancers than has hitherto been suspected.

George W. Gray, writer on science, was awarded the annual A.A.A.S.-Westinghouse prize for the best science writing in a magazine for his article on the brain, "The Great Ravelled Knot," in the October, 1948, issue of SCIENTIFIC AMERICAN. The prize for the best science articles in a newspaper went to Lester Grant, of the New York *Herald Tribune,* for a series on cancer. Herbert Yahraes, a free-lance writer, was given honorable mention in the magazine field for an article titled "How to Keep Away from the Dentist" in *Harper's Magazine*.

Save the Dogs!

THE perennial quarrel of the antivivisectionists with medical scientists, which has had many histrionic moments, reached an unprecedented height of melodrama at a recent public hearing in Baltimore, Md. The question before the house was whether the city pound should turn over unclaimed stray dogs to medical schools in the area for research work. More than 3,500 persons jammed Baltimore's largest auditorium for the city officials' hearing. Present were some of the nation's most ardent antivivisectionists, including the famous dancer Irene Castle and Mrs. Bennett Champ Clark, Jr., wife of the former Senator from Missouri. Also present were physicians of the Johns Hopkins Medical School and several exhibits of the value of animal research—children who had been saved by Alfred Blalock's "blue-baby" operation. The hearing quickly became noisy. The doctors were applauded, hissed and booed. When the mother of one of the successfully treated children asked whether the antivivisectionists preferred to save the lives of babies or of dogs, several in the audience cried: "Dogs! Dogs! Save the dogs!"

Then the antivivisectionists played what they had announced in advance as a trump card. The blue-baby operation, they declared, was originated not at Johns Hopkins but by a British surgeon named Russell C. Brock, of Guy's Hospital in London—and he had accomplished it without experimenting on dogs.

Unfortunately for the antivivisectionists, Brock happened to be in the audience. The surgeon rose and firmly informed the hearing that Blalock had personally taught him how to perform the operation, and that he was himself using dogs for experiments in heart surgery. Said Brock: "I benefited from the technical details and skill worked out and acquired by Dr. Blalock and his associates on dogs. . . . Without this preliminary animal research, the operation could never have been safely developed on human beings."

That was enough for the city officials. Soon after the hearing Baltimore became the 22nd U. S. city to decide to give its medical institutions the dogs they need.

Why Do Stars Twinkle?

ACCORDING to the usual explanation, stars twinkle because the upper atmosphere is unstable. Local turbulences alter the density and optical properties of the air. As a result, the amount of light passing through it varies continually, and the stars appear to flicker. This commonly accepted physical explanation is now challenged by a new physiological theory reported in the British journal *Nature*. H. Hartridge of the Institute of Ophthalmology in London, a leading authority on vision, believes that the twinkling takes place not in the skies, but in our eyes.

Hartridge bases his theory on two well-known facts: 1) the eye is always in motion, and 2) its rod-shaped cells, which serve as "brightness meters," are not all equally sensitive. The eye rests on a point for only about a tenth of a second, and then shifts slightly to some other nearby point. Because of these rapid jerking motions, images continually move back and forth on the retina. Since the rod cells in the retina vary in sensitivity, images seem to vary in intensity as the eye shifts.

To test his theory that twinkling has nothing to do with the upper atmosphere, Hartridge experimentally observed "artificial stars" at ground level. Watching an electric lamp from a distance of several miles on a dark night, he found that to the naked eye it twinkled "very obviously." But the twinkling disappeared when he used an eight-power telescope. On the basis of further experiments in his laboratory, Hartridge believes he has found the explanation for this phenomenon. A telescope, collecting more light than the naked eye, makes the image considerably brighter. Hence small local variations in the sensitivity of the retina's rod cells are not noticed. In support of this conclusion, Hartridge notes that extremely bright stars do not twinkle and that many stars stop twinkling when viewed through a telescope. The biologist did not, however, attempt to explain why stars twinkle more on nights of poor "seeing" than on clear nights.

Fossil Thumb

HOW ancient is the opposable thumb, that invaluable asset of *Homo sapiens*? There is good evidence that the Neanderthal and Cro-Magnon men had it, for they used many manipulable implements. But the case is less clear for man's more primitive anthropoid ancestors that lived several million years ago. Most anthropologists believe that the anthropoids probably had poorly developed thumbs and were unable to use tools. Now Robert Broom of the Transvaal Museum in South Africa, who has long been of a different school of thought, reports that he has found a fossil thumb belonging to a South African ape-man. The fossil, discovered in one of Brown's favorite deposits near Krugersdorp, is shorter, more curved and a bit thicker than the human thumb. But its structure shows that it was easily opposable. Broom concludes that early ape-men had "a useful grasping organ and were able to manipulate tools and weapons."

NORTH AMERICAN NEBULA here resembles the continent with its Pacific coast facing the lower left corner of the page. The "continent" is a mass of luminous gas; the "Atlantic," the "Pacific" and the "Gulf of Mexico" are regions obscured by intervening cosmic dust. This photograph, made with the 24-inch Schmidt telescope at Harvard Observatory on a plate sensitive to all wavelengths of light from violet to red, shows many stars through the dust in the Pacific region. Red light penetrates the dust better than the shorter wavelengths.

THE MILKY WAY

The great band of stars that arches across the night sky is our galaxy seen from inside. Astronomers have pressed beyond it, but they are still investigating its structure

by Bart J. Bok

GET away from the glow of city lights and step outdoors in the open country on a clear, dark night. It is like stepping out on a platform in space. Roads, hills and houses hardly make their presence felt; the sleeping earth is hushed, like the audience at a play, by the great show of the heavens. And soon the delighted eye, exploring the vast, twinkling spectacle, is drawn to the most fascinating sight of all—the luminous band of the Milky Way that stretches in quiet majesty all around the sky.

I have lived with the Milky Way for more than a quarter of a century and have never stopped marveling at its beauty. It remains one of the grandest phenomena of nature, and a never-ending challenge to scientific curiosity. What is it made of? Why does it vary so greatly in appearance along the band, showing comparatively dull sections in winter and reaching a height of glory at our latitude in late summer and early fall? These questions, not yet completely answered, are important ones in astronomy. If we can fathom the mystery of the structure of the Milky Way, we shall have learned much about the arrangement of the universe.

Even with a pair of field glasses or a small telescope, one can discern that the Milky Way band is composed of countless stars. They form the body of the galaxy of which our sun is a modest member. As a matter of fact, all the stars in the sky that can be seen with the naked eye, and the majority of those that can be distinguished by the most powerful telescopes, are members of the Milky Way system. The Milky Way, our galaxy (a word derived from the Greek *gala,* meaning milk), has great depth. Its distances are most conveniently measured in terms of traveling times at the speed of light. At this speed, 186,000 miles per second, it would take us only about one seventh of a second to circle the earth, a little more than one second to go from the earth to the moon, about eight minutes to go from the earth to the sun, and about 12 hours to make a comfortable sight-seeing tour of the whole solar system, visiting all the planets. But at the same rate we would have to travel more than four years to reach the star nearest the sun—Alpha in the southern-hemisphere constellation of Centaurus; and it would take roughly 100,000 years to pass from one end of the Milky Way to the other.

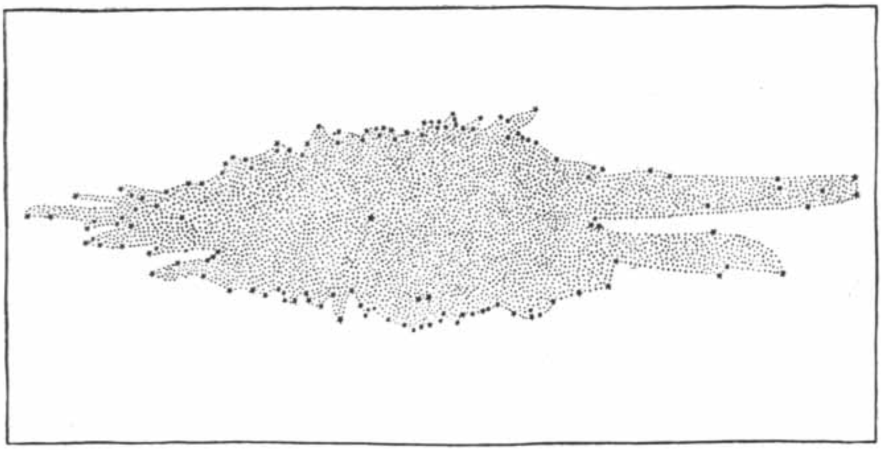
Even through a large telescope, the crowded star fields of the Milky Way look very tightly packed, yet the distances between the stars are measured in light-years. Although there are more than 100 billion stars in the Milky Way system, the system is so enormous that only a very minute fraction of the total space it occupies is taken by the stars themselves. There is truly lots of room in our Milky Way system! We could readily store a million times as many stars in the present volume of the system without the risk of an undue frequency of stellar collisions.

Huge as the Milky Way is, modern telescopes enable us to look beyond its limits and see that distant space is filled with many other galaxies like our own. A single photograph with a large telescope may show easily 1,000 faint galaxies outside the Milky Way. The only distinguishing feature of our own galaxy seems to be that it is about as big as they come. The new 200-inch Hale telescope of Palomar Mountain has brought many more galaxies within reach and expanded the diameter of the visible universe to about two billion light-years—20,000 times the diameter of our own galaxy.

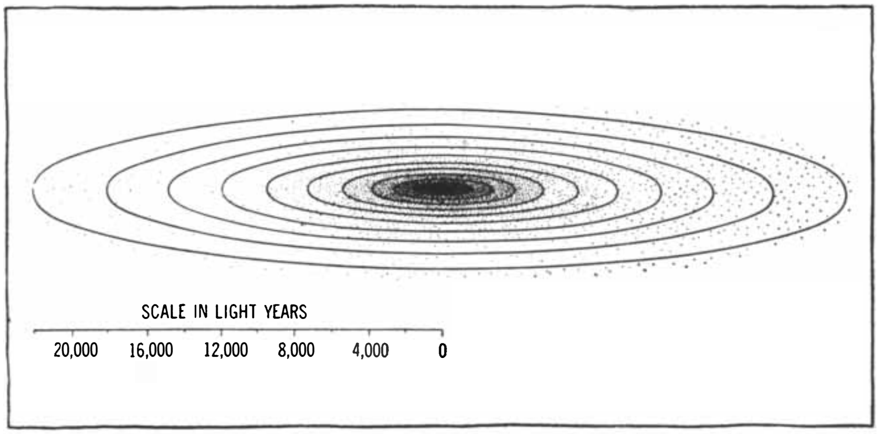
The Shape of the Galaxy

Why study the arrangement of stars and nebulae in the Milky Way system, when it occupies so insignificant a fraction of the total volume of observable space? One might as well ask: Why study our sun, which is after all one mediocre star among billions? Not only can we examine our home galaxy in much more detail than other galaxies, but the Milky Way is a near and ever-present invitation to investigation.

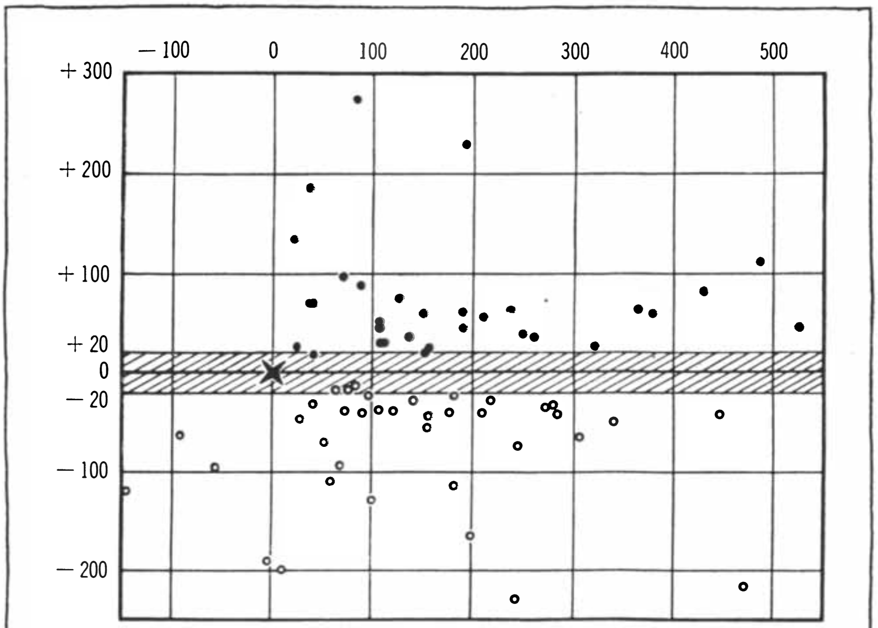
We would like to know, first of all, the general shape of the galaxy and the point of view from which we are looking at it; in other words, what position our solar system occupies in it. When we survey the visible stars in the sky we note at once that they are concentrated most thickly in or near the band of the Milky Way that arches across the sky from horizon to horizon. If you stand with your hands pointing toward the ends of this arch and look out at the sky at right angles to it, you will find the stars scattered thinly there; they become progressively more concentrated as you move your gaze across the sky toward the Milky Way band. Even more significant is the fact that the fainter (*i.e.,* generally more distant) stars show greater concentration toward the band than do the brighter ones, indicating that the galaxy extends farthest in the direction of the band. This evidence shows that



HERSCHEL'S DIAGRAM of 1785 showed a cross section of our galaxy as a "cloven grindstone" with the sun at the center. The stars about the edge of his diagram were not bigger than the others but were farthest away.



KAPTEYN'S DIAGRAM of 1922 still had the sun in the center of the galaxy. The other stars thinned out in all directions. By studying selected areas, Kapteyn estimated the galaxy to be some 50,000 light-years in diameter.



SHAPLEY'S DIAGRAM of 1918 showed distribution of globular clusters (*dots*). Plane of Milky Way is band in center; sun is cross at left. Position of sun with respect to clusters indicated that it was not center of system.

our galaxy has the shape of a flattened disk, or a big wheel, and that we are looking at it from some place in or very near the central plane in the disk. Just as, in looking at a column of marching soldiers, we see many more soldiers and see them stretching farther away in the distance when we look along the length of the column than when we look through a cross section of it, so we see more of our galactic system along the plane of the disk than through a section of it.

Where in this great wheel-shaped galaxy does our solar system lie? Is it at the hub of the wheel, or out toward the rim? The evidence seems conclusive that we are at a great distance from the hub or center of our galaxy. As we look out toward the rim, the Milky Way appears very much brighter (*i.e.*, more extensively populated with stars) in some sections than in others. For example, the section of the Milky Way that includes the constellations of Perseus, Auriga and Orion, which is seen best in winter, is relatively weak, while the section in the direction of the Sagittarius, Aquila and Cygnus constellations, seen best in summer, is so brilliant that parts of it may readily be mistaken for cumulus clouds when observed near the horizon. Photographs to very faint limits show that there are 10 times as many stars per unit area of sky in the Sagittarius cloud as in the richest part of the winter Milky Way. In short, one half of the Milky Way is comparatively thin and dull, the other dense and vivid. Detailed surveys of the weak half show a conspicuous lack of distant objects, star clusters and nebulae; in a careful recent study at the Harvard Observatory not a single object was found in this section that could be placed with certainty at a distance greater than 10,000 light-years from our sun; there may be a few stars beyond this distance, but if so they are certainly spread thinly. On the other hand, the brilliant Sagittarius section abounds in objects that are known to be very far away. All this strongly suggests that we are looking at the galaxy from a position out toward the rim of the wheel, and that the center of our galaxy lies in the direction of the Great Star Cloud of Sagittarius.

On the basis of several wholly independent kinds of evidence astronomers now are certain that our galaxy is a great, wheel-shaped collection of stars rotating in space, with the sun and earth occupying a position about 30,000 light-years from the center. Our sun and the stars near it are whirling in roughly circular orbits around this center at a velocity of about 150 miles a second. So vast is our galaxy that at this fantastic rate of speed the sun takes 200 million years to complete a single swing around the Sagittarius center!

The first serious attempt to study the Milky Way was made by a German-born

English astronomer, Sir William Herschel, shortly after the American Revolution. Earlier investigators, notably Thomas Wright, Immanuel Kant and John Mitchell, had made some fair guesses about the shape and structure of the universe, but no pertinent astronomical observations were available to check their guesses. In 1784 Herschel, assisted by his sister Caroline, undertook a systematic survey of the heavens with a telescope 20 feet long. He made accurate counts of the total numbers of stars visible in the field of his telescope, and surveyed 683 such fields. From these observations he derived a diagram of our stellar system which gave it the shape of a flattened grindstone, with the sun located close to the hub. It was a "cloven grindstone," for there is a dark, star-empty rift in a section of the Milky Way between Sagittarius and Cygnus, and Herschel interpreted this rift as a partial void.

Herschel began his work long before accurate methods for measuring star distances or accurate scales of apparent star magnitudes had been developed. In his first communications he assumed that he had reached the limits of our stellar system with his 20-foot telescope. But when, in 1789, he began work with a new 40-foot telescope, he found many more stars than his smaller instrument had shown, and he began to doubt that he would ever be able to fathom the depth of the Milky Way.

During the 19th century surprisingly little further progress was made in studies of the Milky Way. Herschel's son John extended his father's observations to the southern hemisphere, but he made no significant contributions to our knowledge of the Milky Way's structure. The astronomers of the 19th century made important advances, however, in basic research techniques and precise observations of single stars that were to prepare the way for general theories on galactic structure. The first stellar parallaxes, giving the distances of a few stars, were measured. (The parallax of a star is half the arc measuring its shift in relative position when it is observed from opposite points in the earth's orbit around the sun; from this the star's distance is determined by triangulation.) Stellar photography and the spectroscope were developed as powerful tools in astronomical research; scales of stellar magnitudes were established; the "proper motions" (across the line of sight) and the "radial velocities" (in the line of sight) of many stars were determined.

Toward the end of the 19th century J. C. Kapteyn of Holland began an investigation that resulted in a new theory of the structure of our Milky Way system. He believed that the problem was largely statistical: the system would gradually reveal its structure as astronomers gathered more and more accurate data on the magnitudes, spectral characteristics and motions of the stars. He recommended that they concentrate their various methods of study upon certain sample regions of the sky—the so-called Kapteyn Selected Areas. It took Kapteyn about 30 years to carry out the assignment he had set himself; a little before his death in 1922 he summarized his lifework in a diagram setting forth his picture of the galaxy. Like Herschel's, it showed a flattened system, with the sun close to the center, but Kapteyn introduced a scale of distances that represented the first attempt to indicate the approximate size of the galaxy.

In his zeal to obtain a general picture of the system, Kapteyn had imposed upon himself two clearly stated limitations. First, he deliberately ignored the variations in star numbers and in total brightness along the band of the Milky Way itself, and concentrated on recording the striking decline in the number of stars as we move away from the Milky Way band. Second, he decided to ignore the possibility that his observations of stellar distribution might be distorted by the presence of interfering interstellar material that would dim the light of the more remote stars more than that of the nearby stars.

Shapley's Discovery

In the early part of this century probably most astronomers agreed with Kapteyn that the next big advance in our knowledge of the Milky Way would come from an analysis of more accurate and more extensive data like those collected by Kapteyn, without the restrictions he had imposed. Actually the next great illumination of the subject came from a totally unexpected quarter—a study that seemed to have little or nothing to do with the structure of our galaxy. This was the investigation by Harlow Shapley, then a young astronomer at Mount Wilson Observatory, of globular star clusters.

A globular star cluster is a collection of very faint stars, distinguished by its global shape and extreme central density. About 100 such clusters have been observed by astronomers. In 1914 Shapley, following in the footsteps of Solon I. Bailey of Harvard University, began to study faint variable stars in these clusters with the 60-inch telescope at Mount Wilson. Variable stars of this type, known as Cepheid variables, had been studied previously by the astronomer Ejnar Hertzsprung of Denmark and Holland and by Henrietta S. Leavitt of Harvard. The Cepheids, named after their prototype in the constellation of Cepheus, occur in great abundance in the Clouds of Magellan, two star systems that are satellites of our Milky Way system. Each Cepheid variable fluctuates in brightness with a certain definite rhythm or period. Miss Leavitt found that in the Magellanic Clouds all the Cepheids with a given period had the same intrinsic brightness, or what an astronomer calls "absolute magnitude," as distinguished from apparent brightness. It has since been found that this relation is a universal one applying equally to the Cepheids near our sun, the Cepheids in globular clusters and the Cepheids in stellar systems outside our own galaxy, such as the spiral nebulae. With this discovery it became possible to estimate the intrinsic brightness of any Cepheid once its period is known. Comparing the Cepheid's intrinsic brightness with its apparent brightness, measured directly from the photographic plate, an astronomer can readily determine the distance from us of the Cepheid and of the star system of which it is a part.

Shapley, adapting this method to globular clusters, was soon able to determine the approximate distances of about a fourth of the 100 known globular clusters. He also noted a very curious fact that had previously been overlooked: almost without exception, the globular clusters are found in one half of the sky. And even in this half, they are not distributed uniformly; they show a very marked concentration toward the Great Star Cloud of Sagittarius. One third of all the globular clusters fall within an area covering only four per cent of the entire sky!

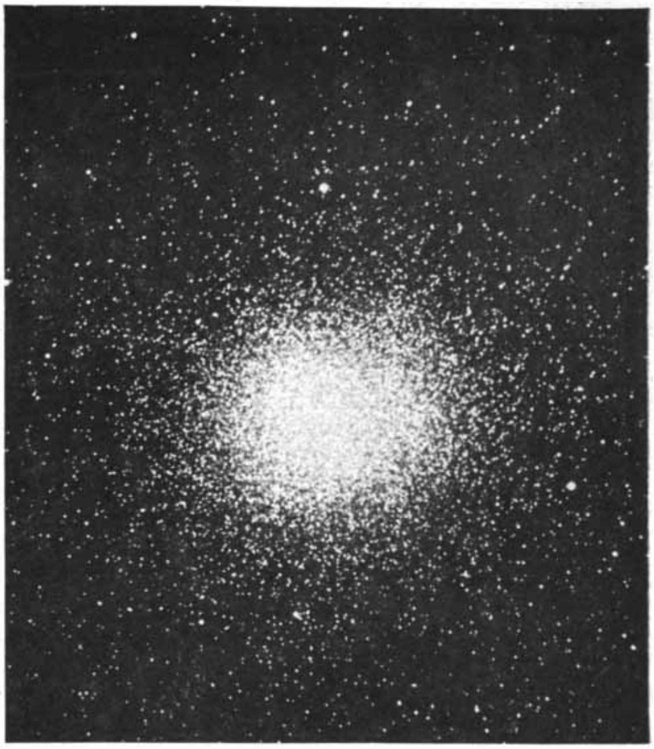
Thus the center of the globular star-cluster system was conveniently located within a relatively small area. It was logical to identify this center with the center of our galaxy. Shapley estimated that this center, in the direction of the Great Star Cloud in Sagittarius, lay about 50,000 light-years from us.

With this revolutionary work, published in 1918, Shapley did for the Milky Way system what Copernicus had done for the solar system: just as Copernicus had shown that the earth was not the center of the solar system, Shapley showed that our sun was not the center of our galaxy but out toward its outskirts.

Supporting Evidence

Shapley's new ideas did not by any means find immediate general acceptance. Note that Kapteyn, one of the many doubters, placed the sun at the center of the galaxy in his final diagram, published four years after the announcement of Shapley's discovery. At the time there were good reasons to doubt Shapley's conclusions. Kapteyn and others had shown by a straightforward analysis of available star-counts that the number of stars per unit volume of the sky dropped off in all directions away from the sun, which seemed to prove that the sun was at the center. This interpretation could be disputed by assuming that there

GREAT STAR CLOUD in Sagittarius is assumed to be in the direction of the center of the Milky Way. This photograph covers about a twentieth of the whole sky, but it contains about a third of all the observed globular clusters. Bright spots are both stars and clusters.



GLOBULAR CLUSTER Omega Centauri is composed of more individual stars than any other member of its species. Its total population is probably well in excess of 100,000 stars. This photograph was made with the 60-inch reflector at Harvard's South African station.

NEBULA Eta Carinae is the most conspicuous feature in a region of the southern sky that is remarkably rich in close and very luminous stars. This region is possibly a nearby vortex of stars, or "spiral knot," such as we see in photographs of galaxies outside our own.

LARGE CLOUD of Magellan is a small stellar system close to our Milky Way system. Both the large and small Magellanic Clouds are visible from the Southern Hemisphere. They are satellites of our galaxy resembling similar satellite systems observed close to other galaxies.

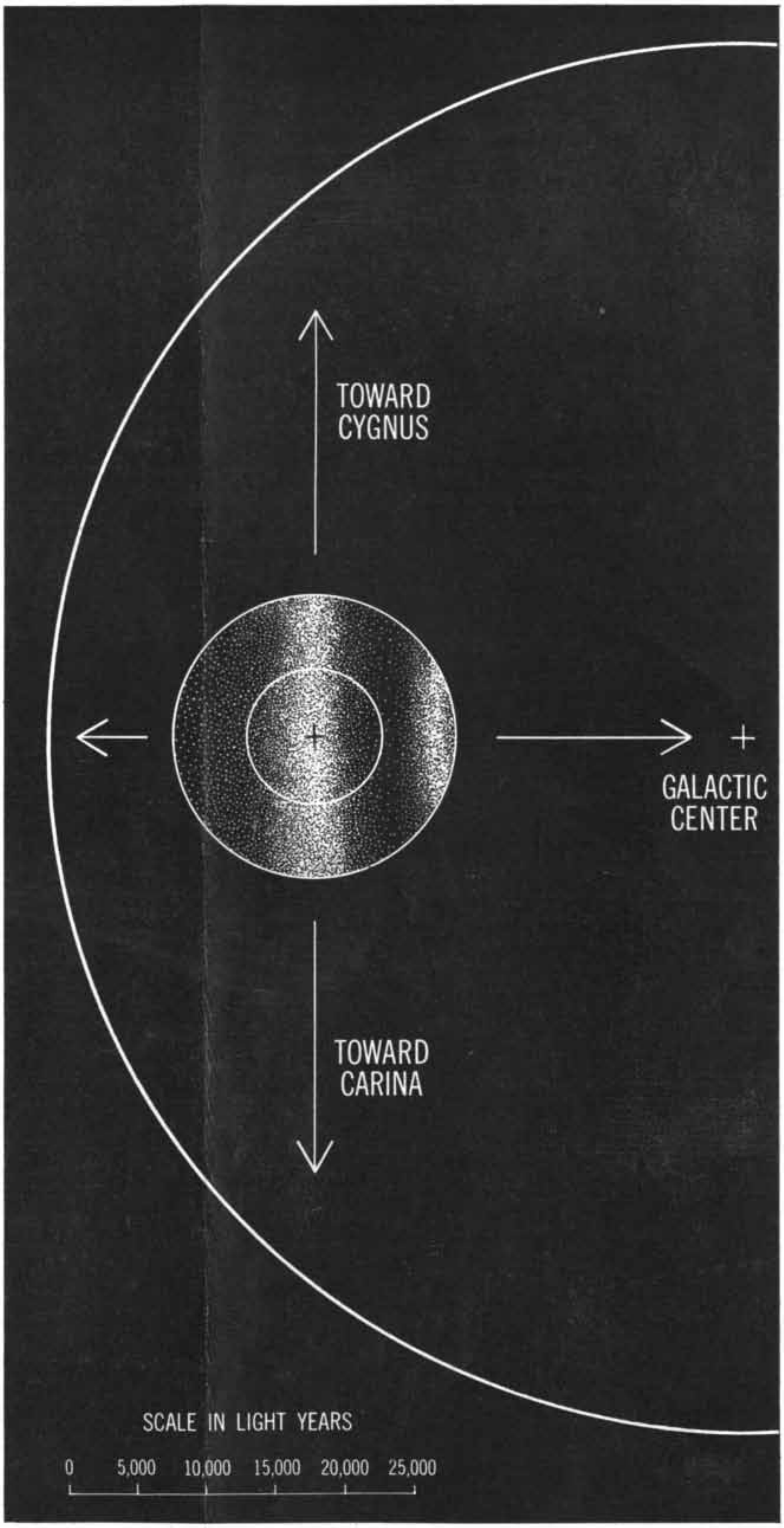
was an obscuring haze of interstellar material near the central plane of the Milky Way which made the star-counts unreliable, but at the time most astronomers, including Shapley, believed that the evidence was against the existence of any such haze.

Two major discoveries in the late 1920s and early 1930s settled the question. First Bertil Lindblad of Sweden and Jan H. Oort of Holland showed that our galactic system as a whole was in rapid rotation, and that the center of rotation was located at a distance of 25,000 to 30,000 light-years in the direction of Shapley's center for the globular clusters system. Then Robert J. Trumpler of the University of California and Carl Schalen of Sweden found that astronomers had been wrong in supposing that there was no general interstellar haze. They demonstrated that the light of an average star in the Milky Way band at a distance of 5,000 light-years from us was dimmed through interstellar absorption by at least one full magnitude. The revised computations made necessary by this discovery confirmed Shapley's conclusions regarding the direction of the center of the galaxy, though they reduced its estimated distance from 50,000 to 30,000 light-years.

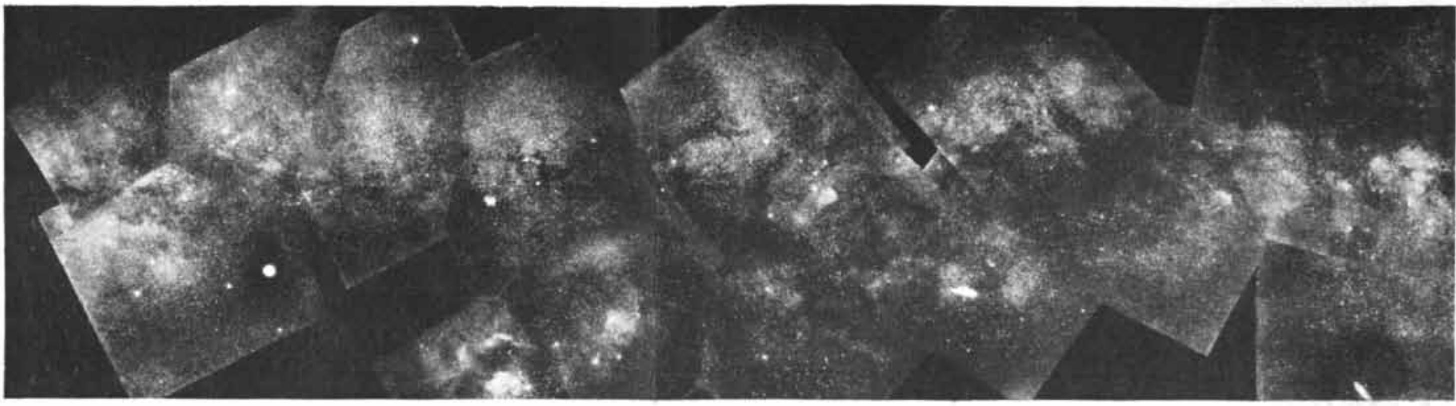
On the basis of the facts then available, Mrs. Bok and I drew an outline of the Milky Way system a little more than 10 years ago. No findings have occurred since then that would make it necessary to change the diagram, nor does it seem likely that any major revision will be required in the years to come. However, while we know the general shape and outline of the system, we have only begun the task of filling in the details.

New Tools

For this task the Milky Way astronomer today has very much more effective tools of research than were available 10 years ago. One particularly useful tool is the Schmidt-type telescope. The purely local variations in stellar distribution are so great throughout the band of the Milky Way that to get significant results we need a telescope that combines the widest possible field of good images with the greatest possible penetrating power. The traditional reflecting telescope can penetrate to great distances, and the traditional refractor type can cover a relatively wide area with perfect image quality over the whole photographic plate, but neither type can do both. The Schmidt instrument, invented by Bernhard Schmidt of Hamburg, resolves the dilemma. It is a reflecting telescope with an added correcting lens at the center of curvature of the primary mirror. It has the faint limiting magnitude corresponding to the large size of the correcting lens and at the same time it possesses a



DETAILED EXPLORATION of our galaxy has pushed out from the sun (*cross*) for a distance of only about 5,000 light-years (*small circle*). We have just begun the thoroughgoing exploration of the region out to 10,000 light-years (*larger circle*). The density of the stars in these nearby regions, in the author's opinion, suggests the internal structure of a spiral galaxy.



THE NORTHERN MILKY WAY is depicted in one continuous band by photographs assembled in a mosaic. The mosaic was prepared by the University of Chicago's Yerkes Observatory from photographs in the Ross-Cal-

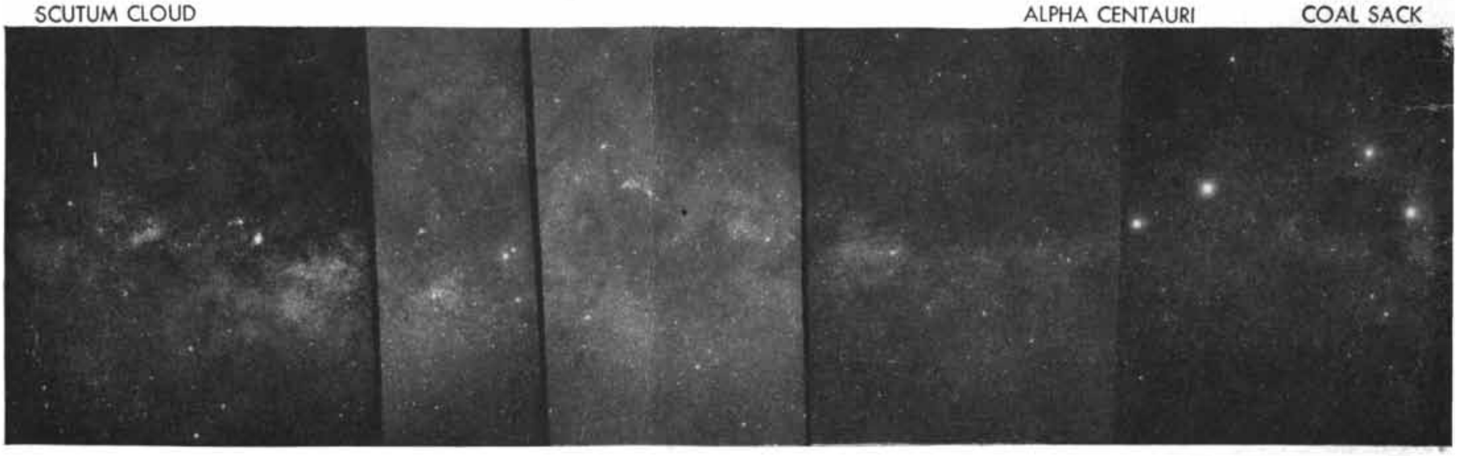
field of perfect image quality even greater than that of the best refractors of comparable focal length. The Schmidt design has certain minor disadvantages, but even these are eliminated in a slightly modified type, the Baker-Schmidt, which has two mirrors in addition to the correcting lens. A Baker-Schmidt telescope is now under construction by the Perkin-Elmer Corporation for installation at the Harvard Observatory Southern Station in Bloemfontein, Union of South Africa, where it is to be owned and operated jointly by the Armagh Observatory of Northern Ireland, the Dunsink Observatory of Eire and the Harvard Observatory.

The largest ordinary Schmidt now in operation is the 48-inch telescope at Palomar; it has a 48-inch correcting lens, a 72-inch primary mirror and an effective focal ratio of one to 2.5. Next in size come the Schmidts of the Warner and Swasey Observatory in Cleveland, the Mexican National Astrophysical Observatory and the Harvard Observatory station at Oak Ridge, Mass.; these three have correcting lenses of approximately 24 inches, primary mirrors of 33 to 36 inches and effective focal ratios of one to 3.5. A Milky Way astronomer who, like the author, learned his trade in the 1920s will never cease to marvel at the performance and speed of even a modest Schmidt. It is a great joy to be able to operate a telescope powerful enough to record star images of perfect quality for 16th-magnitude stars over an area of 25 square degrees of the sky on photographic plates exposed only one to five minutes.

Another great advance is the improvement in photographic emulsions, which has more than doubled the effectiveness of existing photographic telescopes. The sensitivity of the normal blue-sensitive emulsions has been increased twofold, and we now have reasonably fast emulsions that are sensitive to the red and near-infrared end of the spectrum, to wavelengths of 9,000 Angstroms and more. The red-sensitive emulsions are especially important for work on faint stars, since most of these stars are either instrinsically redder than the average brighter stars or are apt to be considerably reddened through the influence of the intervening cosmic haze.

Milky Way research, like all astronomy, also depends heavily on the increasingly important technique of spectroscopy. An ordinary stellar photograph produces for each star only a tiny black dot on the photographic plate, giving us no indication of the kind of star that we are photographing. A comparison of two photographs of the same star, one in blue light, the other in red light, gives us a fair indication of the star's color; but if, for example, the star is found to be quite red, we have no indication as to the cause of the star's redness. It may be (1) an intrinsically red nearby dwarf, (2) a true red giant at much greater distance, or (3) a blue-white star reddened by the effect of the intervening interstellar haze. To determine which of these three possible types it really is, we must split the star's light to determine the strength of the various colors in its spectrum.

From the appearance of the lines and bands in the spectra of stars, we can sort them into certain classes that describe their physical characteristics. For example, a star that shows certain strong and broad lines of hydrogen is deduced to have a surface temperature of about 13,000 degrees Centigrade and an intrinsic brightness of 50 to 100 times that of our sun. The presence of sharp helium lines, coupled with relatively weak and sharp hydrogen lines, suggests a much more luminous star, perhaps 10,000 times as bright intrinsically as our sun. The first of these classes is known as



THE SOUTHERN MILKY WAY is similarly constructed in a mosaic of photographs. This mosaic was assembled by the Harvard Observatory from photographs made at Harvard's Boyden Station in South Africa. In

vert *Atlas of the Milky Way*. The stars denoted by the type above the mosaic are bright objects immediately below the type. A small part of what is usually considered the Southern Milky Way also appears in the mosaic.

spectral type A, the second as type B. Other frequently observed classes have been named F, G, K and M, and certain less frequent groups have been classified as O, R, N and S.

The principal reason for the astronomer's enthusiasm for spectral classification is that this is a means of determining a star's absolute magnitude. Most stars fall into a more or less orderly arrangement according to size in the remarkable chart known as the Russell-Hertzsprung diagram (SCIENTIFIC AMERICAN, January, 1950, page 42). If the spectral classification is made with care, it is possible to determine whether a given star is a dwarf, a giant or a supergiant. Once we know its spectral class and whether it is a giant or a dwarf, we can read its absolute magnitude from the diagram. It is then easy to determine its distance from us, in the same way as we calculate the distance of a Cepheid.

Jason J. Nassau and colleagues at the Warner and Swasey Observatory have shown that highly accurate mass determinations of spectral classes can be obtained with the Schmidt-type telescope. They found that in some parts of the sky spectrum plates made with emulsions sensitive to the near infra-red have terrific space-penetrating power.

Still another important new aid to astronomy is the photoelectric photometer, a device for accurate measurement of the light received from a star. This device, which has as its primary element a sensitive photoelectric cell, receives a star's light on a specially prepared light-sensitive surface. The impact of the light releases a small stream of electrons from the surface, thus producing a very weak electrical current whose strength is directly proportional to the amount of starlight. The electrical current is amplified in several stages and is finally recorded on an electronic recording device. The photoelectric photometer, used with properly selected color filters, is a most efficient tool for the measurement of colors of faint stars. It is also very valuable for the establishment of scales of apparent magnitudes. As a method of recording the amount of light from a star it is far more convenient and accurate than the standard photographic plate. With photoelectric means we can also explore regions of the far infra-red in which it is hardly feasible to work by photographic means. The photographic plate, however, retains one great advantage: a single photographic exposure can record hundreds or thousands of stars; with the photometer at present we can study only one star or nebula at a time.

One more new astronomical tool that should prove particularly useful in Milky Way research must be mentioned: the technique of radio astronomy (SCIENTIFIC AMERICAN, September, 1949). The studies of Karl G. Jansky of the Bell Telephone Laboratories, Grote Reber, now of the Bureau of Standards, and teams of investigators in Great Britain and Australia all have shown that powerful radiations of galactic radio noise are coming to us from the direction of the center of the Milky Way system. Reber's charts of this "cosmic static," received at two radio wavelengths, indicate that most of it comes from regions within 10 degrees of the central line in the Milky Way band. There are remarkable variations in intensity along the band itself. The strongest static reaches us from the direction of the Great Star Cloud in Sagittarius; powerful secondary sources are found in the Aquila-Cygnus section; but from the thin winter Milky Way of Auriga, Gemini and Orion the static is weak. We are as yet quite in the dark about the origin of this cosmic static, but no one can doubt that we have here a new type of phenomenon bearing upon the structure of our Milky Way system.

All these new tools should make it pos-

left center is the Southern Cross. The "Coal Sack" is the area of dark nebulosity in the same region. To the left of the Coal Sack is Alpha Centauri, the star nearest the sun. Right: Sirius, which also appears in mosaic above.

sible within the next decade to sketch in many of the details of the structure of our galaxy, about which, alas, we have as yet all too little information. My own guess is that in all likelihood we shall find that the Milky Way system bears considerable resemblance to the spiral nebula in Andromeda, but I must admit that the evidence is fragmentary and incomplete.

Our present knowledge of the structural details of our galaxy is summarized in the diagram on page 35. The region in which our detailed Milky Way surveys can be said to be more or less complete is indicated by the circle with a radius of 5,000 light-years, centered upon the sun. Inside this circle the evidence seems to point to fairly constant star densities in the directions of Cygnus and Carina, to a steady dropping off of the star density in the direction away from the center of the galaxy, and to an initial dropping off, followed by an increase at much greater distances, in the direction of the center in Sagittarius. The next region, from 5,000 to a little beyond 10,000 light-years from the sun, has been partially explored; here we have studied mostly star clusters and other special objects of high luminosity. A study now under way at the Warner and Swasey Observatory should soon give us much more information about star distributions in this outer ring. In general the structural pattern in this ring seems to be much like that in the inner circle. It looks as though our sun is located in an elongated region of higher-than-average star density. It is tempting to deduce that this region of high density constitutes part of a spiral arm of the galaxy. But we must stress the preliminary nature of this conclusion. The star-counts themselves are subject to further checking, and even at best, the total volume of the Milky Way system that has been explored with any degree of completeness is ridiculously small.

It will, of course, take some time to extend these studies to cover a significant portion of the Milky Way. Our powerful new tools for research are difficult to make and very expensive; they are not yet generally available. And the task of gathering the required accurate basic information with regard to spectra, magnitudes and colors of faint stars is truly gigantic.

It seems absurd, but it is a fact, that we know much less about the detailed structure of our own galaxy than we do about some foreign ones, such as the great spiral nebula in Andromeda and the Magellanic Clouds. In the case of these nearby external systems we can obtain from a single photograph a good over-all view of the arrangement of the stars and their velocities, and of differences in relative distribution of, say, the blue and red stars. The Milky Way system, on the other hand, is too close for us to see it whole. It is much simpler to obtain a general impression of the arrangement of a large city from a plane flying overhead at 10,000 feet than from a prison somewhere near the center of the town, or even worse, from one in the suburbs. The astronomer's problem is actually even tougher than this, for he is asked to study the arrangement of the Milky Way from a suburban prison on a day with a pretty heavy fog! The fog, of course, is the great haze of interstellar dust and gas that floats near the central plane of our galaxy.

Some Current Researches

Yet the astronomer's position is by no means hopeless. There are various stratagems by which he can obtain important clues. One of these is to hunt for the directions of greatest transparency in the system. In the sections of the sky away from the central band of the Milky Way this is not too difficult; at a distance of 10 or 15 degrees from the band there are places where the faint spiral nebulae come into view, which means we are looking right through the haze of our own galactic system into the wide expanse of the universe of galaxies. The chances of finding many transparent regions in the central band of the Milky Way itself are rather slight, but here also we can get some indications of relative transparency, and thereby a measure of the extent of the system in the various directions. For example, since the interstellar haze produces a certain amount of reddening in the light of distant objects, we can locate the regions of greatest transparency by searching for the regions of smallest excess reddening.

Another intriguing problem for the Milky Way astronomer is the study of the central region of our galaxy. The investigation of this region was begun 25 years ago with an examination of variable stars by Shapley and Henrietta H. Swope of Harvard. Inspecting many photographs, they discovered hundreds of variable stars of the Cepheid variety close to or at the center of the Milky Way system. In recent years Walter Baade, using photographic plates with red-sensitive emulsions at Mount Wilson Observatory, has extended this survey to fainter limits. He found one region in the Sagittarius cloud where there were as many as 600 short-period Cepheid variables per square degree of the sky. It will be exceedingly interesting to study the colors of these faint stars for the effect of space-reddening. Already it seems quite likely that Baade's survey has penetrated right to the center of the Milky Way system.

There is also considerable encouragement in the recent discovery that in the direction of the center of the galaxy the obscuring interstellar haze seems to be concentrated mostly in the region relatively near us; beyond our neighborhood the haze appears to thin out. We come to this conclusion not only from studies of the central region itself, but also from inspection of other galaxies. The central regions of practically all spiral nebulae appear to be very much freer from cosmic dust than the outer parts. This gives us hope that once we penetrate the nearby haze, extending perhaps a third of the distance to the galactic center, we shall come to a quite transparent path for the remaining two thirds of the way.

There is another extremely interesting recent discovery that does not help but rather complicates our problem. This is the finding, made clear in studies by Baade, that the various star types are not distributed at random in the sky but seem to be organized in two distinct populations. In the outer regions of a galaxy, such as the region of our sun, the star population is marked by considerable numbers of highly luminous stars, notably the blue-white O and B stars, and by galactic star clusters such as the Pleiades; and there is a great deal of cosmic dust and gas. The central regions of spiral galaxies, on the other hand, apparently have no super-luminous stars, no galactic star clusters and no cosmic dust, but they abound in red giant stars, dwarf stars and short-period Cepheid variables.

The recognition of these two basically different populations in spiral galaxies, one in the outer and the other in the central region, reinforces two earlier conclusions. First, it supports the promise that we may be able to penetrate through the cosmic haze in which our sun is imbedded to study the center of the galaxy. Second, it emphasizes the importance of obtaining accurate data on the spectra and colors of the stars with which we are dealing.

Of the many sections of the Milky Way awaiting examination with our new research tools, none seems more ripe for exploration than the center of the galaxy. The 200-inch Hale reflector and the 48-inch Schmidt on Palomar Mountain are now available for this study. The Harvard Observatory also is making preparations. Harvard's South African station at Bloemfontein is a particularly favorable site for studying the galactic center, because during the best observing season there the Sagittarius center nightly passes directly overhead. By the time many readers see this article, the author and his family will have sailed for South Africa to mount the Baker-Schmidt telescope at Bloemfontein and initiate a study of the center of our galaxy—known around Greater Boston as the "Hub-of-the-Universe Project."

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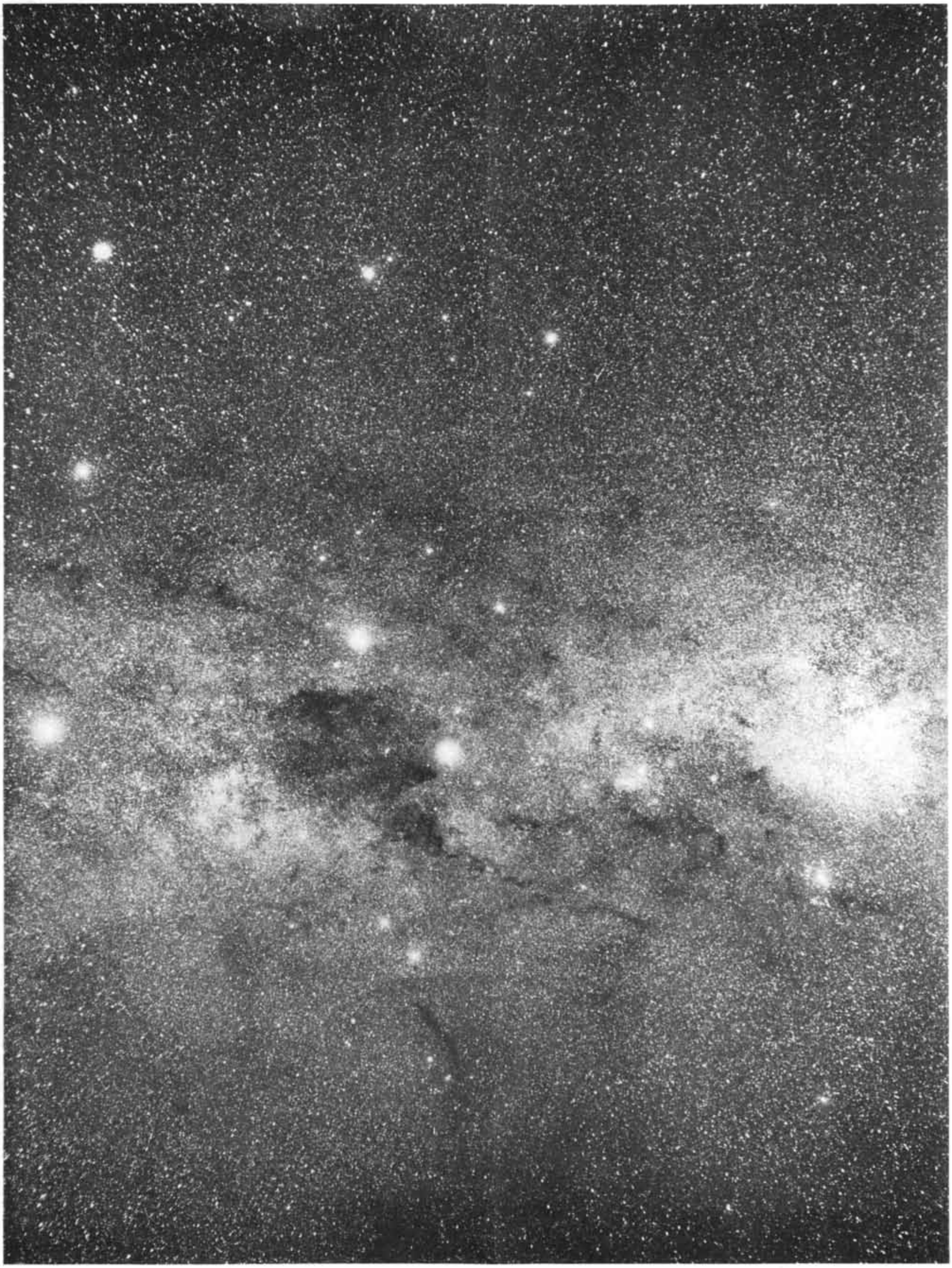
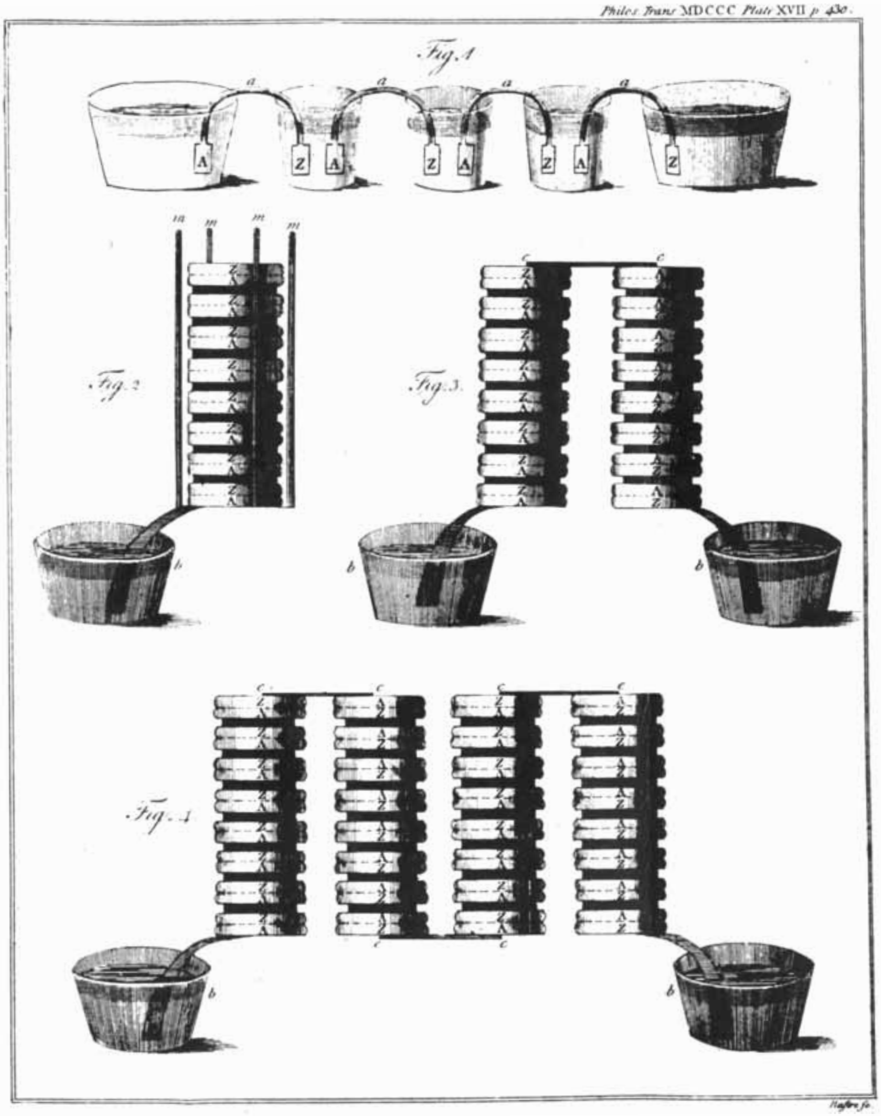


THE COAL SACK is one of the best-defined dark nebulae in the entire Milky Way. It is in the constellation of the Southern Cross, visible only from the Southern Hemisphere. The stars of the Southern Cross here appear of unequal brightness because of their various colors. The blue-sensitive plate makes the redder stars appear faint.

ANIMAL ELECTRICITY

A phenomenon that did much to awaken our early investigations of electricity is still of great interest to biologists

by H. B. Steinbach



VOLTA'S PILE was illustrated in a published letter to the English Royal Society. It was made up of disks of silver (A), zinc (Z) and absorbent material piled atop one another. An earlier arrangement is shown at the top.

IF you were to collect two dozen frogs and connect them in series, running a wire from the inside of the skin of each to the outside of the skin of the next, you could measure between the ends of the amphibian chain a voltage equal to that of a flashlight battery. You can observe the same effect in pieces of frog skin stacked inside surface to outside, or in excised muscles joined side to end. Electricity is produced wherever there are living cells. Sometimes cellular elements are connected in series within a single animal which generates large voltages and strong currents; such an animal is the electric eel.

In 1792 experiments with frogs started a vigorous scientific controversy. Out of the controversy came the electric battery, which made possible the control and study of electricity and our present ability to harness its subtle power. In a way, frogs started it all. The controversy of 1792 was deceptively simple. Was the electricity that made a frog's leg twitch produced by the frog or by metals connecting the parts of the frog?

Luigi Galvani was professor of anatomy at the University of Bologna and the proud possessor of an electrical machine, a device of the day for producing discharges of static electricity by rubbing glass or other substances with suitable materials. It was perhaps natural that a biologist's laboratory should be equipped with an electrical machine; throughout most of the 18th century the curious phenomenon of electricity had been thought to have something to do with life. The static machine was just about the only reliable source of electricity in Galvani's time, and it could develop only brief discharges. Electricity was laboriously collected, discharged and collected again. The Leyden jar had recently been developed, but it was merely a means of storing the stuff. Although enterprising demonstrators made comfortable incomes using the jar for "shocking parties," its transient discharge could not be measured precisely. Benjamin Franklin complained of this difficulty, and he died before it was overcome.

Before Galvani began his experiments with animal electricity he spent much time studying the reactions of freshly prepared animal tissues. His principal subjects were the nerves and muscles of the frog's hind legs—a preparation now familiar to college biology students. The animal was killed and eviscerated, and the upper half of its body was removed so that its legs dangled from a segment of spinal column. When the nerves of the legs were pinched or otherwise irritated, the muscles contracted. Galvani reported many of these observations in 1777, and it was apparently at about this time that electrical phenomena first engaged his attention.

The first record of electrical experiments in his notes is dated November 6,

1780. Some unkind contemporaries suggested that Galvani made these magnificent discoveries by accident when his wife Lucia happened to leave some frogs' legs on his laboratory table, but although fortuitous circumstances undoubtedly played a part, the experiments were probably planned well in advance. Galvani's notes record that freshly prepared frogs' legs were seen to contract when the electrical machine sparked. Further observations showed that the contractions did not occur every time the machine sparked, but only when the metal scalpel used for dissection was touching a nerve. Electricity fed into the nerve by the metal was vitalizing the frogs' legs, an observation that fitted in perfectly with the idea that electricity was closely related to life.

THE excited Galvani made many studies of the twitching frogs' legs. He tested them with electricity from various sources, for the nature of electricity was so poorly understood that it was not then realized that all electricity was the same, whatever its source. Even electricity drawn from storm clouds was applied. It was during this period that Galvani made an observation which led him to announce that not only the electrical machine and the storm cloud but also living matter produced electricity. His "usual manner" of preparing frogs' legs was to fasten a copper hook in the severed spinal column and suspend the whole preparation on an iron stand. He noted that when a frog's moist feet touched the base of the stand, the legs contracted! The reaction was in every way similar to that observed on the application of electricity, yet only the frog's legs and the stand were present. Galvani soon concluded that the living substance produced its own electricity. So startling and so revolutionary was his conclusion that he did not publish his monograph *De Viribus Electricitatis in Motu Musculari* until 1791.

Curiously Galvani's basic observations had been made before. In 1678 the Dutch biologist Jan Swammerdam had demonstrated muscle contraction to the Duke of Tuscany with the aid of a glass tube, a loop of silver wire and a copper rod. The loop of wire and a frog muscle were mounted inside the tube in such a way that the nerve attached to the muscle hung down through the loop and touched its inner surface. When the copper rod was passed up through the loop to touch the nerve, the muscle contracted. Swammerdam did not connect the phenomenon with electricity, however, and why he performed this elaborate ritual is not known. Galvani was also anticipated in 1767 in a book by J. G. Sulzer entitled *Nouvelle Théorie des Plaisirs*. Sulzer described the pleasurable sensations that could be obtained when coins of two different metals were connected with wires and their edges touched to the tongue.

Galvani explained his results by saying that the frog preparation was the source of two different electricities, positive and negative, and that contraction was the result of connecting two parts, nerve and muscle, through an arc of two metals. Another electrical experimenter named Alessandro Volta read *De Viribus Electricitatis* with deep interest. Volta, a teacher at the University of Pavia, at first accepted Galvani's views and repeated his experiments, but soon decided that Galvani was wrong. Electricity, insisted Volta, did not come from the frog but from the two dissimilar metals of the arc. As evidence he pointed out that two metals were essential to Galvani's experiments. Galvani countered with other experiments that showed that one metal, or even a salt solution, was enough. Finally a student performed an experiment that Galvani thought settled the question. When the muscle was abraded slightly, it could be made to contract by touching the nerve to the injury without any artificial arc at all.

But Volta had become a man with a fixed idea. He had thought up a perfect experiment. According to his thinking the frog was merely a device to detect the electricity coming from the two metals; it should therefore be possible to use some device other than the frog to show the electricity of the metal arc. Volta made the most sensitive electroscope of his time and actually found an electric charge on a plate of copper after it had been in contact with a plate of zinc. The effect was weak, so Volta planned a logical further experiment. He joined many pieces of metal to multiply the effect. He connected strips of copper and zinc that were dipped in bowls of salt water in such a way that the sequence ran from copper to zinc to salt to copper, and so on. A more vigorous movement of the straw leaves of his electroscope could now be seen!

Volta then made his famous *pila*, or pile, as the word has been corrupted. Instead of using bulky strips and wires and bowls he piled disks of copper and zinc and fluid-soaked absorbent material. Sometimes he used silver instead of copper, and tin instead of zinc. When the two ends of the pile were connected, wonderful things happened. Sparks flew, not just once, as in the case of the Leyden jar, but repeatedly. Wires connected to the pile got hot and even melted. Thus came into being the first battery and the study of the physics of electricity. Soon the magnetic effects of current flow were detected, electrolysis was studied and better batteries were built. The mathematicians became interested and formulated laws of electricity.

THE extraordinarily rapid development of the physics of electricity shifted attention from the subject of Galvani's studies. Frogs' legs died and were otherwise unreliable in the study of electricity. Voltaic piles lived on and were dependable. Volta reigned supreme. His supremacy, however, may not have been entirely due to his scientific accomplishments. A recent historian records that politics came into play. Napoleon had conquered Italy, and Galvani, refusing to swear allegiance to the invaders, was dismissed from his post in Bologna. Volta, however, did not object to taking the loyalty oath and he received great honors in Paris and at home. Galvani was finally restored to his post, but he died a few months later.

Whatever the merits of his political position, Volta was found to be scientifically wrong. The pile he had built to show that electricity was produced by the contact of two metals was found instead to produce electricity by chemical changes at the junctions of the metals and the solutions. So far as the original experiments were concerned, however, both Galvani and Volta were partly right. Electrical forces do arise at the junctions of unlike metals, and living cells do produce electricity.

The production of electricity by living things was independently established at about the same time as Galvani's frog experiments. For centuries it had been known that certain fishes of the Nile and other waters could deliver mysterious paralyzing blows. In the Mediterranean there was the electric ray, or torpedo, which was briefly studied by Galvani and Volta. In South American rivers there were electric eels. The 17th-century Italian poet and naturalist Francesco Redi had studied the torpedo and concluded that its special force came from strong and rapid contractions of certain muscles in the winglike extensions of its body. This erroneous explanation was "proved" in considerable detail by the mathematician Giovanni Alphonso Borelli—a fate common to many biological observations. Fortunately matters were set straight by the French naturalist Michel Adanson, who observed and felt the potent electric catfish of Senegal. Adanson had been shocked by the Leyden jar, and his chance contact with the catfish convinced him that the two shocks were of the same nature. He reported this to others, who confirmed his impression.

MANY men worked to prove that the electricity from the electric fishes was the same as that from the Voltaic pile and similar sources. The talented but eccentric English chemist Henry Cavendish constructed a leather model of the torpedo and connected it to a Leyden jar to show that he could get the same force from the model as from the fish itself. The great French chemist Joseph Louis Gay-Lussac was proud of his invention which made it easier to handle electric fishes by short-circuiting them between two metal plates. Another enterprising investigator reported that he had received a shock from a stream of water flowing out of a barrel that contained a restless electric eel. But it was Michael Faraday who did the most to prove that the electricity from electric fishes and Voltaic piles and Leyden jars was the same.

Faraday listed his experiments in a letter to the Royal Society in 1838. Of his attempts to obtain electric eels he wrote: "I, in the year 1835, applied to the Colonial Office, where I was promised every assistance in procuring some of these fishes, and continually expect to receive either news of them or the animals themselves." He went on to say that he had finally borrowed an eel from a "gallery" on Adelaide Street with the stipulation that he "have a regard for its life and health." At first Faraday drew the current from the fish with his hands, but he quickly gave that up for copper saddles that could be placed over its ends. In this way he was able to spare himself repeated shocks of 100 volts or more.

With his ingenious saddle connections Faraday satisfied himself that electricity was being generated by the fish. He was able to prove it by the following observations:

1. The shock when the fish was poked caused the pointer of a galvanometer to be deflected.

2. The current from the fish, when led through a coil of wire, could magnetize a needle.

3. A strip of paper, when moistened with potassium iodide and connected at both ends to wires from both ends of the fish, was stained near the wire coming from the front part of the fish. By changing the positions of the saddles on the fish Faraday was able to establish that within limits a given part of the fish was electrically negative to the parts in front of it.

4. A "thermo-electrometer" connected to the fish appeared to give evidence of "a feeble elevation in temperature." Wrote Faraday: "I was not observing the instrument myself and one of those who at first believed they saw the effect now doubts the result."

5. An electric spark was produced when the discharge of the fish was conducted through the primary windings of an induction coil.

Faraday and others had already shown that the discharge of the electric eel could cause physiological effects such as the stimulation of frogs' legs. In his letter of 1838 to the Royal Society he noted that the discharge had a physiological effect equal to that of 15 Leyden jars. Although the observer was partly protected by an arrangement of balls of wet yarn which short-circuited the discharge, this must have been a heroic experiment.

Faraday also considered the immunity of the fish to its own shocks, and investigated the distribution of the shock in the surrounding water. To obtain information about this he placed the fish in a wooden tub and had several of his assistants dip their hands in the water at various distances from it. Faraday poked the fish, the assistants jumped in varying degrees, and he was able roughly to plot the lines of force about the source of the shock.

IN all the electrical experiments of the period the frog remained important, not as a source of electricity but as a detector. The muscle-nerve preparations were more sensitive than the best electroscopes, which were more sensitive than the best galvanometers. In investigating the discharge of the torpedo Galvani arranged several muscle-nerve preparations along the back of the fish. The fish was then poked into action and the sequence of contraction in the frogs' muscles indicated the spread of the shock over its back. These findings have been confirmed by the modern cathode-ray oscillograph.

But what of the mechanism by which living cells generate electricity? Many able men since Galvani have labored to explain it, and they have produced little more than a series of descriptions of electrical behavior. This is not due to lack of effort or brains on the part of the workers. The ubiquity of electrical potential differences in living things has a formal explanation in the basic fact that protoplasm differs in salt composition from the fluids of its environment. The 19th-century German physiologist E. H. Du Bois-Reymond, one who worked long and well in the attempt to explain animal electricity, came to the conclusion that it must originate in the arrangement of electrically charged units at the boundary between protoplasm and environment. Later the term ion was substituted for charged unit, but the basic idea remained the same. The correlation between the orientation of charged units and the ability of cells to generate electricity cannot be doubted; if a cell were electrically neutral there would be something wrong with it.

The reason for our ignorance of how living things produce electricity probably resides in the fact that electrical potential differences merely reflect that the cell is living. Every living cell has a discrete boundary which separates its protoplasm from materials that are quantitatively different. Since protoplasm is an electrolytic system, this necessarily means differences in electrical potential. Animal electricity will be explained when life is explained, which may not be for some time.

The lack of a fundamental explanation, however, does not detract from the need for further investigations. Nor does it depreciate the practical value of measurements of animal electricity. The phenomenon finds useful applications in the electrocardiograph and the electroencephalograph, powerful tools in medicine and research. Many phenomena of animal electricity other than those of heart and brain can also be measured. We may expect progress along the lines first plotted by Joseph Erlanger of Washington University and Herbert Gasser of the Rockefeller Institute, who applied the cathode-ray tube to the study of the electrical variations accompanying the nerve impulse. Such studies have already benefited from the knowledge and interest of engineers familiar with the electronic advances of the war period. The discovery in the squid of a giant axone, the long process of a nerve cell, has placed material in the hands of physiologists that was completely unknown 20 years ago. These giant axones are truly huge in comparison with the nerve axones of the human body. Mammalian axones usually are only a few thousandths of a millimeter in diameter; squid axones are commonly half a millimeter in diameter. When fine electrodes are inserted into these huge tubes of protoplasm, the charged units first suggested by Du Bois-Reymond can be studied with a directness that is otherwise impossible.

THE first studies of animal electricity should be remembered in these days of specialized investigation. A list of those working on the problem from 1700 to 1900 would be a list of outstanding biologists, mathematicians, chemists, physiologists and philosophers. Ideas flowed freely; conclusions were defended stoutly and in public. Men tended to be scientists and philosophers and not members of departments of zoology or physics. The scientific papers of the past 50 years are in the main only understood by specialists. Fortunately biology shows signs of again becoming a common ground for all kinds of scholars. Physicists have begun to write more books about biological phenomena and biologists appear on the programs of physical and chemical societies. The specialized language of each cult is a hindrance; so is the departmental habit of our universities. But these are minor obstacles. One need only attend a meeting on bacterial genetics or cybernetics or spend a season at the Marine Biological Laboratory on Cape Cod to realize that there is now a strong tendency to return to the "general science" illustrated so well in the study of frogs' legs by Galvani and Volta.

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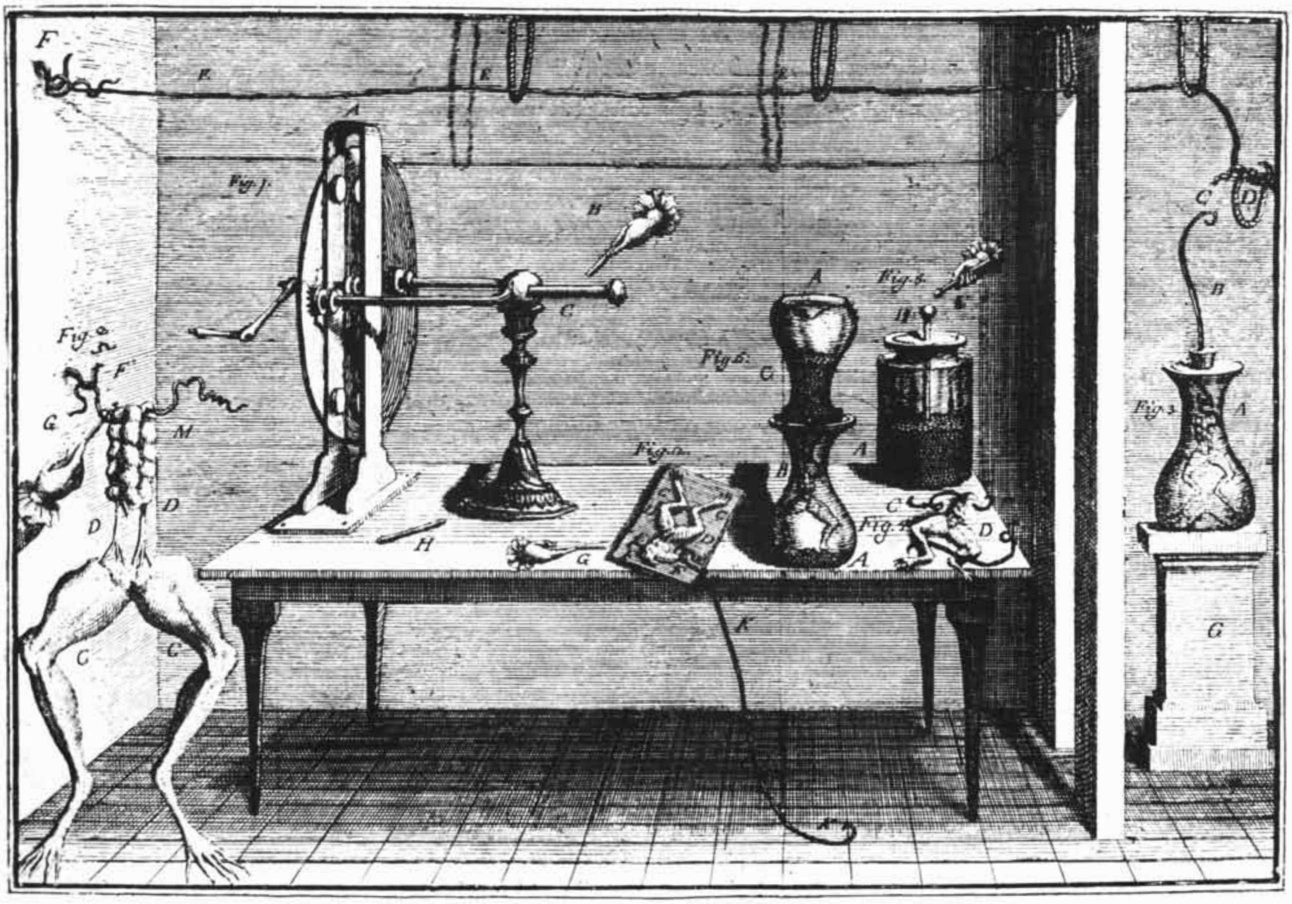
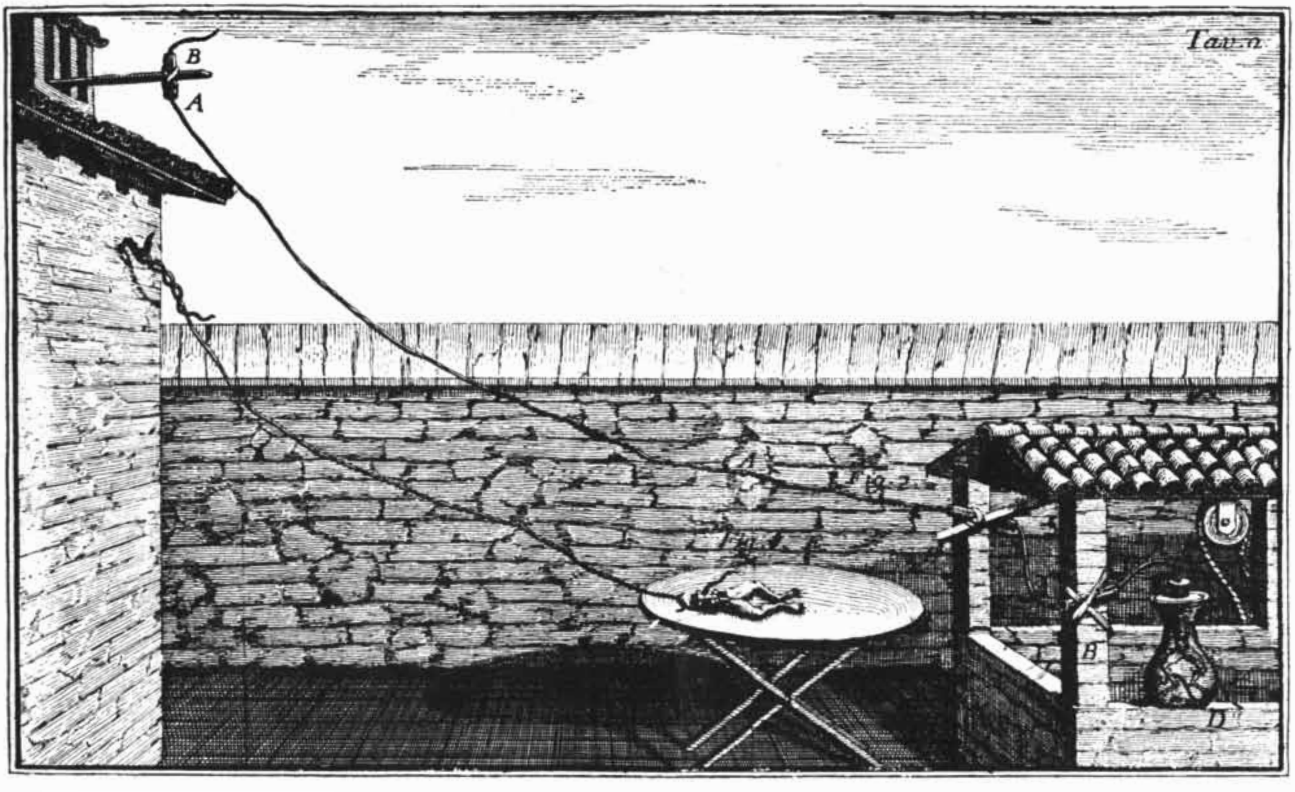


GALVANI'S LABORATORY was illustrated in his monograph *De Viribus Electricitatis.* At the left are frogs' legs prepared in his "usual manner." On the table are his electrical machine (*left*) and a Leyden jar (*right*).



GALVANI'S EXPERIMENT to determine whether the electricity gathered by Franklin from storm clouds was the same as that noted in the experiments with frogs' legs was also illustrated in *De Viribus Electricitatis.*

Prefrontal Lobotomy: Analysis and Warning

The psychosurgical operation has now been performed on more than 5,000 Americans. An account of a recent investigation into how it affects the mental capacities

by Kurt Goldstein

THE treatment of mental disorders has gone through a series of radical changes during the past few decades. At the turn of the century it consisted primarily in custodial care, with efforts to quiet the patient and give him relief from suffering. A more active procedure came into existence with the development of psychotherapy, especially psychoanalysis. This was effective in treating neuroses, but much less successful for severe mental conditions, particularly schizophrenia, or dementia praecox, which according to a statistical analysis made in 1942 accounts for more than 45 per cent of all the cases in mental institutions.

The great development of chemotherapy in general medicine induced some physicians to attack mental conditions by similar means; an outstanding result of this attempt was the successful treatment of general paresis, or mental paralysis, with malarial infection. But such methods had no success in the treatment of schizophrenia, nor have the results of the more recent technique known as shock treatment been too satisfactory.

We are now in a phase in which direct surgical attack upon the brain itself has come into wide use in the treatment of psychotic symptoms. This is a natural culmination of the trend to treat mental conditions by physical means. The idea is not, however, entirely new. In 1890 the Swiss psychiatrist G. Burkhardt, believing that mental abnormalities had their seat in certain specific areas of the brain, began to remove parts of the brain cortex to relieve patients of their hallucinations and other difficulties. His purpose was to transform sick, dangerous individuals into persons who would be harmless to themselves and to society. He accomplished this purpose: his patients lost their violent behavior and could be kept in a quiet ward. Burkhardt, however, abandoned these operations because of the adverse criticism of his colleagues.

The present vogue of mental treatment by surgery began in 1935, when the Portuguese physicians Egas Moniz and Almeida Lima, without knowledge of Burkhardt's attempt, performed the operation now known as prefrontal lobotomy. Two new factors favored their approach: 1) the development of brain surgery, principally by the great Harvey Cushing, which had divested operations on the brain of much of their former danger, and 2) the increase in our knowledge of the functions of the brain. Studies of a great number of patients with brain injuries of various kinds had located the areas of many of these functions. In particular it was found in examinations of soldiers wounded in the First World War that damage to the frontal lobes of the brain was followed by defects in the higher mental functions and by symptoms similar to those in some mental diseases. In later studies, notably those of the late Walter B. Cannon of Harvard University, the effects of damage to the basal part of the frontal lobes and their connections with the thalamus, or midbrain, drew special attention, for lesions in this fronto-thalamic apparatus were found to be related to emotional disturbances, which play so large a role in psychoses.

Egas Moniz and Lima assumed that in schizophrenia there might be abnormal physical conditions in this fronto-thalamic apparatus. They suggested that the abnormal "fixed patterns" in the behavior of a psychotic patient might derive from "abnormally fixed arrangements in the organization of the brain." If so, the condition of the patient could perhaps be improved considerably by attenuating or destroying these abnormal arrangements. This was the rationale of Egas Moniz and Lima for performing the prefrontal lobotomy.

The operation they devised was to make a burr hole at a chosen place in the skull, insert a knifelike instrument into the white matter of the brain, and by a turn of the instrument cut the troublesome connections in the frontal lobes.

Despite some initial resistance in the medical profession, their method was soon accepted with enthusiasm in the U. S. and some other countries, especially after Walter Freeman and James W. Watts of George Washington University had achieved striking results in a number of patients. Schizophrenic patients who had been confined for many years in institutions, and who had been irritable, uncooperative, unclean and utterly helpless, became quiet, more cooperative, clean, able to eat by themselves, capable of working in the hospital, and could even be sent home to their families. Some improved to such an extent that they were able to take jobs and become adjusted to a measure of social life.

These successes led to the widening use of the operation, not only for chronic, hopeless schizophrenics but also for those in the early, acute stages of the illness, who sometimes improve spontaneously, and for manic-depressives and neurotics. The effect of prefrontal lobotomy on some depressives and neurotics was good, even in cases where other treatment, particularly psychotherapy and shock treatment, had been unsuccessful.

ACCORDING to a recent report by the Group for the Advancement of Psychiatry, since 1936 approximately 5,000 patients in the U. S. have undergone prefrontal lobotomy. All over the country projects have been instituted to perform this operation on a large scale. In the near future an increasing number of patients suffering from various mental conditions will be subjected to it. In view of this situation, we have every reason to consider with the greatest care all the possible effects of the operation.

If it could be conclusively determined that the operation does no harm to the mental capacities of the patient, or at least that the harm is negligible compared with the improvement, there could be no doubt that we would possess in prefrontal lobotomy a method of the greatest significance, a treatment which might change the entire outlook of psychiatry. Thus it is of supreme importance to investigate whether the claims of the optimistic advocates of the operation correspond to the facts.

MY own experience with patients suffering from gross lesions of the frontal lobes due to disease or injury, and similar observations made by other physicians, led me to doubt that prefrontal lobotomy produced no damage to the patients' mental capacities, as some psychiatrists assumed. Direct observation of lobotomized patients, and reports published by other authors concerning the behavior of these patients, confirmed my doubts.

The assumption that lobotomized patients suffered no loss of mental capacity was based on their performance in conventional intelligence tests. Apparently the operation did not reduce their Intelligence Quotient. But is it certain that such tests can reveal the presence of a defect of the kind that might be produced by damage to the frontal lobes? There is good reason to believe that they cannot, for intelligence tests, as usually applied, fail to provide an unambiguous measure of certain important qualities of the mind.

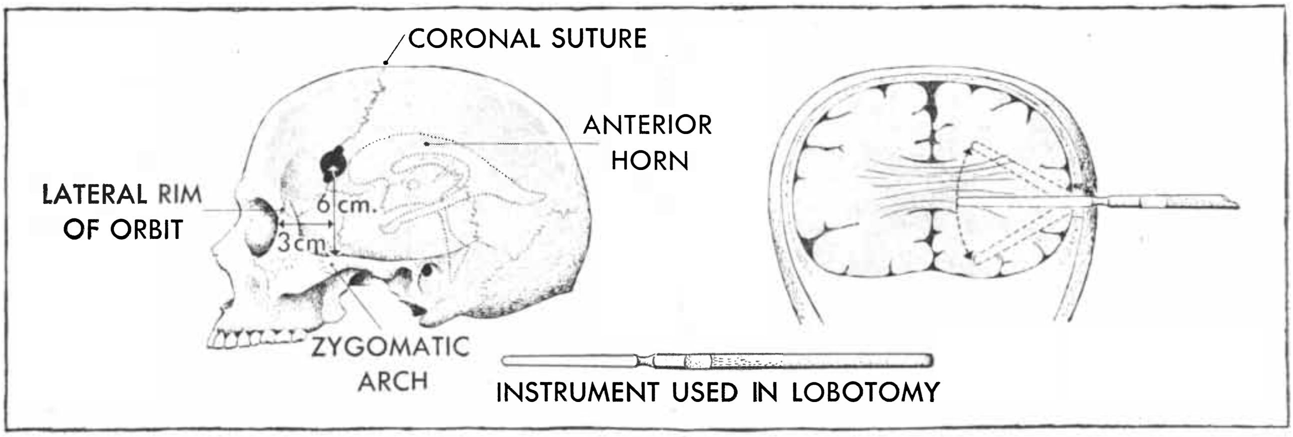
The I.Q. test consists in a number of tasks, called "subtests," each of which is supposed to be solved by the exercise of a particular faculty, such as memory, knowledge of language, abstract thinking, and so on. It is assumed that every person solves each subtest in approximately the same manner. The scores the subject achieves in the different subtests are added together, and the numerical end result permits one to evaluate quantitative differences between individuals. But suppose an individual, unable to solve a subtest in the expected way because of some special defect, say in "higher mental capacity," solves it in some simpler manner. His score on this section of the test is then necessarily ambiguous, for in his case the subtest may not measure the function it was intended to measure. Moreover, the numerical end result for the test as a whole may be misleading, since a low score in some subtests may be compensated by particularly good scores in others. And even if the end number be somewhat below normal, this does not enable us to identify the particular mental capacity in which the individual has failed. The "intelligence" evaluated by the so-called intelligence tests does not represent the totality of the human mind.

To understand mental behavior and its deviations in pathology, we require something more than the quantitative measurements of the conventional intelligence tests. We must take account of the fact that normal thinking and action bring into play two qualitatively different forms of behavior: concrete and abstract. In concrete behavior, we react directly to the immediate claims of an object or situation. For instance, when we enter a room in darkness and automatically switch on the light, we are acting concretely. If, however, we reflect that we may awaken someone who is sleeping in the room and therefore refrain from turning on the light, we are invoking the abstract form of behavior. Our action is based on reasoning; it is determined not merely by the given objects but by the fact that they belong in a larger context in which alone the situation can be handled correctly.

Analysis has shown that the capacity to assume this abstract attitude, also known as the "conceptual" attitude, is a prerequisite for normal human behavior: acting voluntarily, taking the initiative, shifting voluntarily from one activity to another, making adequate choices, classifying objects or ideas, grasping the essentials of a complex situation, synthesizing new ideas, reacting correctly to objects or situations with which one is not directly confronted, detaching one's ego from the outer world and reacting in an objectively correct manner. And it is exactly in the problems or tasks which require these abilities that we find patients with gross frontal-lobe lesions defective. Indeed, such a patient may show some peculiarities even in concrete behavior, when the latter becomes dependent on abstract considerations. For example, the patient may be able to recite a series of numbers, but if he is interrupted he cannot continue where he left off; he must start again at the beginning.

THE author and his associates have examined a number of patients with frontal-lobe injuries by means of special abstraction tests devised to detect the impairment of mental capacities. In all of these tests the individual is confronted with the problem of copying, matching or organizing certain objects in a certain definite way. He cannot come to a correct solution if he lets himself be guided by the immediate sense experience by which he may be impressed. Only if he considers the material from a conceptual viewpoint will he succeed.

One of these tests, the so-called Goldstein-Scheerer Cubic Test, uses four colored cubes. Each cube has four of its sides colored with single colors—blue, red, yellow and white—and the remaining two sides are divided diagonally into



PREFRONTAL LOBOTOMY is performed by drilling a hole in the skull at a point carefully located in relation to prominent skull features (*drawing at left*). Drawing at right shows a cross section of the cranium from the front, and the pathways connecting the left and right hemispheres of the brain. The special knife used in lobotomy is inserted through the hole to cut similar pathways between the frontal lobes and rest of brain.

two colors, one side half blue and half yellow, the other half white and half red. With these blocks the subject is asked to form certain simple geometric designs that are given to him to copy.

Now if one tries to copy separately the elements in the design, such as the red or white stripes or the arrowhead shown in the illustration, he will not be successful. There are no cube-sides which make a direct copying of these elements possible. To solve the problems one must disregard the immediate impression of the stripes or the arrowhead and consider the presented pattern as a whole. He must then divide the figure imaginatively into four equal squares. With this approach it becomes easy to find the sides of the cubes that correspond to the separate squares and to copy the figure with four cubes.

A normal individual, though he may require some trial and error to place the cubes in the correct position, readily arrives at the correct approach. Analysis of the mental process he goes through reveals that he recognizes that he must disregard the sensory impressions which are thrust upon him and must divide the figure in a somewhat unnatural way into four squares. In other words, to fulfill the task the individual has to take the attitude we have called the abstract attitude. The ability to solve this problem, it should be noted, does not depend on intelligence; any normal individual can solve it if his I.Q. is within the normal range.

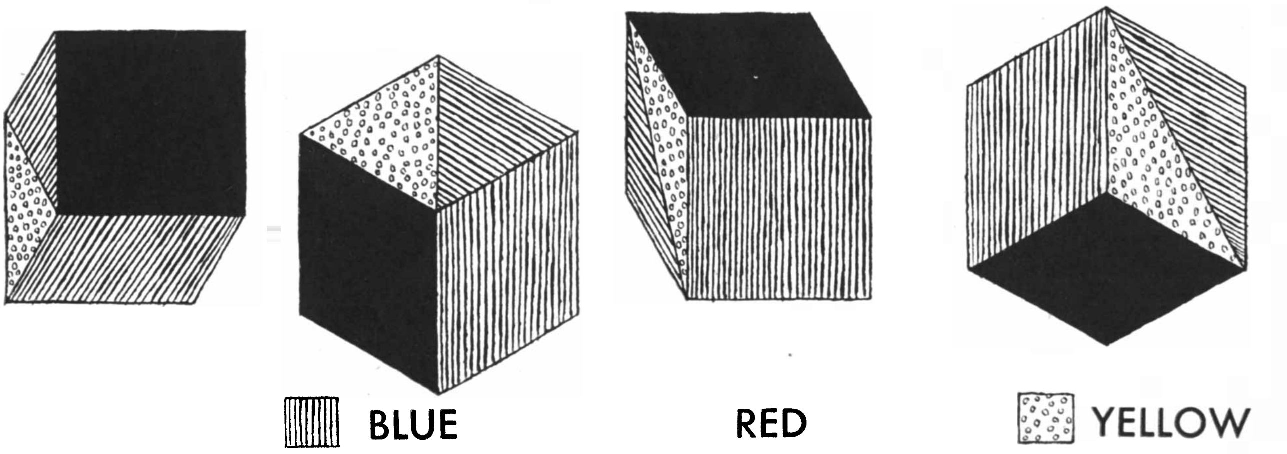
Patients with severe damage of the brain cortex, particularly of the frontal lobes, fail the test, however. Thus with the help of this simple test we are often able to show that a patient is impaired in his capacity for abstract thinking even when the usual intelligence tests do not show statistically reliable differences from the norm.

ANOTHER test of the abstract attitude is the Goldstein-Gelb Object Sorting Test. In this the subject is required to select from a variety of simultaneously presented objects all those that he thinks belong together. The objects, all familiar to the patient, can be sorted in different ways, depending on how the subject looks at them. For example, he may choose from the collection as belonging together all the eating utensils, or all the smoking utensils, or all the books, or all the edible things, or all the objects made of metal or of wood, or all those colored in the same way, or all those with the same form. If he approaches the problem with a strictly concrete attitude, he is likely to associate objects only on the basis of their use in everyday life; *i.e.*, he will bring together all those things which belong to a situation of smoking, eating, or the like. But bringing together objects that do not occur in such concrete situations, and that are associated only because they have the same color or form or are made of the same material, requires some power of abstraction. Analysis has shown that the way an individual behaves in this test indicates whether he is able to take the abstract attitude or not.

Another test, the Goldstein Stick Test, calls upon the subject to remember simple geometrical figures built with short wooden sticks. He is shown a vertical line, a diagonal, a square, an angle or a little house, and after a few moments is asked to reconstruct the figure from memory. A normal person can do this easily. But a brain-injured patient may be unable to reconstruct even an angle or a straight line in the presented direction. He cannot repeat the straight line or angle because the task presupposes perception of a definite direction or of relations in abstract space, *i.e.*, abstract reasoning. On the other hand he may be able to reconstruct the small house perfectly, because it represents a familiar and concrete object. His understanding of an object depends entirely on its concrete meaning to him. For example, whereas a normal person can reconstruct an open angle with the opening upward just as easily as one with the opening downward, the brain-damaged patient may be able to repeat the latter immediately but be absolutely unable to repeat the former, because, as he explains, the downward angle reminds him of a peaked roof, while the other "is nothing." Two patients with the same defect may react differently to the same figure, according to whether it suggests a concrete experience. Thus one patient may be unable to repeat a design composed of a vertical line and a circle because he can not discover anything concrete in this arrangement, while another can repeat it because the combination suggests to him the number 10. It is clear, therefore, that the test result alone is not conclusive; it must be interpreted in relation to the patient's experiences and what is going on in his personality. For a reliable judgment of the patient's capacity it is necessary to consider his performances on various tests. Besides those already mentioned we use a Color Sorting Test and a Color-Form Sorting Test. Because tests involving language are subject to the ambiguities of language itself, all our tests are performance tasks in which language plays no role, or at most a negligible one.

Obviously the evaluation of the results gained in these tests is not always simple, and interpretations must be made very carefully. But the tests, when properly used, are successful in detecting an impairment in abstract reasoning in patients with damaged frontal lobes, even when the damage is as subtle as that following prefrontal lobotomy. This is shown in the results obtained by investigators who have examined a considerable number of such patients.

It is not surprising that lobotomized patients show few or no obvious signs of this defect in everyday life. In the sheltered, simple life that the patients live with their families, they are not often confronted with tasks that can be fulfilled only by abstract reasoning. Moreover, the patient's family, delighted to



CUBIC TEST uses four cubes, each with one blue side, one red side, one yellow side and one white side. The remaining sides are yellow and blue and red and white. Here white is omitted to simplify demonstration.

see him relieved of particularly disagreeable and tormenting symptoms, is likely to overlook the more subtle changes in his personality. We are in possession of some reports, however, which show definitely that even where the patients seem to behave well in learned routine activities and in those originating from a known situation, they manifest abnormalities characteristic of the impairment we have been describing. The English psychiatrists L. Frankl and W. Mayer-Gross tell us about a number of patients whose home behavior is described in letters from their families. One patient, who in general seems to live in a normal way, has no relationship with even the closest members of his family; he manifests no interest in his children. Another exists in "a kind of vacuum"; no friendship is possible; one can neither like nor dislike him. Another, a skilled mechanic who is still considered to be an excellent craftsman, has lost the ability to undertake complicated jobs, has stopped studying and seems to have resigned himself to being a routine worker. An unemployed clergyman, who seems to do his work well enough when he occasionally substitutes for a colleague, is not in the least concerned that he is out of work. He is passive, shows poor initiative, depends on his wife to decide everything, does not help at all to plan for the future.

It is significant that these reports deal with patients who before their prefrontal lobotomy operations were manic-depressives or neurotics. In these cases it can be assumed that the patients' abstract behavior was normal before the operation, because these diseases are not characterized by a defect of abstraction. But the number of such cases is too small to permit a conclusion as to whether prefrontal lobotomy will produce this defect in all operated patients or what degree of impairment it will bring about. Most of the patients who have undergone the operation have been schizophrenics, and there is considerable evidence that in schizophrenia the disease itself produces impairment of abstract behavior. The test results on operated schizophrenic patients cannot determine whether the disease or the operation was responsible for the abstraction defect.

So it is too early to form a definite judgment concerning the amount of damage to be expected from frontal lobotomy or similar operations. It is certainly an exaggeration to refer to all lobotomized patients as "human vegetables," as one author has done.

YET the results are serious enough to give us considerable concern. Even if a statistical evaluation based on many more cases eventually reveals that only a certain percentage of operated patients show impairment of abstraction, this will not help in a decision as to whether to operate in any particular case. All the evidence indicates that the ability to handle abstract problems, once impaired, cannot be recovered, either spontaneously or by training. This means that the individual must remain permanently deprived of one of the most characteristic possessions of human nature, that he is doomed to live on a lower level of human existence. He is restricted in all his relations with the world, intellectually and emotionally. How much this restriction may mean to any given individual, how much of it he may be able to bear without life being rendered valueless to him, of course depends upon his personality, the role that abstraction played in his previous life, and the amount of this capacity he will require under the conditions in which he will have to live in the future.

One may seriously wonder whether the defect produced by the operation may not sometimes be more disastrous to the patient than the disease it is intended to relieve. The problem is not so serious when we deal with severely disturbed schizophrenics who have been sick for many years. For them improvement, even with a defect, certainly would be preferable to the condition in which they are. But in the case of schizophrenics in the first stage of the disease, who may improve without treatment, and of neurotics and depressives, the situation is quite different. Here we must consider whether we want to run the risk of making them incurable mental cripples for the rest of their lives.

At the very least, a careful evaluation of the structure of the personality of the individual patient, his aspirations and duties, his whole "philosophy of life," should precede any recommendation of the operation. It can be recommended to those who could not be helped by any other method and who would require institutionalization for the rest of life. But it should never be resorted to in diseases where spontaneous recovery may be expected, even though the patient may have to suffer for a longer period without the operation. One should be particularly cautious in operating upon young persons, even schizophrenics. Freeman and Watts, who have by far the greatest experience with the operation in this country and who were at first very enthusiastic, themselves cautioned recently: "Prefrontal lobotomy is an operation of last resort."

There is of course a possibility that the operation may eventually be modified in such a way as to obtain the beneficial results without appreciable impairment of the capacity of abstraction. But at present this operation presents to the physician a very difficult challenge. It requires him to encroach upon the very core of the human personality. We can assume this responsibility only if we are always aware of the complexity of our endeavor and if we do not forget that the basic law of medicine, according to Hippocrates, is that we do not harm the patient.

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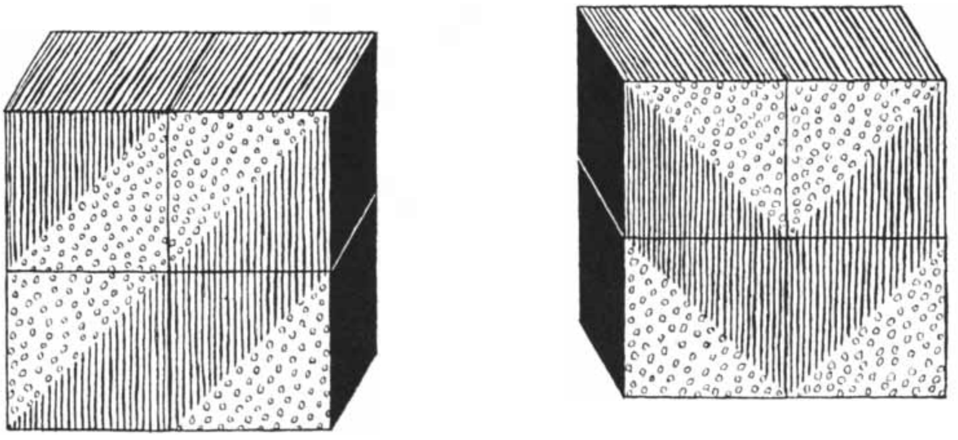


OBJECT of the cubic test is to present the subject with patterns he must reproduce with the four cubes. Here two patterns are shown after they have been made with cubes. Lobotomized subjects cannot reproduce them.

A Chess-Playing Machine

CHESS MACHINE of the 18th century was actually run by man inside.

Electronic computers can be set up to play a fairly strong game, raising the question of whether they can "think"

by Claude E. Shannon

FOR CENTURIES philosophers and scientists have speculated about whether or not the human brain is essentially a machine. Could a machine be designed that would be capable of "thinking"? During the past decade several large-scale electronic computing machines have been constructed which are capable of something very close to the reasoning process. These new computers were designed primarily to carry out purely numerical calculations. They perform automatically a long sequence of additions, multiplications and other arithmetic operations at a rate of thousands per second. The basic design of these machines is so general and flexible, however, that they can be adapted to work symbolically with elements representing words, propositions or other conceptual entities.

One such possibility, which is already being investigated in several quarters, is that of translating from one language to another by means of a computer. The immediate goal is not a finished literary rendition, but only a word-by-word translation that would convey enough of the meaning to be understandable. Computing machines could also be employed for many other tasks of a semi-rote, semi-thinking character, such as designing electrical filters and relay circuits, helping to regulate airplane traffic at busy airports, and routing long-distance telephone calls most efficiently over a limited number of trunks.

Some of the possibilities in this direction can be illustrated by setting up a computer in such a way that it will play a fair game of chess. This problem, of course, is of no importance in itself, but it was undertaken with a serious purpose in mind. The investigation of the chess-playing problem is intended to develop techniques that can be used for more practical applications.

The chess machine is an ideal one to start with for several reasons. The problem is sharply defined, both in the allowed operations (the moves of chess) and in the ultimate goal (checkmate). It is neither so simple as to be trivial nor too difficult for satisfactory solution. And such a machine could be pitted against a human opponent, giving a clear measure of the machine's ability in this type of reasoning.

There is already a considerable literature on the subject of chess-playing machines. During the late 18th and early 19th centuries a Hungarian inventor named Wolfgang von Kempelen astounded Europe with a device known as the Maelzel Chess Automaton, which toured the Continent to large audiences. A number of papers purporting to explain its operation, including an analytical essay by Edgar Allan Poe, soon appeared. Most of the analysts concluded, quite correctly, that the automaton was operated by a human chess master concealed inside. Some years later the exact manner of operation was exposed (*see drawing at upper left*).

A more honest attempt to design a chess-playing machine was made in 1914 by a Spanish inventor named L. Torres y Quevedo, who constructed a device that played an end game of king and rook against king. The machine, playing the side with king and rook, would force checkmate in a few moves however its human opponent played. Since an explicit set of rules can be given for making satisfactory moves in such an end game, the problem is relatively simple, but the idea was quite advanced for that period.

AN electronic computer can be set up to play a complete game. In order to explain the actual setup of a chess machine, it may be best to start with a general picture of a computer and its operation.

A general-purpose electronic computer is an extremely complicated device containing several thousand vacuum tubes, relays and other elements. The basic principles involved, however, are quite simple. The machine has four main parts: 1) an "arithmetic organ," 2) a control element, 3) a numerical memory and 4) a program memory. (In some designs the two memory functions are carried out in the same physical apparatus.) The manner of operation is exactly analogous to a human computer carrying out a series of numerical calculations with an ordinary desk computing machine. The arithmetic organ corresponds to the desk computing machine, the control element to the human operator, the numerical memory to the work sheet on which intermediate and final results are recorded, and the program memory to the computing routine describing the series of operations to be performed.

In an electronic computing machine, the numerical memory consists of a large number of "boxes," each capable of holding a number. To set up a problem on the computer, it is necessary to assign box numbers to all numerical quantities involved, and then to construct a program telling the machine what arithmetical operations must be performed on the numbers and where the results should go. The program consists of a sequence of "orders," each describing an elementary calculation. For example, a typical order may read A 372, 451, 133. This means: add the number stored in box 372 to that in box 451, and put the sum in box 133. Another type of order requires the machine to make a decision. For example, the order C 291, 118, 345 tells the machine to compare the contents of boxes 291 and 118; if the number in box 291 is larger, the machine goes on to the next order in the program; if not, it takes its next order from box 345. This type of order enables the machine to choose from alternative procedures, depending on the results of previous calculations. The "vocabulary" of an electronic computer may include as many as 30 different types of orders.

After the machine is provided with a program, the initial numbers required for the calculation are placed in the numerical memory and the machine then automatically carries out the computation. Of course such a machine is most useful in problems involving an enormous number of individual calculations, which would be too laborious to carry out by hand.

THE problem of setting up a computer for playing chess can be divided into three parts: first, a code must be chosen so that chess positions and the chess pieces can be represented as numbers; second, a strategy must be found for choosing the moves to be made; and third, this strategy must be translated into a sequence of elementary computer orders, or a program.

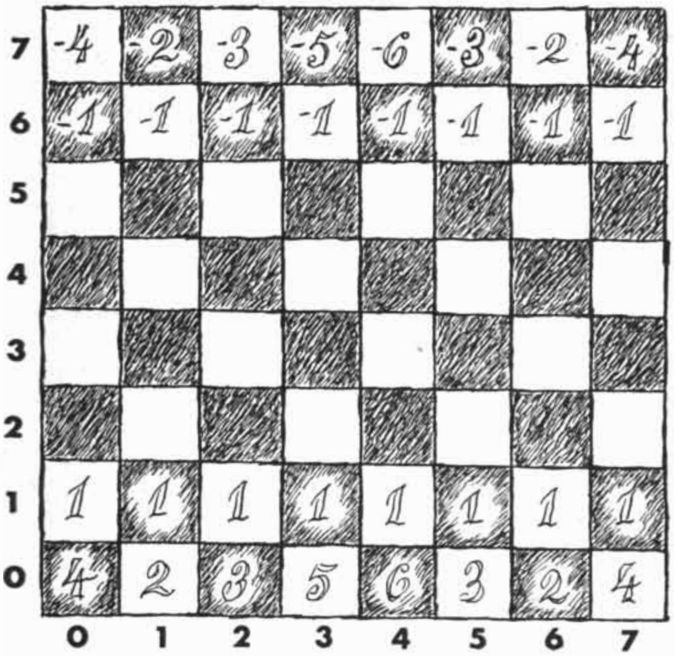
A suitable code for the chessboard and the chess pieces is shown in the diagram to the left at the bottom of this page. Each square on the board has a number consisting of two digits, the first digit corresponding to the "rank" or horizontal row, the second to the "file" or vertical row. Each different chess piece also is designated by a number: a pawn is numbered 1, a knight 2, a bishop 3, a rook 4 and so on. White pieces are represented by positive numbers and black pieces by negative ones. The positions of all the pieces on the board can be shown by a sequence of 64 numbers, with zeros to indicate the empty squares. Thus any chess position can be recorded as a series of numbers and stored in the numerical memory of a computing machine.

A chess move is specified by giving the number of the square on which the piece stands and of the one to which it is moved. Ordinarily two numbers would be sufficient to describe a move, but to take care of the special case of the promotion of a pawn to a higher piece a third number is necessary. This number indicates the piece to which the pawn is converted. In all other moves the third number is zero. Thus a knight move from square 01 to 22 is encoded into 01, 22, 0. The move of a pawn from 62 to 72, and its promotion to a queen, is represented by 62, 72, 5.

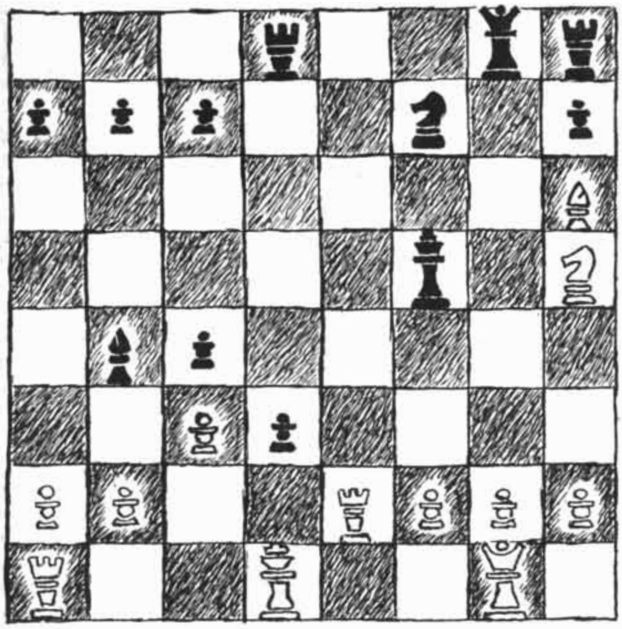
The second main problem is that of deciding on a strategy of play. A straightforward process must be found for calculating a reasonably good move for any given chess position. This is the most difficult part of the problem. The program designer can employ here the principles of correct play that have been evolved by expert chess players. These empirical principles are a means of bringing some order to the maze of possible variations of a chess game. Even the high speeds available in electronic computers are hopelessly inadequate to play perfect chess by calculating all possible variations to the end of the game. In a typical chess position there will be about 32 possible moves with 32 possible replies—already this creates 1,024 possibilities. Most chess games last 40 moves or more for each side. So the total number of possible variations in an average game is about 10^{120}. A machine calculating one variation each millionth of a second would require over 10^{95} years to decide on its first move!

Other methods of attempting to play perfect chess seem equally impracticable; we resign ourselves, therefore, to having the machine play a reasonably skillful game, admitting occasional moves that may not be the best. This, of course, is precisely what human players do: no one plays a perfect game.

In setting up a strategy on the machine one must establish a method of numerical evaluation for any given chess position. A chess player looking at a position can form an estimate as to which side, White or Black, has the advantage. Furthermore, his evaluation is roughly quantitative. He may say, "White has a rook for a bishop, an advantage of about two pawns"; or "Black has sufficient mo-



CODE for a chess-playing machine is plotted on a chessboard. Each square can be designated by two digits, one representing the horizontal row and the other the vertical. Pieces also are coded in numbers (*see text*).



PROBLEM that the machine could solve brilliantly might begin with this chess position. The machine would sacrifice a rook and a queen, the most powerful piece on the board, and then win in only one more move.

bility to compensate for a sacrificed pawn." These judgments are based on long experience and are summarized in the principles of chess expounded in chess literature. For example, it has been found that a queen is worth nine pawns, a rook is worth five, and a bishop or a knight is worth about three. As a first rough approximation, a position can be evaluated by merely adding up the total forces for each side, measured in terms of the pawn unit. There are, however, numerous other features which must be taken into account: the mobility and placement of pieces, the weakness of king protection, the nature of the pawn formation, and so on. These too can be given numerical weights and combined in the evaluation, and it is here that the knowledge and experience of chess masters must be enlisted.

ASSUMING that a suitable method of position evaluation has been decided upon, how should a move be selected? The simplest process is to consider all the possible moves in the given position and choose the one that gives the best immediate evaluation. Since, however, chess players generally look more than one move ahead, one must take account of the opponent's various possible responses to each projected move. Assuming that the opponent's reply will be the one giving the best evaluation from his point of view, we would choose the move that would leave us as well off as possible after his best reply. Unfortunately, with the computer speeds at present available, the machine could not explore all the possibilities for more than two moves ahead for each side, so a strategy of this type would play a poor game by human standards. Good chess players frequently play combinations four or five moves deep, and occasionally world champions have seen as many as 20 moves ahead. This is possible only because the variations they consider are highly selected. They do not investigate all lines of play, but only the important ones.

The amount of selection exercised by chess masters in examining possible variations has been studied experimentally by the Dutch chess master and psychologist A. D. De Groot. He showed various typical positions to chess masters and asked them to decide on the best move, describing aloud their analyses of the positions as they thought them through. By this procedure the number and depth of the variations examined could be determined. In one typical case a chess master examined 16 variations, ranging in depth from one Black move to five Black and four White moves. The total number of positions considered was 44.

Clearly it would be highly desirable to improve the strategy for the machine by including such a selection process in it. Of course one could go too far in this direction. Investigating one particular line of play for 40 moves would be as bad as investigating all lines for just two moves. A suitable compromise would be to examine only the important possible variations—that is, forcing moves, captures and main threats—and carry out the investigation of the possible moves far enough to make the consequences of each fairly clear. It is possible to set up some rough criteria for selecting important variations, not as efficiently as a chess master, but sufficiently well to reduce the number of variations appreciably and thereby permit a deeper investigation of the moves actually considered.

The final problem is that of reducing the strategy to a sequence of orders, translated into the machine's language. This is a relatively straightforward but tedious process, and we shall only indicate some of the general features. The complete program is made up of nine sub-programs and a master program that calls the sub-programs into operation as needed. Six of the sub-programs deal with the movements of the various kinds of pieces. In effect they tell the machine the allowed moves for these pieces. Another sub-program enables the machine to make a move "mentally" without actually carrying it out: that is, with a given position stored in its memory it can construct the position that would result if the move were made. The seventh sub-program enables the computer to make a list of all possible moves in a given position, and the last sub-program evaluates any given position. The master program correlates and supervises the application of the sub-programs. It starts the seventh sub-program making a list of possible moves, which in turn calls in previous sub-programs to determine where the various pieces could move. The master program then evaluates the resulting positions by means of the eighth sub-program and compares the results according to the process described above. After comparison of all the investigated variations, the one that gives the best evaluation according to the machine's calculations is selected. This move is translated into standard chess notation and typed out by the machine.

It is believed that an electronic computer programmed in this manner would play a fairly strong game at speeds comparable to human speeds. A machine has several obvious advantages over a human player: 1) it can make individual calculations with much greater speed; 2) its play is free of errors other than those due to deficiencies of the program, whereas human players often make very simple and obvious blunders; 3) it is free from laziness, or the temptation to make an instinctive move without proper analysis of the position; 4) it is free from "nerves," so it will make no blunders due to overconfidence or defeatism. Against these advantages, however, must be weighed the flexibility, imagination and learning capacity of the human mind.

Under some circumstances the machine might well defeat the program designer. In one sense, the designer can surely outplay his machine; knowing the strategy used by the machine, he can apply the same tactics at a deeper level. But he would require several weeks to calculate a move, while the machine uses only a few minutes. On an equal time basis, the speed, patience and deadly accuracy of the machine would be telling against human fallibility. Sufficiently nettled, however, the designer could easily weaken the playing skill of the machine by changing the program in such a way as to reduce the depth of investigation (*see drawing on opposite page*). This idea was expressed by a cartoon in *The Saturday Evening Post* a while ago.

AS described so far, the machine would always make the same move in the same position. If the opponent made the same moves, this would always lead to the same game. Once the opponent won a game, he could win every time thereafter by playing the same strategy, taking advantage of some particular position in which the machine chooses a weak move. One way to vary the machine's play would be to introduce a statistical element. Whenever it was confronted with two or more possible moves that were about equally good according to the machine's calculations, it would choose from them at random. Thus if it arrived at the same position a second time it might choose a different move.

Another place where statistical variation could be introduced is in the opening game. It would be desirable to have a number of standard openings, perhaps a few hundred, stored in the memory of the machine. For the first few moves, until the opponent deviated from the standard responses or the machine reached the end of the stored sequence of moves, the machine would play by memory. This could hardly be considered cheating, since that is the way chess masters play the opening.

We may note that within its limits a machine of this type will play a brilliant game. It will readily make spectacular sacrifices of important pieces in order to gain a later advantage or to give checkmate, provided the completion of the combination occurs within its computing limits. For example, in the position illustrated at the lower right on page 49 the machine would quickly discover the sacrificial mate in three moves:

	White	*Black*
1.	R-K8 Ch	R X R
2.	Q-Kt4 Ch	Q X Q
3.	Kt-B6 Mate	

Winning combinations of this type are frequently overlooked in amateur play.

The chief weakness of the machine is

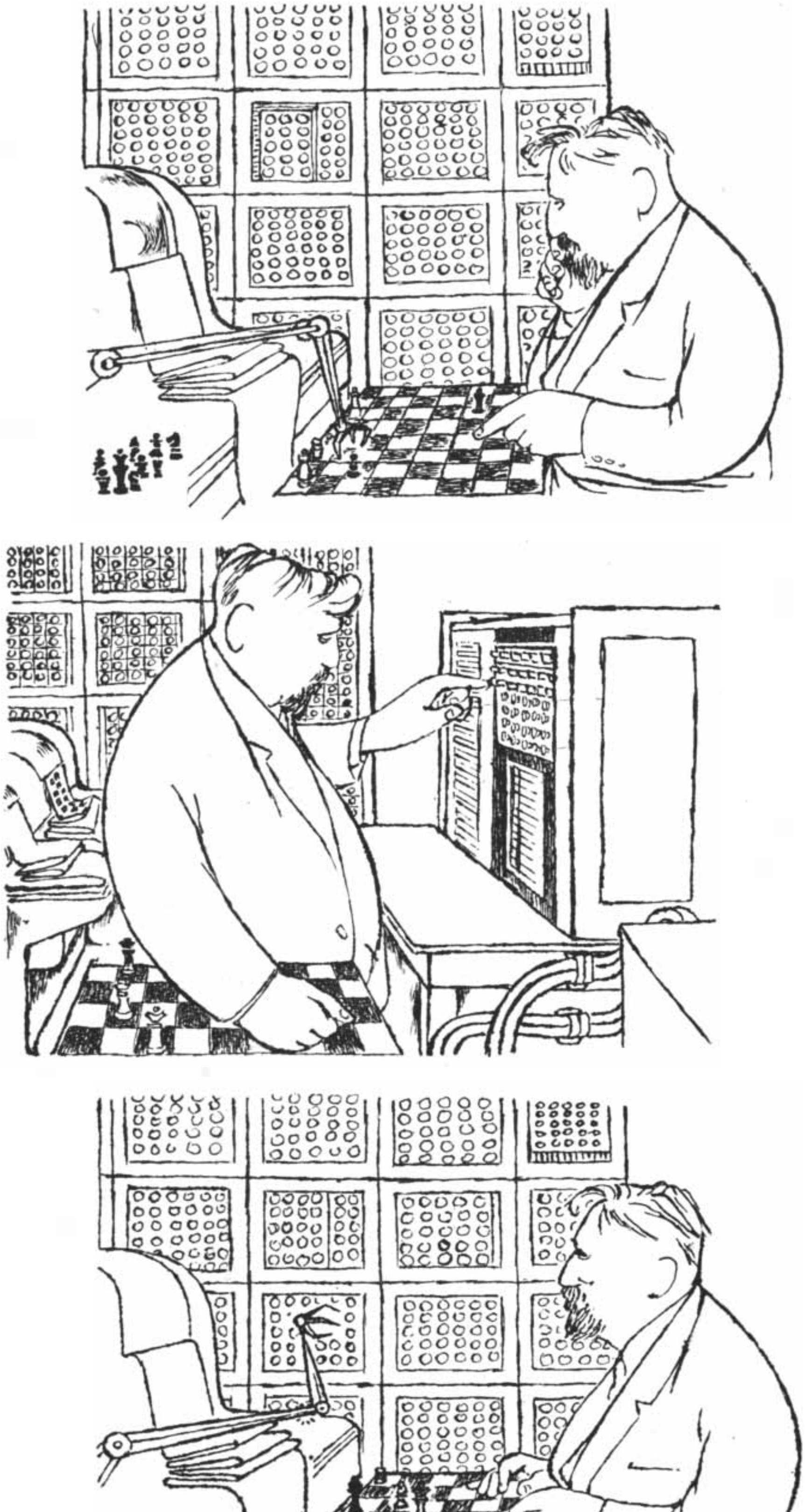
that it will not learn by its mistakes. The only way to improve its play is by improving the program. Some thought has been given to designing a program that would develop its own improvements in strategy with increasing experience in play. Although it appears to be theoretically possible, the methods thought of so far do not seem to be very practical. One possibility is to devise a program that would change the terms and coefficients involved in the evaluation function on the basis of the results of games the machine had already played. Small variations might be introduced in these terms, and the values would be selected to give the greatest percentage of wins.

THE GORDIAN question, more easily raised than answered, is: Does a chess-playing machine of this type "think"? The answer depends entirely on how we define thinking. Since there is no general agreement as to the precise connotation of this word, the question has no definite answer. From a behavioristic point of view, the machine acts as though it were thinking. It has always been considered that skillful chess play requires the reasoning faculty. If we regard thinking as a property of external actions rather than internal method the machine is surely thinking.

The thinking process is considered by some psychologists to be essentially characterized by the following steps: various possible solutions of a problem are tried out mentally or symbolically without actually being carried out physically; the best solution is selected by a mental evaluation of the results of these trials; and the solution found in this way is then acted upon. It will be seen that this is almost an exact description of how a chess-playing computer operates, provided we substitute "within the machine" for "mentally."

On the other hand, the machine does only what it has been told to do. It works by trial and error, but the trials are trials that the program designer ordered the machine to make, and the errors are called errors because the evaluation function gives these variations low ratings. The machine makes decisions, but the decisions were envisaged and provided for at the time of design. In short, the machine does not, in any real sense, go beyond what was built into it. The situation was nicely summarized by Torres y Quevedo, who, in connection with his end-game machine, remarked: "The limits within which thought is really necessary need to be better defined . . . the automaton can do many things that are popularly classed as thought."

Claude E. Shannon is an applied mathematician and co-author of The Mathematical Theory of Communication.



INEVITABLE ADVANTAGE of man over the machine is illustrated in this drawing. At top human player loses to machine. In center nettled human player revises machine's instructions. At bottom human player wins.

UP FROM THE EMBRYO

The process by which a fertilized egg cell evolves to a highly specialized organism has been revealed by brilliant techniques of experimental embryology

by Florence Moog

WHEN the sun rises on Chicago tomorrow morning, it will shine into the eyes of 225 infants who are not there today. The next day there will be 225 more, and as many the day after that. In New York there will be perhaps 450 each day, in St. Louis 70, in San Francisco 60. Next week the U. S. will have 55,000 citizens who are now unborn.

Yet all these young human beings are but a tiny fraction of the new life that unceasingly struggles into the light. Green shoots pushing their way through the soil, tadpoles wiggling free of their slimy capsules, turtles bursting from their horny shells, tiny 'possums scrambling up to the maternal pouch—the increase in life in a single week of spring is incalculable. No event in nature is more common than the appearance of a new individual.

Nor is any event more marvelous. Every living creature is unlikely in its mere existence, representing as it does an elaborate constellation of atoms and molecules resisting the forces of disintegration and dispersion that will rush in upon it at death. But if the maintenance of an organism is unlikely, what is to be said of its development? In the development of an organism the germ takes up the small and simple molecules of the sea or the soil, of egg yolk or blood, and builds them into starfishes or oak trees, blacksnakes or men. This ability to assimilate and to organize inert material is of the essence of life.

Nowhere is that ability better shown than in the familiar hen's egg. Within that common object a tiny, transparent, living dab wrestles with a mass of yolk thousands of times its size, and emerges after 21 days a triumphant chick, with the last traces of the conquered yolk in its belly.

At the time of laying, the living part of the hen's egg consists only of a disk of protoplasm resting on the surface of the yolk. This disk, the blastoderm, is not more than an eighth of an inch in diameter and is almost invisibly thin. For more than half a day of incubation no other structure can be seen. Then a superficial streak appears on the blastoderm, and a little later a second streak, terminating in a crescent-shaped fold, materializes in front of the first. This fold, which proves to be the initial manifestation of the head, soon begins to lift itself from the flat blastoderm. Behind the incipient head the future trunk grows steadily longer.

After 28 hours a pair of large blood vessels connects the embryonic body with the yolk outside, and half a day later the heart is vigorously pumping red blood through a network of vessels from embryo to yolk and back. In the head, disproportionately large at the early stages, the divisions of the vertebrate brain are molded, and the eyes and ears and nostrils become evident. In the trunk appear the kidneys, the liver, the parts of the digestive system, and the tiny flaps that are the first indications of the limbs. During the third day the tail end of the embryo commences to lift itself from the flat surface on which it has formed, and gradually, as the lifting process proceeds backward from the head and forward from the tail, the embryo, which began as a bas-relief, acquires a complete, rounded body. Before the fourth day has passed the deceptively simple blastoderm has turned itself into something the layman can recognize as the foundation of at least an animal—if not yet a chicken.

EDITOR'S NOTE

The illustrations for this article are from *Fundamentals of Comparative Embryology of the Vertebrates*, written by Alfred F. Huettner and published by The Macmillan Company. These outstanding examples of scientific illustration are reproduced with the kind permission of the author and the publisher.

While the body of the embryo is thus materializing, the tissue surrounding it is not idle. The peripheral part of the blastoderm, which is not incorporated into the embryonic body, spreads rapidly until in less than a week it envelops the entire yolk. On the first day, however, blood vessels develop on this expanding yolk sac, and after the blood circulation is established the sac begins to manufacture enzymes which digest the yolk substance; thus the sac serves the embryo in place of its still-unfinished gut. By the fifth day the thick, viscid yolk of the fresh-laid egg is reduced to a watery solution. The digested food molecules are carried through the blood vessels into the body of the embryo, where they are promptly made into more embryo.

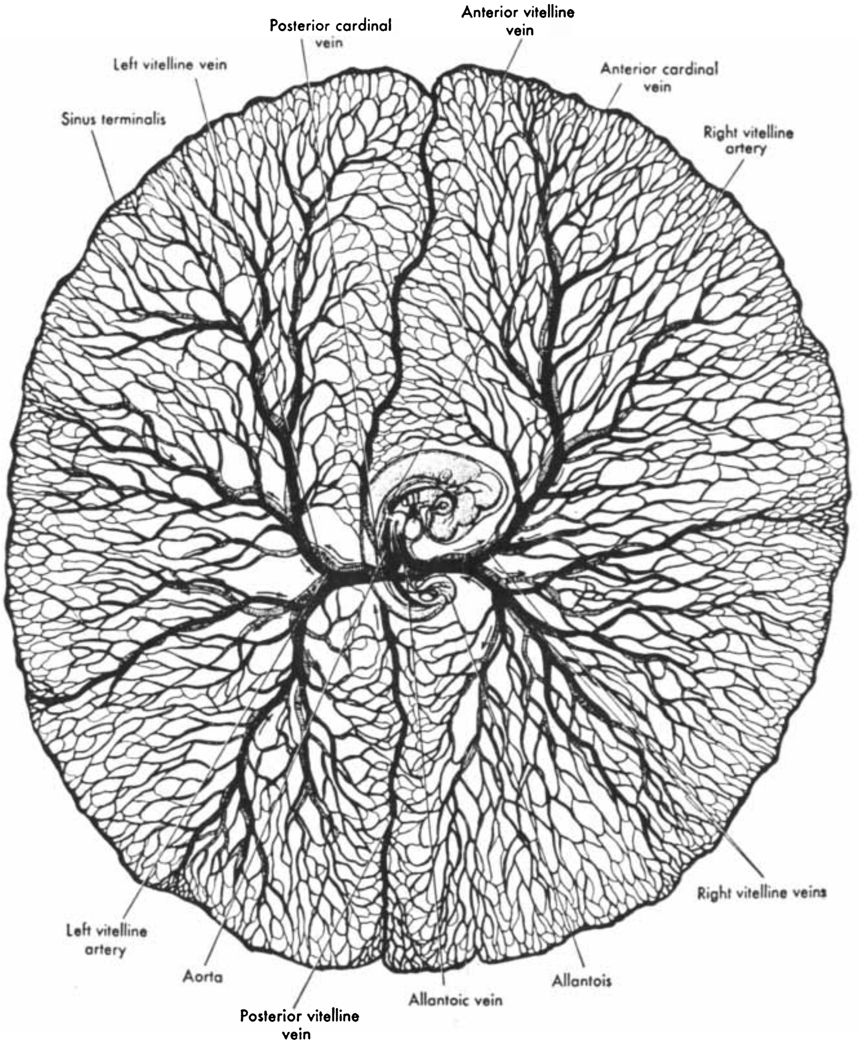
So the young organism, barely a quarter of an inch long where we left it on the fourth day, grows and develops. The flaps that were the first signs of limbs turn into paddles on which the outlines of the toes are crudely sketched, and then the paddles resolve themselves into tiny legs and feet. The eyes, at first two hollow balls of tissue jutting out from the brain, become equipped with light-perceiving apparatus and persuade the skin that overlies them to become clear and transparent. The internal organs pass from mere suggestions of their adult selves to complex structures ready to take over their share of the chick's work. Bones, hardening out of the membranous material, begin to stiffen the body. On the skin tiny hillocks appear from which feathers sprout. By the time the incubation period has run half its course, the erstwhile disk of protoplasm is a bird to the most casual eye.

THE events thus sketched are not a matter of recent discovery. Aristotle was the first to describe the day-by-day development of the chick, and by the middle of the 19th century the embryology of many other animals had been carefully described. But to describe development is not to explain it. Until recent years the forces that guide the embryo along its sure and marvelous path were wrapped in mystery.

Three centuries ago the explanation was invented that development is really no more than the unfolding of a miniature individual already present in the germ. The want of good microscopes made this so-called "preformation" theory excusable; the attraction that a simple and clear-cut explanation has for the scientific mind made it popular. Before the 17th century was out, preformed animals had been "discovered" in every egg or sperm that could be examined. Imagination played a considerable part in these researches. It is hard to decide whether the most inspired report was that of Niklaas Hartsoeker of Holland, who thought he saw a baby curled up in the head of a human sperm, or that of William Crooke of England, who boldly resolved the outlines of a wrinkled and shrunken blastoderm into the figure of a chicken!

But sober thought, unbiased observation—and better microscopes—ultimately forced upon biologists the realization that the more difficult theory of development is the correct one: the new individual does not merely unfold but is truly created, the germ passing from simplicity to complexity, from homogeneity to heterogeneity. The most detailed scrutiny of the fertilized egg reveals no pattern, no hint of the form that is to be assumed. Whatever it is that causes the pattern to become manifest is totally invisible.

This tremendous fact staggered the biological world. For many decades after development had been fully described for numerous forms, biologists took refuge in the theory of evolution, which, according to some enthusiasts, required that the embryo recapitulate its ancestral history as a means of assuming its definitive form. The 19th century had almost passed before researchers made their first real move toward solving the mystery of development. As is so often true in science, progress followed hard on the discovery of a suitable object for research; in the 1880s it occurred to an Innsbruck professor named Wilhelm Roux that the egg of the humble salamander (a frog's or a toad's egg will do equally well) is made to order for experiments in embryology.



CIRCULATION OF BLOOD in the 96-hour chick embryo illustrates its utilization of the egg yolk. The yolk is first surrounded by a yolk sac, on which the blood vessels grow. The yolk sac produces enzymes that digest the yolk, and the blood vessels then carry the food to the developing embryo.

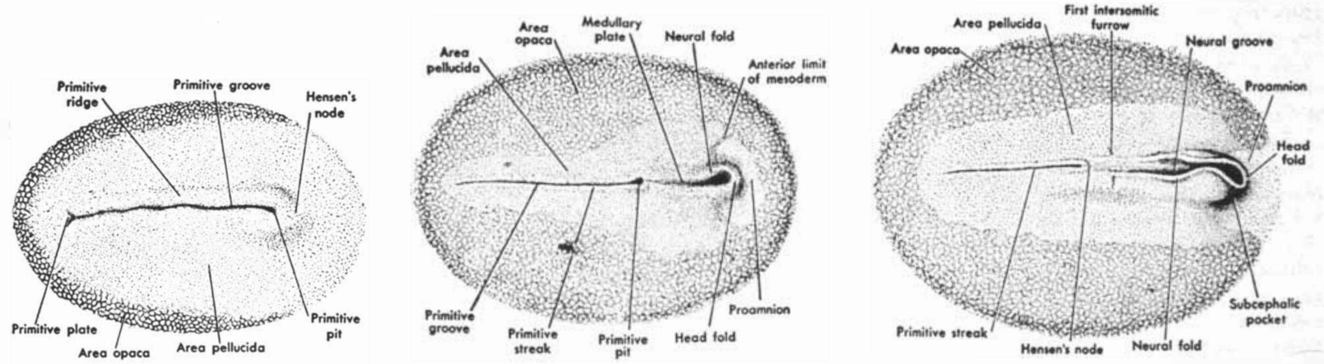
THE eggs of amphibians are large, as eggs go, often measuring an eighth of an inch in diameter. With magnifications of only 10 or 20 times one can easily watch such an egg split itself into many small cells, arrange the cells into layers and gradually stretch itself out to assume the form of a tadpole. But one can do more than watch; with a pair of simple glass needles—and a pair of reasonably steady hands—an experimenter can readily interrupt the developing system, cut it up, rearrange its parts, alter its course of action. From such experiments has come a broad understanding of the factors that make the egg carry through to its unlikely, inexorable end.

Let us take the case of the eye. The descriptive embryologist can point to the future eye already in the neurula stage, when the egg is still a sphere distinguished only by a pair of shallow folds that arise on one side. Between these folds there is a tiny area which in the normal course of events will be carried inside the head, where it will give rise to an eye. But can we fairly refer to that area as "eye" in the simple neurula? How would it behave if it were cut out and put in a strange environment? How would the embryo respond if deprived of an eye-forming area? How far, we are really asking, does a given part carry its future within itself, how far is it influenced in its development by its surroundings and how far does it affect its surroundings?

Put the right question to nature and you will get a cogent answer. The man who first started putting questions systematically to embryos, a modest Württemburger named Hans Spemann, founded a new science and won a Nobel prize. The eye was one of his first, and classic, investigations.

Spemann turned first to the neurula stage, when an eye-forming area can be delimited. With a fine glass needle in one hand and a loop of hair in the other, he cut out the area—a piece of tissue measuring less than a sixty-fourth of an inch on a side and differing in no apparent respect from the neighboring tissue. But the tadpole that resulted lacked an eye on the operated side. Apparently the tiny, undistinguished scrap of tissue that had been excised was already the seat of all the eye-forming potentialities on one side of the body.

This conclusion was also supported by the development of the excised tissue itself. The piece Spemann had cut out he tucked into the flank of another young embryo. Here it proceeded to develop into a quite normal eyeball, provided with retina and lens and cornea and pig-



EARLY DEVELOPMENT of the chick embryo is depicted in these three drawings. The oval patch in all the drawings is the blastoderm, a thin piece of protoplasm on the surface of the egg yolk. On the blastoderm grows the "primitive streak." In the drawing at the left the blastoderm and primitive streak are shown after 16 hours. In the drawing in the center they are shown after 19 hours; in the drawing at the right after 21 hours.

ment. But it peered out of the body wall quite uselessly, because it had one defect: lacking a proper connection with the brain, it could not see.

Such results—which other investigators have repeated with the ear and the heart and the limbs and the gills—might be interpreted as a subtle kind of preformation. Perhaps the germ contains an invisible pattern which development only makes manifest. But Spemann eliminated this possibility by carrying the experiment back to the gastrula stage, just before the neural folds begin to rise on the egg's surface. At this earlier stage, cutting out the site of the future eye causes the embryo no inconvenience at all; the wound simply closes and a perfectly normal eye develops from the tissue remaining. Nor does the excised piece betray any proclivity for eye formation; transplanted to some abnormal position, it simply blends into its new surroundings and assumes a foreign form. Plainly, then, the egg is not provided from the beginning with an invisible blueprint. Rather, between the gastrula and the neurula stages the system produces its own pattern.

The pattern is actually not created in detail at one swift surge. Like a series of artist's sketches, it is first roughly blocked out, then elaborated. Thus in the case of the eye, cutting out half of the eye-forming area in the neurula stage results in a tadpole not with half an eye, but with an eye half the normal size. The limb provides a whole series of striking illustrations of this same phenomenon. As soon as a small field on the side of the neurula becomes "determined" to form a limb, it is capable of telling back from front. A limb-forming area at this stage transplanted to the flank of another embryo will develop parallel with the normal member only if it is oriented with its original front edge forward; if reversed, the visiting member will have an elbow bending forward and a thumb on the rear border of the "hand." At this time, however, the up-and-down axis of the transplant is borrowed from the host. A little later, when the embryo begins to sprout a tail, the limb area acquires its own sense of up-and-down, so that if a transplant is now made with its upper border directed downward, the result is a limb reaching futilely toward the sky. Still later, when the field has grown to be a small bump on the surface of the body, the actual parts of the definitive limb can be found foreshadowed in it. If the tip of the bump is cut off, the result is a leg with no foot; and transplanting the tip produces a foot with no leg.

THE history of the individual organ-fields is really the history of the whole germ. Early in his investigations Spemann discovered that he could separate a newly fertilized salamander egg into two parts by tying a loop of hair tightly around it; each half then developed into a perfectly normal animal. (Nature sometimes performs this sort of experiment, producing identical twins.) As the egg divides into many small cells, the ability of parts to develop into wholes persists. But when the cells organize themselves into layers and flow about to form a triple-layered system—the gastrula stage—the equipotence disappears. Tying a hair about the gastrula results in two incomplete individuals. Among human beings the natural equivalent of this experiment results in Siamese twins or partly double monsters.

The newly fertilized egg has little more pattern than a fresh sheet of photographic film. Just as light rays bring about changes at first imperceptible in the film, so the factors that guide the embryo's course produce in the cleaving cells changes too subtle for the cleverest biologist to detect. But the changes have been wrought, and continued development—this analogy uses the word in a double sense—only makes the pattern manifest. The setting of the embryo on an inevitable course is always early, never requiring more than a few weeks. The young human being, for example, is in possession of a detailed directory of its future development by the end of the first month. This fact alone, incidentally, is sufficient to show the absurdity of the still-lingering belief in maternal impressions. A four-month fetus is no more likely to become a furry monster from its mother's fright at glimpsing a rat than is the mother herself.

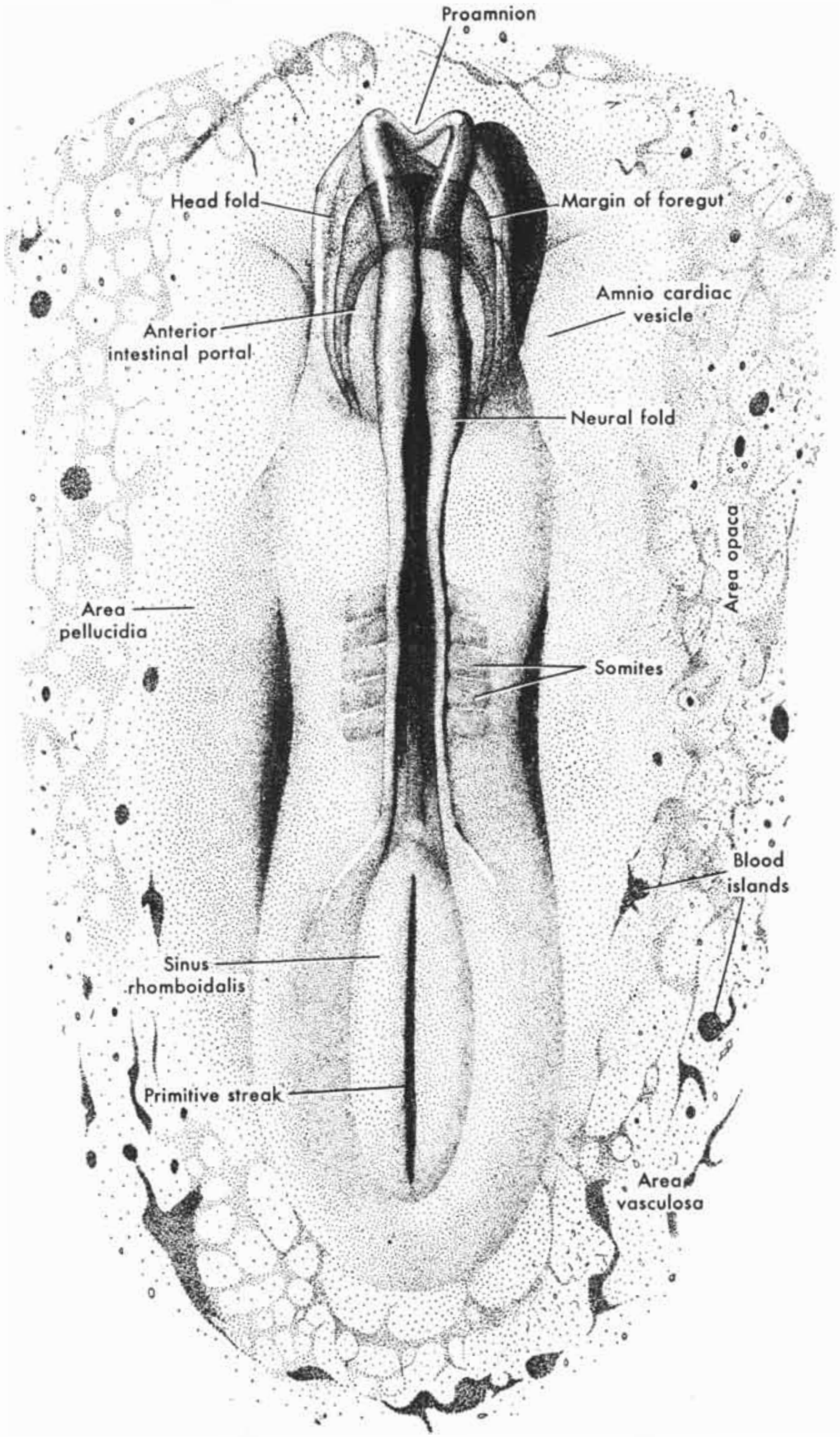
AS is usual in science, the elucidation of the events underlying the visible changes in the formation of an animal has only served to focus attention on events still more remote. What are the factors that cause various parts of an embryonic system to become different from one another? What happens to make one group of cells turn into pulsating heart wall, no matter how strange its surroundings may be, whereas another group of cells, looking no different from the first, inevitably becomes a shaft of cartilage? The outlines of the answer are now emerging from studies in the genetics of molds and yeasts. These simple organisms—not so simple to the specialist's eye—have characteristics of color, surface, shape and biochemical capacities that are controlled, like the color of the human eye or the shape of the human nose, by genes. The greater accessibility of the genes in the molds and yeasts has made it possible to determine that genes, which are submicroscopic, are essentially minute chemical factories that produce substances that influence the behavior of the entire cell. An important new finding is that genes are capable of altering their activity in conformance with the environment in which they find themselves. Take, for example, a yeast strain which has a gene that enables it to make an enzyme capable of breaking down glucose, and another gene that enables it to break down the similar sugar galactose. If such yeasts are raised in glucose, they will produce only the glucose-splitting enzyme. If they are switched to galactose, they will stop producing the glucose enzyme and turn out the galactose-splitting enzyme instead. Other results of the same kind are leading to the conclusion that the functioning of the nucleus, the directive center of the cell, is a compromise between the inherited factors which the nucleus contains and the milieu in which it finds itself.

The interaction of gene and environment may be the core of the ability of a simple egg to give rise to a diverse individual. Even in the egg there are subtle differences; at least a sense of top-and-bottom or right-and-left are tentatively built into the system during its construction in the ovary. The food material, or yolk, moreover, is generally concentrated toward one pole of the egg. The cleaving of the egg tends to accentuate these trifling differences, for it results in some cells with much yolk, some with little yolk, some in which the factors of "topness" prevail, and so on. Further differentiation may then follow from the interplay of nuclei with the cytoplasm in which they become encased.

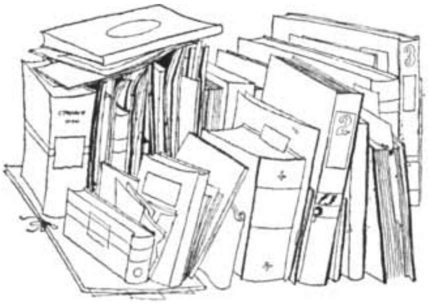
FAR more than merely theoretical interest attaches to this problem of embryonic differentiation at the present time. In embryology we see foot-loose young cells with tremendously wide potentialities becoming bound into a pattern through which they are strait-jacketed into the highly specialized forms and functions of elongated muscle fibers or light-sensitive cells or hydrochloric acid factories in the stomach. When we know what forces push them toward these diverse fates, we shall be much closer to knowing why they sometimes break out of their adult restraint into the deadly second childhood we call cancer. Understanding the factors that come to restrain the normal developing cells may prove to be our best means of learning how to restrain the pathological cells.

The problem of aging enters here, too. Prenatal life and senility may seem to be two very diverse things, but these extremes are really only two time-slices through an uninterrupted stream of development. To a mechanic a machine is more than an incomprehensible whole because he knows how the machine is assembled out of its parts, so that it functions and wears in a given way. The biologist too will understand better what mature cells and organs are, what they do and how they wear down when he knows how they are organized into their fully differentiated selves. By delving further into the problems that experimental embryology poses, we may hope to obtain the kind of understanding that will enable us to prevent the premature wearing of body parts and to stave off the deterioration of age for the longest possible time.

Florence Moog is assistant professor of zoology at Washington University.



AFTER 25 HOURS the embryo of the chick has begun to form structures that give rise to the specialized tissues of the adult chicken. The folds at the top of this drawing are forerunners of the head. Shortly after this stage the blood vessels that bring embryo nourishment from the yolk begin to form.



BOOKS

The fruitful life of Louis Pasteur, as told by one of his direct scientific descendants

by I. Bernard Cohen

Louis Pasteur: Free Lance of Science, by René J. Dubos. Little, Brown and Company ($5.00).

EVERYONE who is familiar with the work of René J. Dubos of the Rockefeller Institute, discoverer of the antibiotics gramicidin and tyrocidine, will welcome a book by him on Louis Pasteur. Dubos has long been an admirer of his French predecessor, and his own research has always had a Pasteur-like quality.

Pasteur holds an unusual dual place in history as a "scientist's scientist" and as the layman's ideal of a great scientist who labored heroically for mankind. Most of the men of science have either been altogether practical, like Edison, or above the battle of human destiny, like

. . . Newton with his prism and silent face,
The marble index of a mind forever
Voyaging through strange seas of thought alone.

Pasteur's work simultaneously embraced deep and penetrating discoveries and their applications to pressing problems of humanity. His great popular success as a crusader who devoted his life to the welfare of man was achieved, Dubos points out, by "the sacrifice of higher ambitions. As a young man, he had planned to devote his life to the study of lofty theoretical problems: the fundamental structure of matter and the origin of life; but instead he soon began to devote more and more time to practical matters—asking of nature questions relevant to the immediate preoccupations of his time." Pasteur himself always argued against the dichotomy of a "pure" and an "applied" science. He insisted that basic science and its applications were as inseparably linked "as the fruit to the tree that bears it."

It is difficult to think of anyone of equal scientific stature before Pasteur who played the same dual role of discoverer and applier; today increased specialization and the complexities of technical development make it even more difficult for any single individual to achieve so much in both the theoretical and the practical spheres. Pasteur's career was possible only in the time during which he lived: during the evolution of the scientist from natural philosopher to technologist and narrow specialist.

The facts of Pasteur's life have been recorded in the famous biography by his son-in-law René Vallery-Radot, and his writings and part of his correspondence also have been published. Dubos therefore decided wisely to devote his book to Pasteur's internal biography: his mind and his scientific achievements. Thus after a brief discussion of Pasteur's personality, the scientific and social world in which he lived and his almost legendary career, Dubos introduces the reader to Pasteur's work, a chapter being devoted to each major achievement. His book naturally invites comparison with an earlier work, *Pasteur: The Story of a Mind*, written by Pasteur's close associate E. Duclaux. Dubos' account, it may be said, not only is written with greater detachment and from a wider historical perspective but reveals more penetratingly the unifying elements in Pasteur's career.

Reading the successive chapters in Dubos' book, one cannot escape the feeling that despite Pasteur's increasing immersion in practical problems as his career progressed, his scientific life followed an inner compulsion and logic of its own. The first 10 years of his scientific life (1847-1857) were spent on investigations of the ability of organic substances to rotate the plane of polarized light and the relation of this property to crystal structure and molecular configuration. Pasteur was interested in the fact that the salts of tartaric and paratartaric acids, while identical in chemical composition and chemical properties, seemed to differ in their behavior with regard to polarized light. He found that paratartaric acid was a mixture of two different tartaric acids possessing equal optical activity, except for the fact that one rotated a polarized beam of light to the right, the other to the left. Pasteur became convinced that one of the fundamental characteristics of living matter was its asymmetrical nature, and throughout a good part of his life he had the fantastic dream of developing techniques for the creation or modification of life by introducing asymmetrical forces in chemical reactions.

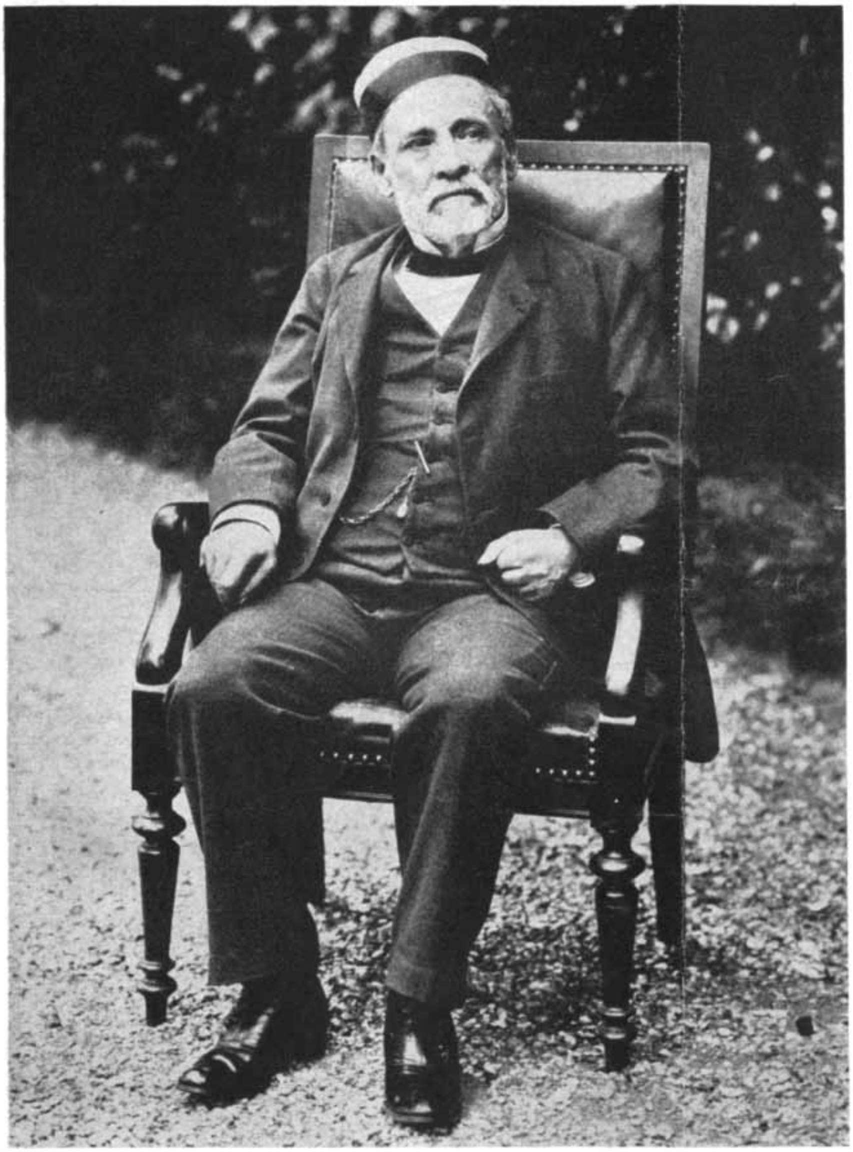
His pioneering studies of tartaric acid also had some less visionary results. From them came the science of stereochemistry, developed during his own lifetime. From them too arose Pasteur's intuitive belief, Dubos says, "that fermentation is the manifestation of living processes, a belief that eventually led him to the germ theory of fermentation and of disease." The uninitiated may find it hard to see how the optical properties of tartaric acid could possibly have anything to do with the phenomenon of fermentation. But Pasteur had observed that when a mold infected a solution of paratartrates, the right-polarizing form of tartaric acid disappeared, while the left form persisted. This finding, says Dubos, for the first time revealed the close dependence of a physiological process upon the asymmetry of a chemical molecule.

Yet Pasteur was led to his specific investigation of fermentation by a purely fortuitous circumstance. One of his pupils in Lille asked his help on certain difficulties encountered in the alcoholic fermentation of beet sugar. Fermentation and putrefaction were then generally regarded as caused by purely chemical agents. Although Pasteur had been trained as a chemist, he had always had an eye for the biological implications of his work. Now his studies of fermentation brought him into intimate contact with the chemical phenomena of living processes and the role of microorganisms. This led him inescapably to the problem of disease.

Pasteur's many experiments on the nature and life-cycles of microorganisms, and his demolition of the then-current theory of spontaneous generation, prepared him for his general studies of disease. First there was the disease of the silkworms, pébrine, which Pasteur was asked to investigate although he knew nothing of silkworms or of their diseases. When Pasteur told his former teacher Jean Dumas that he was totally unfamiliar with the subject, the latter replied, "So much the better! For ideas you will have only those which shall come to you as a result of your own observations!" His studies on the diseases of silkworms introduced him to the complexities of the infectious processes. Dubos' account of the way in which Pasteur mastered the many problems involved affords the reader a superlative and well-documented example of the workings of the scientific mind at its best. The work on pébrine was an apprenticeship to Pasteur's later general study of pathological problems; Pasteur himself used to tell those who came to work in his laboratories: "Read the studies on the silkworms: it will be, I believe, a good preparation for the investigations that we are about to undertake."

Everyone knows today of the heroic labors of Pasteur and his German contemporary Robert Koch to identify the bacillus causing anthrax disease and of the subsequent "golden era of bacteriology" in which others applied the techniques of Pasteur and Koch to search out the microbial agents of many diseases. Dubos points out that "most of the bacterial agents of disease were discovered by the German school of bacteriology. This was due in part to the mastery by Koch and his disciples of the techniques used in the isolation and identification of microbial cultures. Even more important was the fact that, under the dominating influence of Pasteur, the French school . . . became chiefly concerned with another aspect of the study of infectious disease, namely the problem of immunity."

Pasteur's studies of the mechanisms of contagion and disease unexpectedly had led him to the possibility of vaccinating against infectious diseases. Dubos says: "Immediately the prospect of this development took precedence over his other scientific interests and from then on he directed all his experimental work to the problem of vaccination. . . . When he discovered vaccination, in 1882, he was 60 years old, and had only six years of active work left before disease struck him again. The labors and struggles of this last phase of his scientific life never gave him the opportunity of returning to the epidemiological problems and to the mechanisms of toxemia, which appear as sketchy visionary statements in the notes that he published between 1877 and 1882. Historians of bacteriology have neglected this aspect of Pasteur's work. It is very probable, however, that, had not circumstances channeled his efforts into the dazzling problems of vaccination, the study of the physiological and biochemical aspects of infection might have yielded results which now remain for coming generations to harvest."



LOUIS PASTEUR was born in 1822 and died in 1895. Although he is recalled for great work in the early days of bacteriology, he was trained as a chemist.

Perceiving immediately the analogy between immunization against chicken cholera and Jenner's vaccination against smallpox, Pasteur "turned all his energies to the preparation of 'vaccines' against various bacterial diseases," with well-known results. Of his methods Dubos observes: "Pasteur achieved his most startling results through bold guesses which permitted him to reach the solution of a problem before undertaking its systematic experimental study. Because he was well trained in the philosophy of the experimental method, he recognized that these guesses were nothing more than working hypotheses, the validity of which had to be verified and demonstrated by critical scrutiny, and which became useful only to the extent that operational techniques could be evolved to develop and exploit their logical consequences. Interestingly enough, the urge to overcome objections and contradictions, to triumph over his opponents, became in many cases a powerful incentive to the systematic accumulation of the proofs necessary to support theories that had first been affirmed without convincing evidence."

Dubos points out that the logic Pasteur followed in developing and applying his hypotheses was not inevitable; he could have followed many other courses that might have proved as logical and even as fruitful. Discoveries even greater than pasteurization and vaccination might have been attached to the memory of his late years had he elected to live some of the many lives that were offered to him. Discussing some of these other possibilities, Dubos takes occasion to state his own philosophical orientation with regard to the making of discoveries in science; the result is an illuminating dissertation on the scientific process.

In his concluding chapter, entitled "Beyond Experimental Science," Dubos explores the relation between Pasteur's firm belief that the progress of experimental science will make man free, secure and happy, and his strong adherence to the teachings of the Roman Catholic Church, to which he held devotedly throughout his life. Dubos notes that many of Pasteur's opponents "have seen an evidence of the philosophical limitation of his mind in his unwillingness to accept the possibility that human emotions and religious faith could be amenable to scientific scrutiny. They have also regarded his attitude as an intellectual surrender due to an acceptance of the Catholic discipline." Pasteur, however, was not unique in this attitude: Dubos points out that many of his contemporaries in non-Catholic countries—Davy, Faraday, Joule, Maxwell, Lord Kelvin, Helmholtz—dissociated their beliefs as men of sentiment from their behavior as experimental scientists. Pasteur rejected scientific materialism, not merely on the basis of his emotions but rather because, like Claude Bernard, he had reached the conclusion that the mystery of life resides not in the manifestations of vital processes but "in the predetermined specific characters of the organisms which are transmitted through the ovum, through what he called the 'germ.' " Pasteur saw no hope that the experimental method would ever reveal the secret of the life-germ or the origins and ends of the universe.

"With struggle but with great success," says Dubos, "he served through his eventful life many of the deities worshipped by thinking men. He used the experimental method to create for humankind the wealth, comfort and health which make our sojourn on earth more enjoyable. He tried to answer by the techniques of science some of the eternal questions which have been asked in so many different forms by all civilizations. He even dared to attempt to create life anew, or to modify it, by his own artifices. And yet, throughout all these bold ventures—where as much as any living man he manifested the glorious conceit of the human race—he retained, childlike, the creed and worshipful attitude of his ancestors. His life symbolizes the hope that a time will come when the infallibility of the experimental method can be reconciled with the changing but eternal dreams of the human heart."

From Pasteur's life and times Dubos also draws a conclusion about scientists' relations with the people. He remarks that the days seem to be gone when such men as Pasteur, Davy, Faraday, Tyndall, Huxley, Helmholtz, Cuvier, Saint-Hilaire, Arago and Bernard introduced the concepts and achievements of science and the mental processes of scientists to appreciative audiences of children and adults, artisans and artists, earnest scholars and fashionable ladies. While it is true that our own era has witnessed the transfer of popular education in science from the leading men of science to journalists, it is also true that in the last two decades more and more scientists have begun to feel the social responsibility of explaining their own work in terms that the average reader can understand. In this book on Pasteur, Dubos himself shows that he is well equipped for this task.

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AN INTRODUCTION TO CRIMINALISTICS, by Charles E. O'Hara and James W. Osterburg. The Macmillan Company ($10.00). Two detectives of the New York City Police Department have written this manual of scientific crime detection describing in elaborate detail the instruments, methods and critical standards that are (or should be) employed in the field and in the laboratory for the apprehension of criminals. It is comforting to learn that the "criminalistician"—one of the most stupefying of all newly coined words—now tracks down evildoers with the aid of the spectroscope, nuclear physics, Bragg's law, the electron microscope, Boolian algebra and the theory of probability; and that the Federal Bureau of Investigation is not the only police force in the country to use these advanced scientific methods. The authors point out, however, that first-rate police laboratories are few and increasing in number only slowly. In the last decade, with crime mounting at a more sustained rate than the cost of living, the "law enforcement mind" has come up with "nothing more revolutionary than the increased use of two-way radio." The book contains photographs, tables, diagrams, bibliographies and numerous useful reading lists. A thoughtful, well-executed text.

WEBSTER'S GEOGRAPHICAL DICTIONARY. G. & C. Merriam Co. ($8.50). To the celebrated Webster clan has now been added this gazetteer of 40,000 place names, modern and ancient, with essential geographical, and often historical, data provided for each entry. Special emphasis has been placed on current names and on places lying within the U. S. and Canada; there is also a generous allotment of Biblical, ancient and medieval names. The text is accurate and the information for each item has obviously been selected with a good deal of care. There are maps; the typography and design are first rate. The specialist of course has needs which this dictionary was not designed to satisfy, and even the general user will mark inconvenient omissions, but it is nevertheless a handy manual to have around.

THE NEW GOULD MEDICAL DICTIONARY. Edited by Harold Wellington Jones, Theodore Phillips, Normand L. Hoerr and Arthur Osol. The Blakiston Company ($8.50). This comprehensive, well-designed dictionary embodying the contributions of leading U. S. specialists in medicine and allied fields will serve physicians and students as the most up-to-date single-volume work of its kind now available. Good typography, clear illustrative plates, helpful tables, moderately priced (that is, by present-day standards).

FROM CAVE PAINTING TO COMIC STRIP, by Lancelot Hogben. Chanticleer Press, Inc. ($5.00). Lancelot Hogben, who has a high reputation as a popularizer of science, especially in his *Mathematics for the Million,* here undertakes a history of communication—how men since prehistoric times, by pictures, signs, symbols and printed words have expressed and exchanged their ideas. He concludes that, although we have traveled far since Cro-Magnon man first made his magnificent paintings on cave walls in France and Spain, we have scarcely begun to exploit visual aids in education as well as politics. He believes that such methods are essential if we are to preserve our culture by raising the level of mutual international understanding to the point where another world war would be impossible. Unfortunately Hogben himself has difficulty communicating his ideas in a hastily written book that strains after effects on almost every page.

ECONOMIC GEOGRAPHY OF THE U.S.S.R., by S. S. Balzak, V. F. Vasyutin and Ya. G. Feigin. The Macmillan Company ($10.00). Another in the invaluable series of translations of major Russian works undertaken by the American Council of Learned Societies. While this work is partially out of date, having been written in 1940 largely on the basis of 1935 data, its description of natural resources, industry, population, agriculture, transport and kindred matters, is the best available account of Russian economic geography. There are 53 tables, 84 maps, a bibliography, a glossary and numerous appendixes.

THE NEGRO HANDBOOK, 1949. Edited by Florence Murray. The Macmillan Company ($5.00). THE NEGRO IN THE UNITED STATES, by E. Franklin Frazier. The Macmillan Company ($8.00). Two volumes no less indispensable for those concerned with the Negro problem than for serious students of U. S. society in general. The first book, a fourth issue, is packed with vital statistics, information on civil rights, crime, educational opportunities and inequalities, employment, the Negro and the labor movement, the Negro in the armed forces, Negro organizations and the like. In the second book Dr. Frazier, head of Howard University's sociology department, discusses, among other things, Negro social structure, racial conflict, economic stratification, the Negro church, intellectual life and leadership, and the vast area under the heading "problems of adjustment." His book is the companion work to Gunnar Myrdal's monumental study, *An American Dilemma*, in the preparation of which Frazier played an important part.

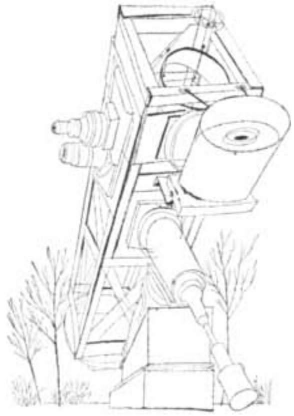
PHILOSOPHY OF MATHEMATICS AND NATURAL SCIENCE, by Hermann Weyl. Princeton University Press ($5.00). A reissue of a rather well-known study of the "interpenetration of scientific and philosophical thought," which first appeared over 20 years ago as part of a German handbook of philosophy. Leaving intact the original essay, which dealt almost exclusively with physics, Weyl has added appendixes on such subjects as quantum mechanics, valence, physics and biology, and evolution. This method of revision does not turn out too happily. It adds nothing to the unity of the main work; the new topics are inordinately difficult, only briefly treated and then not always to full advantage, by reason of the author's involved, academic style. Certainly not for the general reader; nevertheless, a rich and fascinating work by one of the best minds of our day.

THE NATURE-NURTURE CONTROVERSY, by Nicholas Pastore. King's Crown Press, Columbia University ($3.25). Dr. Pastore makes a relatively new and certainly promising approach to this famous debate. To what extent are scientists embroiled in the issue environment versus heredity, affected in their scientific conclusions by social and political preferences? This is the question treated in his book. Its implications of course extend beyond biology and genetics, and the author's discussion is little more than a syllabus of a single method of inquiry. Even so, his data are carefully presented, his conclusions startling, and one looks forward to further studies of the same subject.

THE HISTORY OF PHOTOGRAPHY, by Beaumont Newhall. Museum of Modern Art ($5.00). From Daguerre through Alfred Stieglitz, Weegee and Cecil Beaton, a most readable account of the leaders of the art, their experiments and successes. Mr. Newhall explains the technical side, the development of method and the struggle to win a place for photography in the company of the arts. That the controversy continues is perhaps one of the best proofs of the vitality of photography. Many of the photographs included in this book are familiar, but all of them are superb. One regrets there are not more photographs and, for that matter, that Newhall's story is not longer.

MATHEMATICS DICTIONARY. Edited by Glenn James and Robert C. James. D. Van Nostrand Company ($7.50). In this edition Professor James and his son have enlarged their dictionary by almost half and have obtained the contributions of a number of other specialists in various branches. There have been added, among others, the basic terms of differential geometry, function and group theory, differential equations, integral equations, calculus of variations, analytical mechanics and statistics. Typographical errors appear—fortunately not many—and one may regret certain omissions; nevertheless the revision greatly enhances the value of what was, even in the original edition, a clear, extremely well designed and useful reference work.

THE AMATEUR ASTRONOMER



Conducted by Albert G. Ingalls

BY THE TIME they have made two telescopes most amateur telescope makers develop some secondary interest in optics. While continuing to use their telescopes, they indulge in the side hobbies of making eyepieces, optical flats or any of the wide variety of optical instruments—such as the spectrograph.

One amateur spectrograph maker who uses his spectrograph both for fun and in his work is Robert C. Fairall of Victoria, B. C., a chemist-metallurgist connected with a foundry. Fairall says that he "felt an urge to see whether a grating spectrograph could be made from materials found in the woodshed, scrap box and local stores. At your suggestion," he writes, "I send rough sketches of the spectrograph I made. This instrument gives 'everyday' scientific results. Arc spark, glow tube and solar spectra can be recorded—stellar spectra also if a large enough telescope is available—on motion-picture film in strips about 20 inches long."

From Fairall's shop sketches Roger Hayward has drawn the illustrations on these pages. The lower part of the one on the opposite page depicts the spectrograph in its kite-shaped, fiber-board case, which is about four feet long. The instrument's essential parts and working principle are shown in the upper part of the same illustration, which shows that this conspicuous enveloping case is not the spectrograph itself but only a shell for the auxiliary purposes of holding the essential parts in fixed relationship and excluding light.

The substance to be analyzed is inserted in the electric arc between the carbons, and the arc is struck. The light passes through the narrow slit and reaches a diffraction grating at the rear, which disperses it into a spectrum along the curved negative film. Qualitative analysis is made by comparing the photographed spectral lines with spectral data for known substances. The analysis may be made quantitative by estimating the brightness of the lines.

Today spectrograph analysis is replacing the more familiar chemical analysis because it is quicker and easier, may be done with smaller samples, gives a permanent record and reveals all the metals that are present instead of only the ones that are looked for. Similarly the grating type of spectrograph is crowding back the more conventional prism type, largely because diffraction gratings, which were long scarce because so difficult to make, are becoming more available, while quartz suitable for making prisms is becoming more and more scarce.

In the prism type of spectrograph the light is dispersed to form a spectrum by refraction. In the grating type, dispersion is accomplished by diffraction from a periodic structure consisting of thousands of narrow, closely spaced, equidistant, straight, parallel grooves. The working principle of the diffraction grating is explained in most elementary optical works, for example in *The Principles of Optics*, by A. C. Hardy and F. H. Perrin (McGraw-Hill Book Company, New York). In a coating of aluminum .0001-inch thick, deposited on Pyrex by thermal evaporation, the grooves of the grating are ruled with the fine edge of an artificially shaped diamond, slowly drawn across the surface by a ruling engine, or ruling machine.

Since even small gratings thus painfully made—the engine may work a week on one—cost at least $200, thin casts from these originals in collodion mounted on glass are often substituted. These copies cost roughly 10 per cent as much as original gratings; their usefulness, except on exacting work, is correspondingly greater. They are the "poor man's" grating.

RETURNING to the illustration and following the sequence from the substance under analysis to the spectrogram, the first component of the assembly is the arc light. In the Fairall spectrograph this consists of a pair of spectrographic carbons—ordinary ones are not pure enough—obtainable from laboratory supply houses or from the National Carbon Company, Cleveland, Ohio. These may be supported in any kind of rough home-made stand. The stand has been omitted from the drawing for the sake of clarity. It may consist of a wooden base with simple adjustments for height, inserted in which is a vertical wooden upright carrying two horizontal arms of tin with ends folded around the carbons. These arms are slightly springy, permitting the upper carbon to be pushed into momentary contact with the lower to start the arc, after which smoked glasses should be worn to protect the eyes from ultraviolet radiation.

Traditionally arc spectroscopy calls for five to 15 amperes at 220 volts direct current, used for 10 seconds or more at a time. If this were a real necessity its effect would be to discourage probably 99 per cent of amateur spectroscopists at the outset. Closer investigation reveals that it is one more case of "what would be nice if"—that is, if cost were not an issue, as in some professional laboratories. Instead, 10 amperes at the household 110 volts alternating current can be made to work satisfactorily. To prevent blowing of fuses a resistance may be inserted in series with the arc; for example, one or two electric flatirons. Nichrome-wound heating elements may also be used. Amateurs who can find an ancient direct-current dynamo capable of about one kilowatt at voltages between 50 and 220 will enjoy a few advantages, such as the added fun of experimenting with spectra made by flashed arcs between iron, copper, aluminum, brass, lead, graphite and other electrodes that will not maintain an arc with alternating current.

A little of the substance to be analyzed is ground to a powder and then inserted in a drilled hole or vertical saw-cut in the end of the lower carbon, where it is vaporized in the intense arc; or else a corner of the sample may be inserted directly in the arc. By using a neon-sign transformer with a condenser bridged across its secondary, spark spectra may be obtained. Great caution should be observed because of the danger of serious shock.

Not shown in the drawing is a condensing lens between the arc light and the slit. This focuses the light powerfully on the slit, rendering the spectral lines much more brilliant; its effect is to place the arc in the slit.

The purpose of the vertical sliding diaphragm in front of the slit is to shift the spectrum up or down on the film, permitting comparison spectra of other substances to be recorded beside the one already there. The slit must always be meticulously adjusted parallel to the lines of the grating. Its opening may be perhaps two or three thousandths of an inch.

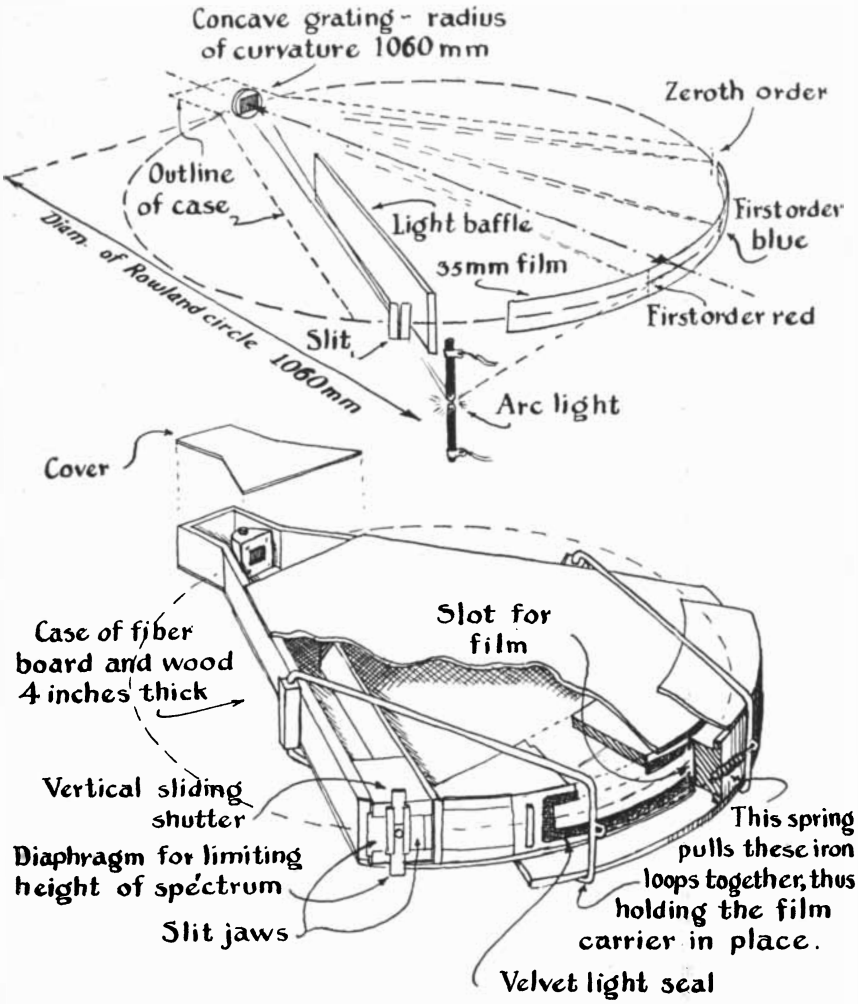
SINCE the grating is ruled on a concave spherical surface, it acts as its own collimator and requires no lenses as in prism spectrographs. The grating used by Fairall is a replica of an A. A. Michelson original with 25,000 lines per inch. It has a radius of curvature of 1,060 millimeters, approximately 41.75 inches, and was obtained for $16 from the Central Scientific Company of Chicago.

As will be seen by comparing the upper and lower parts of the drawing, the essential parts of the spectrograph are arranged on a "Rowland circle." In 1883 the experimental physicist Henry A. Rowland of Johns Hopkins University announced his discovery that if a slit and concave grating are arranged on a circle having a radius half the radius of curvature of the grating, the entire spectrum would be in focus exactly on and around that circle. In the Fairall spectrograph the slit, grating and film remain fixed as in the Paschen-Runge type of mounting.

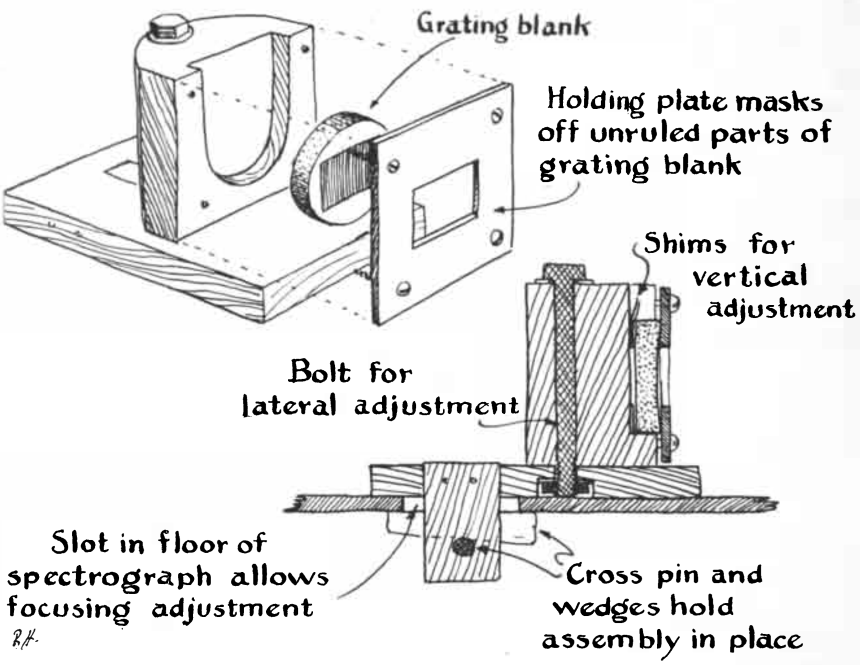
Amateur telescope mirror makers will quickly recognize in a part of the drawing a geometrical identity with the Foucault test setup. The knife-edge would be at the point labeled "zeroth order." The curve of the grating is not coincident with the Rowland circle since it has twice that circle's radius.

Though only one spectral order is used in the Fairall spectrograph, gratings throw several pairs of lateral spectra or higher orders on either side of the central image at "zeroth order." These partly overlap, but the first order is the brightest. Why do gratings throw several spectra? In fact, why do they cast spectra? These questions may send one to an optical treatise for the explanation. The answer in brief is interference, retardation and reinforcement, but the demonstration cannot be presented here. A fair share of the fun in constructing optical apparatus is the insight into optics—an exact and therefore satisfying science—that develops as the scientifically curious worker does a little research reading. A hint, but only a hint, of what is meant by "orders" of grating spectra is given when one looks across a field planted in checkerboard pattern. The median row might then be called the zeroth order; second, third, and even fourth diagonal orders may be seen extending at widening angles on either side of it.

"Prospective constructors of this spectrograph," Fairall writes, "will no doubt make their own modifications of it, such as perhaps to use the remaining orders, substituting a semicircular case." The slit could also be refined to afford automatically parallel motion of the jaws, supplanting the present method of adjustment by gentle tapping with the fingernail. An efficient slit is an interesting challenge to the painstaking mechanic, as is explained in *Amateur Telescope Making*, page 248. The job looks simple, may prove so—and may not. A dark slide could be added to the film carrier. Adjusting facilities, so improved as to be always strain-free, could be provided for the grating. The grating must be so



Robert C. Fairall's homemade spectrograph



A simple slit for the grating spectrograph

placed vertically that the spectrum will fall in the center of the film when the shutter is opposite the center of the slit. Narrower film may be used. The zeroth order can be isolated by a light-baffle to prevent its light from being scattered over the film and reducing contrast.

A useful and simple addition is a lens or telescope eyepiece of about one-inch focal length attached to the side of a long stick near one end of it. The other end of the stick is pivoted at the center of the Rowland circle. As the stick is swung in an arc across a spectrum, prominent lines may be identified visually by their color.

HOW the spectrograph is used in chemical analysis remains to be explained. This is done by measuring certain lines in the spectrum of the unknown substance in relation to lines in known substances, or by direct comparison of the spectra themselves. Fairall constructed a simple spectrum-measuring engine in which the film is wrapped around a drum attached to a large worm wheel rotated gradually by a worm that is turned by a hand wheel. The worm wheel is divided to read in 10-Angstrom units, and the device contains a projector with fine cross-line so that parts of the spectrum under close study can be projected on a screen beside a comparison spectrum or a comparison scale. Another method is to photograph the spectrum of a known material, such as iron, on the spectrogram next to the spectrum of the unknown and to see whether known lines in the latter can be correlated with lines in the former, not only by position or wavelength, but by intensity.

But all this is the ultimate in spectroscopy, and is largely mechanical. There is a less routine, more romantic side to it. When the novice is first given a spectrogram he is aware that it is more than a meaningless row of lines. He knows that each line is characteristic of a molecule or atom that emits it, and that there are precise methods of identifying the corresponding compounds or elements from some 300,000 different spectral lines in extensive tables of standard wavelengths. Yet the worker soon comes to recognize spectra directly by their "faces"—the pattern of the lines. The once meaningless maze of lines resolves itself, just as in a strange city the streets, the buildings and people's faces gradually impress their individuality on a newcomer.

And there is joy in the realization that one has come to understand. What the physician sees in an X-ray photograph that the layman misses, or what he sees in your skin color, vigor, nervous condition and the like even before you have crossed his consulting office to a chair; what the native American sees when watching a baseball or football game that the Tierra del Fuegian misses: the spectroscopist even while still a novice may see in that strip of apparently fortuitous lines, groupings of lines, and spacings—a spectrogram. When you see your old friend Henry approaching, you do not examine him with a caliper and scale and fingerprint equipment, finally saying, "Why, this is Henry!" Similarly you come to know the spectra of many metals at a glance.

The new *Practical Spectroscopy* of G. R. Harrison, C. F. Lord and F. R. Loofbourow (Prentice-Hall, Inc., New York), all of the Massachusetts Institute of Technology, contains a practical chapter on the precise identification of spectral lines and working tables of the main lines encountered in spectroscopy.

Other books contain extensive charts and atlases of spectra.

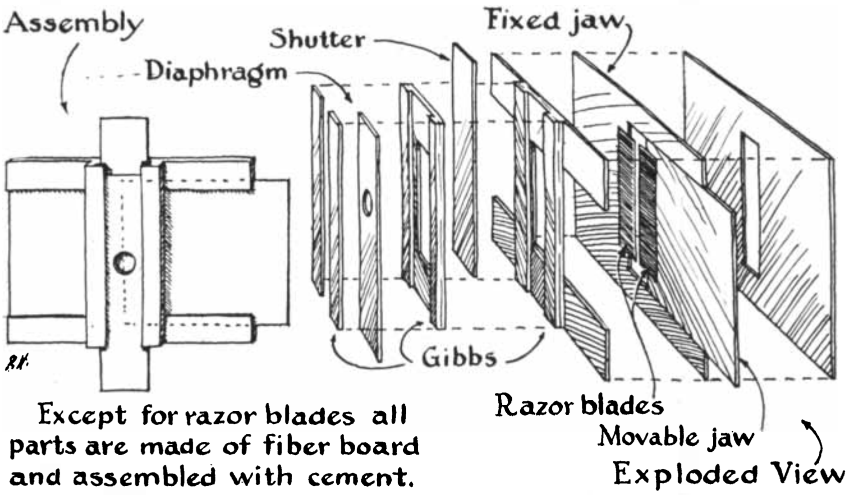
THERE IS a vast literature about spectroscopy, but most of it is too technical for the amateur. Works like the one just named, also the *Chemical Spectroscopy* of Walter Brode (John Wiley and Sons, New York) and the *Experimental Spectroscopy* of Ralph Sawyer (Prentice-Hall), the three basic textbook treatises that are today in print, are partly elementary but partly for the physicist; to this extent they are not ideally suited for the amateur, who has long been forced to do the best he could with what was available. A book has just been published, however, that appears to be the long-sought guide for the amateur spectroscopist. This is the *Manual of Spectroscopy,* by Theodore A. Cutting (Chemical Publishing Company, Brooklyn, N. Y.). This book starts at the level of the average tyro, with the assumption that he will make his own spectrograph; instructions for making prism and grating types are included. At the start he need know practically nothing about spectroscopy. It steers him with direct statements of elementary facts that the authors of treatises for physicists take for granted. By stages it reaches well into advanced practical spectroscopy, dealing with ore, mineral, alloy and inorganic chemical analyses. It includes tabular data on characteristic lines of the elements and an extensive table-chart showing the wavelength spacing of the lines. Such a book, written as it is by a spectroscopist and not by an assembler of potboilers, has been overdue for at least 25 years. It is a book that the amateur can digest without having to piece together fragments that do not fit and without straining at inference to fill the gaps.

ONCE MORE this department has been asked by one of its readers to compile and publish a complete list of possible sources of scratches of the kind that appear mysteriously on optical surfaces while they are being polished. Perennially SOS appeals arrive from "glass pushers" who have reached their wits' end in striving to trace the source of these scratches, and who imagine that diagnosis by mail can show them the cause of their trouble.

No possible list could include all the ordinary and extraordinary sources of scratches, many of which are bizarre. In one instance a dozen beginners, working together in the cellar shop of an advanced amateur and storing their materials between times on a large table, were perplexed for weeks by scratches. They had overlooked the household cat which, put in the cellar at bedtime, prowled the night through over the gritty floor and then over their work.

If half of the scratches may be traced to specific sources, another half will disappear with experience in ways that may never be noticed. The worker, though not too conscious of his new ways, has nevertheless come of age optically.

From a former amateur, now a professional, recently came the statement that in 1949 he produced optics without any scratches at all from thousands of dollars' worth of glass. Another former amateur who has worked professionally recently described conditions where workers tracked coarse grit everywhere, dropped cigarette ashes in the work, changed aprons rarely and were seemingly utterly careless. Yet scratches came to them less frequently than to another who sealed the windows with Scotch tape and created conditions equaling the asepsis of a surgeon's operating theater. He adds, however, lest this be misunderstood by the tyro, "Don't try it. It is studied carelessness. Use reasonable care, but even then, scratches are where you find them. First come conscious efforts to avoid scratches, later greater speed and proficiency and fewer scratches in inverse proportion, and finally, nonchalance. I suppose one then exercises ordinary common-sense care unconsciously."



Details for mounting a spectograph grating

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