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BUSINESS IN MOTION

To our Colleagues in American Business . . .

For many years Revere has been saying that "Copper is the metal of invention." Its numerous qualities, such as high electrical and heat conductivity, resistance to corrosion, easy fabrication into even the most complicated shapes, formability by hand with simple tools, make it attractive to designers and inventors, as well as to manufacturers. Now we would like to add that "Copper is the metal of science," because it is so essential to the operation of the most modern scientific devices.

Take the case of a cyclotron being built by a great Western university for special studies of the atom. The construction of this machine offers an unusual example of the use of copper not only in invention and science, but also education. An essential part of the project was the utilization of the university's own personnel, so far as possible, not only in design, but in construction and assembly. A large group of staff members, engineers, research assistants, electronic technicians, and machinists was formed. Included among the personnel were graduates and graduate students in physics.

The first major undertaking of the cyclotron group was the winding of the seven miles of Copper Bus Bar, supplied by Revere in soft temper, free from scale, rounded edges, to form the great coils for the electromagnet. The necessary winding machine for this work was built in the university shops, largely of surplus materials. It took four months to complete the coils and test each silver-brazed joint. Another important part of the cyclotron was shaped in the shop out of copper sheet, 4,000 pounds of it; the work on this is a story in itself. The heaviest part naturally is the special alloy steel core, weighing about 200 tons, forged in six pieces. Pole faces were machined parallel to a tolerance of 2½ thousandths of an inch, an excellent record on a piece of steel of such a large diameter (over five feet) as is required for the instrument. It is calculated that the magnetic force of attraction between the two poles will reach 160 tons when the current is flowing through the copper coils. We have spoken of copper's high electrical conductivity; another way to express it is that copper has low electrical resistance. The total resistance of the seven miles of Revere Copper in the coils is only one ohm, or less than a hundredth of the resistance of the glowing tungsten wire in a 100-watt light bulb. Tungsten has high resistance, which is why it becomes white hot; copper has low resistance or high conductivity, so that it can carry large amounts of power with minimum loss, little heating.

Eventually this cyclotron will add to man's knowledge of the atom. In the meantime, it has been a project of high educational value, and also an economical one; use of the university's own personnel and facilities cut the cost approximately in half. Revere is glad that it was asked to meet the high specifications drawn up for the copper, but it should also be recognized that many other firms supplied materials, such as the steel company, the makers of insulating paper and plastics, of cement, motor generators, electron tubes, and so on. Demands such as these for high quality demonstrate that American industry can meet challenges. So Revere suggests that the more complex and severe your requirements, no matter what the end product is to be, the more advisable it is for you to draw upon the knowledge and experience of suppliers. They can help not only on something as simple as a shoe, but on complicated machines, like an airplane—or an atom-smasher.

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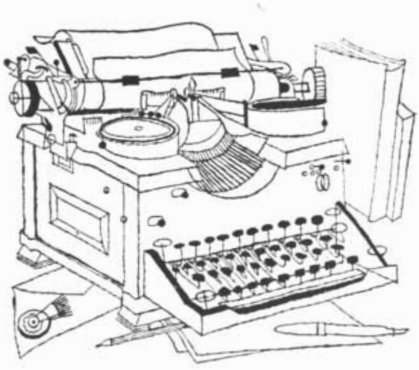

LETTERS

Sirs:

In your interesting December article "Fine Particles" the explanation of the blue color of the sky might be misleading. It can create the impression that here, too, particles are involved which are the main subject of your article: those between one fifth of a micron and 250 microns in diameter.

The theory of Rayleigh assumes that the scattering particles are much smaller than the wavelength of light. The particles causing the blueness of the sky are the air molecules, about 2 Angstrom units in diameter (2×10^{-4} microns). One might say that the purest air is blue.

SAUL LEVY

Gary, Ind.

Sirs:

The very interesting article on "Fine Particles" by Clyde Orr, Jr., in your December, 1950, issue calls for comment on one point. He says: "Were it not for them [the fine particles in the atmosphere] the sky would be black, not blue." Actually, we should have to lose not only the particles in the atmosphere but the atmosphere itself before the sky turned black. The theory of light-scattering developed by Lord Rayleigh applies to all atoms and molecules no matter how small; and the blue color of the sky is actually due primarily to the molecules of oxygen, nitrogen and the other gases of the atmosphere. This was conclusively demonstrated as far back as 1914 by the distinguished French physicist Jean Cabannes. He admitted sunlight into a darkened container filled with dust-free air, and observed the light scattered at right angles to the incident beam, taking extreme precautions to eliminate stray light and reflections of every sort. The faint scattered light which he observed had the same color and spectral distribution as the blue light of the sky, and his calculations showed that the intensity of the light in proportion to the number of molecules present was quantitatively great enough to account for the natural blue of the atmosphere and the number of molecules in it. This work was later described by Cabannes in his book *La Diffusion Moleculaire de la Lumière*; a good brief summary of his results has also been given by R. W. Wood in the third edition of his *Physical Optics*. All later work confirms the validity of the conclusions reached by Cabannes.

Actually the presence of fine particles in the atmosphere tends generally to diminish the purity of the blue color of the sky, giving it more a tone of white, gray, red or yellow. In general, the cleaner the air, the purer the blue color. This is quite natural. The laws established by Rayleigh showed that particles very small compared with the wavelength of the light must scatter with an intensity inversely proportional to the fourth power of the wavelength. Hence the blue end of the spectrum contributes far more than the red, if the particles are small and only scatter light without absorbing it. Larger particles give not only a much greater total intensity of scattering but also a relatively larger amount of scattering at long wavelengths as compared with very small particles or molecules. Hence the change in color of the scattered light with increasing particle size—a phenomenon observed by Tyndall in his classical studies of light-scattering which originally led to the theoretical investigations by Rayleigh.

JOHN T. EDSALL

Harvard University
Cambridge, Mass.

Sirs:

In his review of *Security, Loyalty and Science*, by Walter Gellhorn, I. I. Rabi

Scientific American, March, 1951, Vol. 184, No. 3. Published monthly by Scientific American, Inc., 24 West 40th Street, New York 18, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York, N. Y., Post Office as second-class matter June 28, 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

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

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raises in your January issue a most relevant question, which is more than can be said for Gellhorn's book. During World War II, says Dr. Rabi, the scientists "spontaneously rose to join the defense effort. . . . A nice and informed balance was maintained" between the recognized need for secrecy and "successful progress with the job." The relations between the scientists and the government or the military he describes as constituting "an enviable record." But then came the postwar period and all this was changed. Today conditions exist of the kind described in Professor Gellhorn's book, which means that there is avowed distrust of the scientist, F.B.I. investigations, Loyalty Board hearings, accusations by invisible accusers, petty suspicions resulting from relatives who read suspect journals or previous subscriptions to "liberal" weeklies, and similar symptoms of hysteria, stupidity and reaction, all of which suit a democracy very ill. Incidentally, the reader of Professor Gellhorn's book cannot help but gain the impression that surely Nazi Germany or Soviet Russia could not have had worse stupidity and oppression than the U. S., but if anything were more sensible than our Fair Deal democracy, since they were better organized. . . .

There can be no doubt that Dr. Rabi's statement of the problem is fair and unbiased. Unlike Professor Gellhorn he indicates that he is aware of the several problems involved in security and the need for secrecy. Moreover, he poses the very vital question "Why the sudden change since 1941?" when none of these disturbing problems existed. Professor Gellhorn is too narrow-minded or blinded to even see that there is a question to be asked. Moreover, he does not discuss a single term cited in his title. And surely there is much to be said about security, its technique, needs, excesses, its price and virtue. There is much to be said about loyalty, about the lesson of the Canadian spy trials, the psychological roads to disloyalty, the type of people easily victimized by its allure, the kind of allure prevalent nowadays, favorable conditions for its occurrence, etc. All this goes unnoted. Nor is there a word in the book about science and its role in modern disloyalty or about the forces of devotion and frustration in modern scientists. The book is a typical medieval sample of Aristotelian, or syllogistic, reasoning. Why bother about cases, examples or data if you are able to demolish your enemy, the hated Administration or the idiots in Washington with a legalistic quibble here or a fable or parable there.

Dr. Rabi, on the other hand, indicates in a few paragraphs penetrating insight into many aspects of the problem and poses the basic question: "Why the sudden change in attitude toward the scientist?" Permit me to point out that the answer need not be that the change is due to the American people or to a sudden change in the Administration of their choice, but that the causes of the change reside in the scientists. It is my contention that a large number of the physicists, especially the vociferous ones, are not friendly but are hostile or indifferent to the nation's armament program today, while in 1940 they were by and large enthusiastically for the war against Hitler.

There was a similar group in America in 1940, but they were insignificant in number. Those were people like Lindbergh, Senator Wheeler, outright isolationists, members of the German-American Bund, a few people of German origin who were not convinced the Nazis were as bad as they were painted, some people who sympathized with Hitler because they were anti-Semitic, and some others who had their own motivation for being lukewarm to lend-lease or intervention, or even hostile to such measures. Those were the people who in 1940-41 gave the following arguments: We want peace; if we interfere in the internal affairs of other countries we will get involved in war. Who are we to be God's policemen? Look what we are doing to the Negroes and how we treated the Indians or the Mexicans. We have far to go to improve our own conduct before we improve the world. Why pull England's chestnuts out of the fire? This is a Wall Street plot to get us into a war for their profits or for cheap labor since wars are only fought for such goals, and why should Americans always be suckers? . . .

These same arguments with respective changes to suit the situation are now being presented to us by the Communists of today, by some isolationist groups or by fellow-travelers. They are also repeated by others who, because of the deep penetration into our lives and thoughts of the folklore of radicalism, find it very easy to employ similar arguments against our baffled and tragically hesitant road to the realization that Stalin and his Communist class-struggle philosophy really mean business; and that the Soviets are out to destroy capitalism and its American stronghold because they believe that it must be done if the cause of all evil is to be effectively eradicated. They feel the time is now, since America is weak militarily and the Communist countries are making headway. Right after World War II the Administration simply would not hear that such were the intentions of the Politburo. Now Mr. Acheson is willing to turn his back on Soviet deception, aggression and disregard of treaties. But whatever the Administration fails to do or learn and whatever weak measures it does adopt matter little to the contemporary Lindberghs, Wheelers or Fritz Kuhns. They will go on sniping at Washington and abusing the Administration, no matter whether we crawl in abject appeasement or make a feeble feint at armament. . . .

Why many scientists should be so sorely frustrated as to embrace philosophies of violent hate and resentment, or why they should need outlets for uncompromising hostility to existing conditions or their government, and why they should show so much lack of faith in democracy, these are worthy matters for consideration elsewhere. For the moment let us recognize the fact and establish its depth, dimensions and its effects on our government, the people, rearmament and survival.

MARK GRAUBARD

Department of Physics
University of Minnesota
Minneapolis, Minn.

Sirs:

I should like to refer to the brief item "Hazards of the Stratosphere" in your December issue. The item described the findings reported in "Evaluation of Present Day Knowledge of Cosmic Radiation at Extreme Altitude in Terms of the Hazard to Health," an article by Hermann J. Schaefer in the October issue of *The Journal of Aviation Medicine*. . . .

Data collected by R. A. Millikan (*Physical Review* 61, 299, 1944), using an ionization chamber which measured all of the ionizing radiation, gave a maximum of 480 ions per cubic centimeter per second per atmosphere at 80,000 feet. Data from other experiments such as rocket flights and higher balloon flights indicate that the maximum ionization occurs at 80,000 feet and for higher altitudes the ionization drops to a much lower value. This maximum intensity of ionization from the cosmic radiation is less than one half of the accepted American tolerance dose of .3 roentgen per week. From these considerations, an exposure at 80,000 feet for a continuous period of one year (which is highly improbable) would accumulate a total dosage of 7.3 roentgens. The dose for X-ray fluoroscopy is about 15 to 25 roentgens per minute, usually for less than five minutes.

There is as yet no direct evidence that an appreciable biological hazard exists due to the cosmic radiation. In view of the many considerations, some of which have been given above, such a hazard seems unlikely. It must be remembered that the total energy in cosmic radiation is of the same order as that in starlight, and your point that "the fliers would not necessarily be killed," is a masterpiece of understatement.

M. S. JONES, JR.
LIEUT. (J.G.), U.S.N.

Office of Naval Research
Washington, D.C.

HI-EFFICIENCY DICHROIC MIRRORS OR FILTERS?

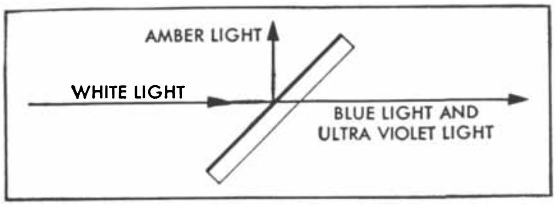


Diagram of typical 45° use of a Liberty Hi-Efficiency dichroic mirror. Such mirrors and filters frequently are used at approximately this angle.

With white light illumination the two separated beams are complementary. With gas discharge tubes or phosphor light sources the two separated beams may be utilized to isolate certain portions of the spectrum of the illumination source.

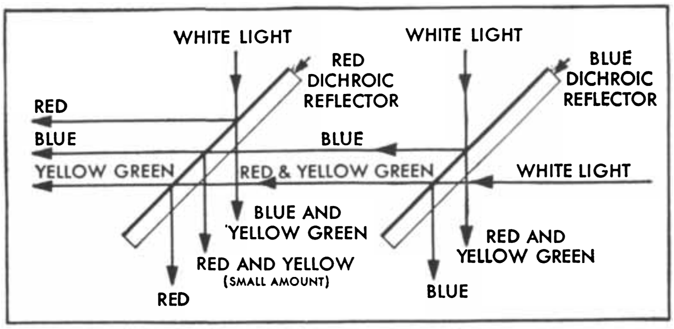
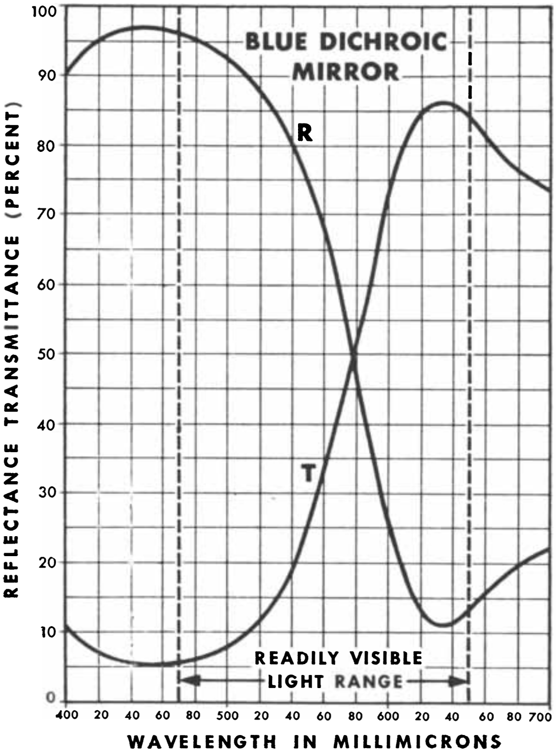


Diagram of typical result obtained by the use of two Liberty Hi-Efficiency dichroic mirrors.



At the left, is the spectrophotometric curve of a Liberty blue-reflecting dichroic mirror recorded at substantially normal incidence. Customer's specification called for peak reflection at 450 millimicrons; our designation for the resultant mirror is 90-450, indicating the approximate reflectivity at the approximate peak.

Comparison of the reflection and transmission curves shows the almost complete absence of light absorption. All Liberty Hi-Efficiency dichroic mirrors and filters possess little or no light absorption.

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Liberty Hi-Efficiency dichroic filters possess rather sharp bands. However, these bands are not as sharp as the well-known "interference filters", and are not intended to replace them. Liberty Hi-Efficiency dichroic filters find application where high selective transmission is the determining requirement.

Liberty dichroic filters are made by coating commercial plate glass or optically ground and polished glass, as the use requires. Such construction has apparent advantages for certain applications, as compared with the use of colored glass filters. It completely eliminates the problems arising from defects such as are common in specially made colored glasses, particularly in large sizes. Further, such special colored glasses are not always readily available, and frequently must be made up on special order. In contrast, Liberty Hi-Efficiency dichroic filters are quickly available, with prompt delivery of uniform production lots—and color characteristics are independent of the thickness of the glass support.

Liberty Hi-Efficiency dichroic mirrors and filters are made in standard production sizes up to 20″ x 30″; larger sizes available on special order.

In making inquiry for dichroic mirrors and filters, please specify approximate reflection peak desired, as well as transmission characteristics intended, angle of use and type of light source.

If a phosphor light source is used, please give number or spectral character of the phosphor. Information as to types of sensing elements and their spectral responses also is helpful.

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50 AND 100 YEARS AGO

MARCH 1901. "Prof. R. T. Fessenden, of the United States Weather Bureau, is making experiments with wireless telegraphy on the Southern coast. Stations will be established at Capes Hatteras and Henry and at other coast points north of Cape Hatteras. It is the government's intention to communicate storm warnings to vessels at sea off this dangerous locality. It is also intended to send storm signals to life-saving stations when the wires are disabled. If the tests are successful, the entire coast will be similarly equipped."

"We have before us the full and authentic report of the proceedings of the Pan-American Medical Congress held in Havana, the most important subject of which was the presentation and discussion of the report of the special yellow-fever commission. Summarized, this report is as follows: Yellow fever cannot be communicated by contact with the patient or with the clothes or other articles worn by a patient before and during the course of the disease, although they may be impregnated with the excretion of the body. The disease is therefore not contagious. Yellow fever is communicated, however, by the bite of a particular kind of mosquito that has previously bitten a yellow-fever patient during the first two days of the attack. It takes 12 days for the specific poison to develop in the mosquito. The report concludes: 'While the mode of propagation of yellow fever has now been definitely determined, the specific cause of this disease remains to be discovered.' "

"The population living in cities and towns of 8,000 or more was 3.35 per cent of the total in 1790, 12.49 in 1850, 22.57 in 1880, 29.20 in 1890, and perhaps is about 35 per cent at the present time, or more than one third of the entire population."

"New York was only commencing in 1891 to erect at the southern end of Manhattan Island those towering structures which today render this portion of the city one of the most marvelous spectacles in the world. It has been found, however, that the space occupied by elevators becomes so great when a building exceeds a certain number of stories in height as to reduce very seriously the available office floor space, and by common consent it seems now to be agreed that the limit of economic height lies somewhere between 16 and 20 stories."

"A sensation has been produced in the realm of stellar science by the recent discovery of a temporary star whose brightness exceeds that of any other object of that class which has been observed in the last three centuries. It is necessary to go back to the famous outburst observed by Tycho Brahe in 1572 to find with certainty one which surpassed this in brightness."

"Rome will soon be connected with Paris by a telephone line. The work has been in progress for many months, and it is thought that communication between the two cities will be accomplished during the summer."

"For many years the attention of inventors has been directed to the question of utilizing the direct rays of the sun as a substitute for coal, wood, or other fuel; large burning glasses or reflectors being the general form of the various machines. It is interesting to note that in South Pasadena, Calif., such a machine has been set up and is successfully accomplishing the work for which it was made—a motor running by the heat of the sun. The inner surface is made up of 1,788 small mirrors, all arranged so that they concentrate the sun upon the central or focal point. Here is suspended the boiler, which holds 100 gallons of water. Up to the present time the motor has produced results equal to about 10 horsepower."

"Prof. Loeb's experiments in artificial parthenogenesis are most interesting. He has been able to develop eggs of Chaetopterus, an annelid, into free-swimming larvae by placing them in solutions which cause them to lose water. Potassium chloride solutions and hydrochloric acid when added to the sea water have been found effective in causing the eggs to develop. The artificially developed larvae did not differ from those produced by natural fertilization."

MARCH 1851. "A Dr. William Turner, of New York City, has petitioned the Legislature of the State to pass a law making the use of the lancet in diseases a penal offense. He says he has practiced medicine for half a century, and his experience convinces him that the habit of bleeding is destructive of health and life. We may put down Dr. Turner as a very bold member of the profession."

"The population of the United States now amounts to 20,067,720 free persons, and 2,077,034 slaves."

"In connection with light and photography, there is still a difference of opinion among philosophers respecting light as a distinct matter of itself. Some at once say, 'light is an imponderable subtle fluid, or matter of itself'; others more cautious say, 'light is conveyed to us by vibrations,' and this is all the length they go, but afford no very good argument even for this theory."

"John Wise, Esq., of Lancaster, Pa., is engaged in constructing another monster balloon, to be about three times as large as the *Hercules,* used last summer, with which he intends to prove the certainty of his ability to cross the Atlantic and circumnavigate the globe."

"The Philadelphia Academy of Natural Sciences has now a library of 12,000 volumes. In its herbarium there are about 35,000 species of plants arranged according to the natural system. Its collection of birds is probably not excelled by any in the whole world. This institution originated in an agreement made by a few gentlemen, in 1812, to meet at their respective residences in town, once a week, for the purpose of receiving and imparting information on subjects connected with natural history. At the present time the Academy numbers about 200 resident members, and more than 500 correspondents in every part of the globe."

"Captain Wilkes, of the United States Exploring Expedition to the Antarctic Seas, has just received an elegant gold medal from the British Government, as an acknowledgment that he was the true discoverer of a disputed continent, from which he saw the volcanic fires bursting from a land of ice and snow, and pouring their lava down the eternal barriers of the frozen mountains."

"*Scientific American* is now in its sixth volume, and from a small beginning it has attained to the extensive circulation of 16,000 copies weekly."

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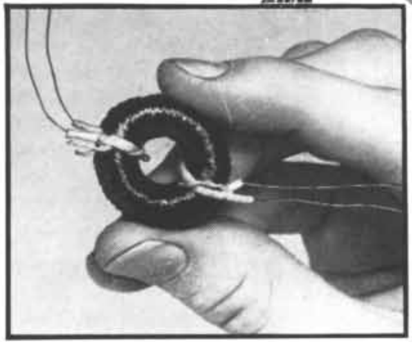

Twenty of the Bell System's newest small loading coils—like the one at the left—are housed in the long black case, mounted in a cable splice. This type of installation permits the economical extension of city cables to serve out-of-town subscribers.

MANY more wires can be crowded into a cable sheath when the wires are fine. But normally, wires don't transmit as well when they are fine and closely packed.

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The 15,000,000 coils in the Bell System today mean thinner wires, more wires in a cable—more economical service for you. They demonstrate once more how Bell Telephone Laboratories work continually to add to your telephone's value.

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THE COVER

The painting on the cover shows two means of separating a mixture into its constituents by the method of chromatography (*see page* 35). Suspended at the lower left is a cluster of spinach leaves. At the right is a glass tube partly filled with a white adsorbent. To separate certain pigments of spinach leaves with the aid of chromatography, the leaves are first extracted with a solvent. The extract is then added to the top of the column and allowed to drain into it. When fresh solvent is percolated through the column, the pigments in the extract separate into colored zones. Hanging in the background is a sheet of paper that has been used in a variation of this process. If a mixture of amino acids is placed on the paper and a solvent is allowed to travel down it, each amino acid will be carried a different distance. After the paper chromatogram is completed, the normally colorless amino acids are made visible by spraying them with the reagent ninhydrin. For their help in the preparation of the painting SCIENTIFIC AMERICAN is indebted to Werner Hausmann of the Rockefeller Institute for Medical Research and Robert L. Peck of Merck & Co., Inc.

THE ILLUSTRATIONS

Cover by Stanley Meltzoff

Page	Source
17	Adolph Brotman
18	Adolph Brotman, from the *Epitome* of *De Humani Corporis Fabrica,* by Andreas Vesalius
20	K. Chester, courtesy of the Chilcott Laboratories Division of the Maltine Company
22-26	Irving Geis
36	Adolph Brotman
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39	Donald Moss
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43	Courtesy The Metropolitan Museum of Art
45-46	Courtesy Gregory Pincus
48-50	Adolph Brotman
57-60	Irving Geis
68-70	Roger Hayward

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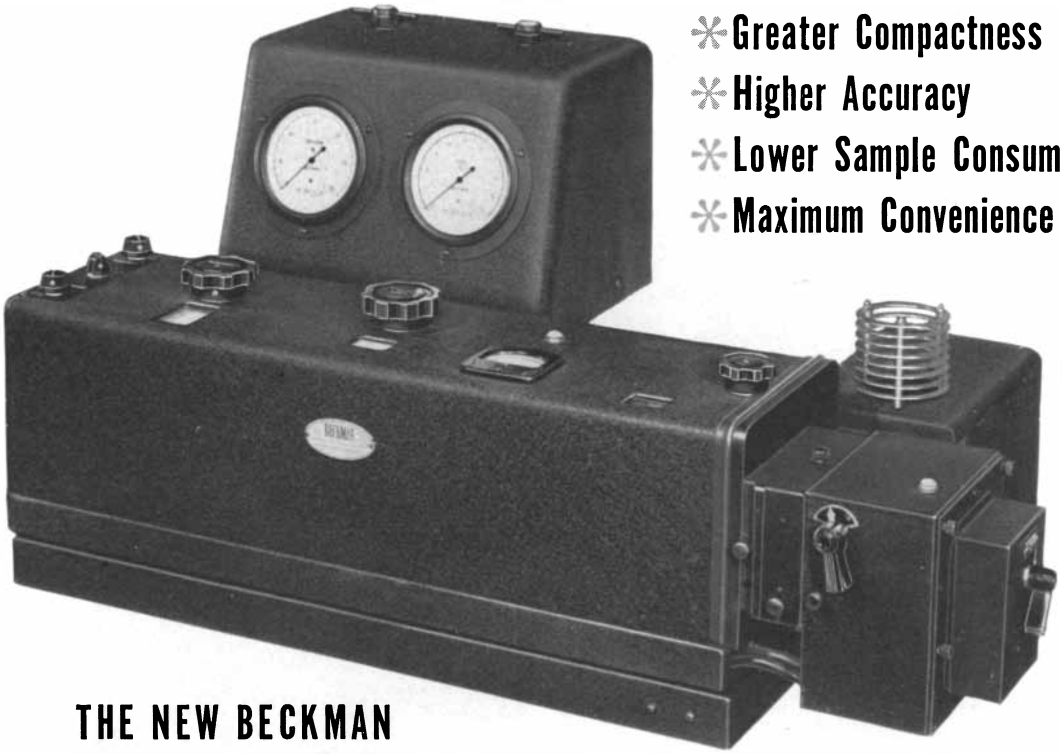

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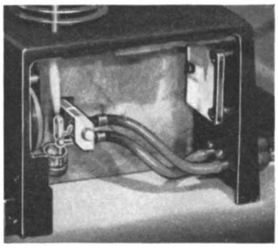

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- The hot flame, coupled with the high resolution of the "DU" Spectrophotometer, permits unusually narrow band widths to be used—less than 10 millimicrons for most determinations—permits accuracies of 0.5% or better.
- Sample concentration is unimportant (provided it is above the lower detectable limit) permitting maximum versatility and convenience in making analyses.
- Although the sensitivity of most elements is improved when the elements are in water solution, non-aqueous solutions are as easily handled as water. Even combustible solvents can be used—and in fact, organic solvents frequently increase sensitivity of the readings.
- The atomizer-burner, sample-positioning device, focusing mirror and adjustments are all unitized into a compact, cast-metal housing. All necessary regulators and gauges (except standard regulators on fuel and oxygen tanks) are conveniently mounted on a separate control panel.

Write for complete details on this important new Beckman advancement!

WANTED:

men who look at their products and ask "WHY?"

Like this auto manufacturer. Aluminum permanent mold clutch housings had been saving him 10% over cast iron. "Could we save still more," he asked, "if you supplied us die castings?"

"It's possible," we agreed. But . . . the clutch housing also acts as the engine mounting. Supporting half the engine's weight, it is highly stressed, must absorb vibration. Could a die casting economically be made that strong?

An Alcoa Development Program was started. We worked with the auto maker to draw up designs. From the die casting alloys developed and tested by Alcoa's Research Laboratories, we selected our strongest die casting alloy. We poured *sand castings* from it; then machined them to the dimensions of the die casting design.

Shear static loads and bending stresses were measured on Alcoa's big Baldwin-Southwark machine. Brittle lacquer and strain gauges showed us stress concentrations. Sample castings were assembled on an engine and transmission in Alcoa's Motor Laboratories; then run with unbalanced weights on the shaft to measure dynamic stresses.

With these test results, the auto maker worked with us to modify designs. Die casting dies were built. While we repeated the lab tests, the manufacturer made actual road tests. The *first* stressed automotive die casting is a success. 25% stronger in shear, 10% stronger in bending, 100% better in fatigue life than the permanent mold casting. It weighs only ¼ as much as the original cast iron housing.

The fact that *it is also 15% lower in cost* demonstrates that, from an economic as well as a performance standpoint, it pays to ask "Why?"

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ALCOA

For more details on the personnel, research and testing, and shop facilities available at Alcoa, write for your copy of the folder, "Road Map to a Better Product". It is your first step toward putting 63 years of aluminum knowledge to work on a long-term project that may effect a major change in your company's competitive position. Address ALUMINUM COMPANY OF AMERICA, 2182C Gulf Bldg., Pittsburgh 19, Pa.

What GENERAL ELECTRIC People Are Saying

F. R. ELLENBERGER

Air Conditioning Department

HEAT PUMP: The trend toward complete year-round air conditioning of residences as well as larger buildings has focused increased attention on the heat pump. Since 1932, when the residential heat pump was first being investigated in this country, 750 heat pumps have been installed in the United States; 60 per cent of the installations are in residences and 40 per cent are commercial. Heat pumps are currently being installed at the rate of approximately ten per week...

The functions of year-round air conditioning provided by heat pumps include heating in winter, cooling and drying in summer, air filtering, circulation, and ventilation. These functions are accomplished electrically, under automatic control, without combustion, and without fuel in the ordinary sense.

The basic principle is the same as is used in a common electrically operated refrigerator. A simple illustration of its operation can be obtained by imagining that a refrigerator with its door removed is placed against an open window. Then heat removed from the outdoor air by the refrigerator evaporator is dissipated from the condenser into the house. For cooling, the refrigerator could be placed outside the house against the same open window. Then heat removed by the evaporator would be pumped outdoors. Of course the domestic refrigerator is not designed for this application; its capacity would be much too small, and its operating economy for this type of operation would be low. . . .

Although it is still early to obtain a clear-cut picture of what the future holds for the heat pump, it appears to be entering a period of rapid growth, and heat pumps for year-round air conditioning in homes and other buildings will be appearing in greatly increasing numbers. . . .

It is sometimes refreshing, even if premature, to exercise the imagination by looking further into the future. In one conception of a "dream" version heat pump, the heat pump is combined with some of the multitudinous equipment which our living standards demand in a single factory-produced package. Such a unit would serve as a complete utility core for the house and would provide a source of hot and cold water, conditioned air the year round, and heating and cooling for the associated appliances. Heat that is pumped from the freezing and cold storage compartments would be used to help heat the air and domestic water. Heat that is otherwise wasted in the kitchen exhaust and for evaporating moisture in clothes drying could be largely recovered. The heat pump, thereby, may serve some day as the central unit of the all-electric home.

General Electric Review
December, 1950

★

R. F. SHEA

Electronics Department

ELECTRONIC UMPIRE: The electronic umpire arose out of a definite need for a device to assist pitchers and batters in learning control and judgment. Other devices were in use or had been tried out for such purposes, but they either interfered with a batter's swing or were bulky and not easily transportable.

In addition to being able to call strikes, it was thought desirable to add speed measurement to the device, thus permitting a reasonably accurate appraisal of a pitcher's ability in terms of speed and control.

The electronic umpire is a portable two-unit device which can be set up in a matter of minutes anywhere where there is an a-c supply available. One unit is placed on the ground and carries a simulation of the home plate. Alternatively, it may be set flush with the surface of the ground. The other unit may be located anywhere within a radius of 25 feet from the ground unit and provides an indication when a ball has passed through the strike zone, and an indication of its speed.

No lights or equipment other than the two units described are required. The strike zone is adjustable to suit batters ranging in height from five feet one inch to six feet five inches and speed in excess of 50 feet per second may be measured to an accuracy of 5 per cent.

National Electronics Conference
Chicago, Illinois
September 25, 1950

★

BERNARD VONNEGUT

Research Laboratory

RAINMAKING: Many farmers, ranchers, and civic-minded people in many parts of the country are now engaged in cloud seeding. In their efforts to produce more rain, these amateurs are releasing large quantities of seeding material which may well contaminate the atmosphere so as to hopelessly confuse the more careful experimenter and precipitation analyst.

The experiments of many of these rainmakers are carelessly carried out with little or no control over the dispersal of the seeding agent and are, for the most part, unrecorded. As a result, experiments of this sort contribute little or nothing to the knowledge of seeding techniques, while at the same time they may render valueless far more painstaking experiments carried out at the same time nearby. These rainmakers can seriously impede the progress of this new phase of meteorological science.

New England Assn. of Chemistry Teachers; Storrs, Connecticut
August 25, 1950

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DEPARTMENTS

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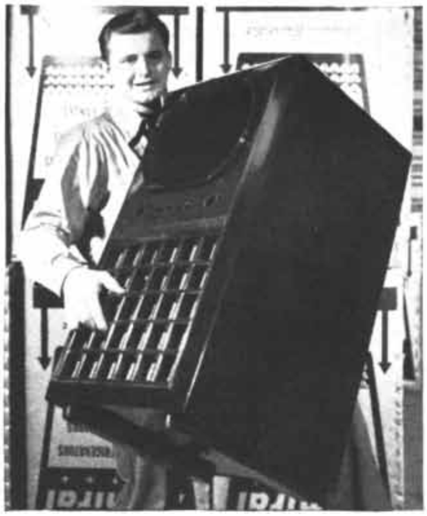
What's New at CRUCIBLE

about plastic mold steels



Cabinet for Admiral TV Console
Height: 34″
Width: 18″
Depth: 18¾″
Weight: 40 lbs.

two plastic TV console cabinets every five minutes for Admiral

Admiral (big name in radio, television, and electronics), Molded Products Corporation (pioneers in plastic molding), and Crucible (first name in special purpose steels), teamed up to produce sturdy, durable, economical TV cabinets. Admiral wanted TV console cabinets that not only would stand up under wear, but be mass-produced as well. Molded Products called on Crucible to provide the steel for the mold assembly.

a Crucible Plastic CSM2 Mold Steel forging that weighs 9300 pounds

The initial development was put into operation two years ago, but recently Admiral wanted an even larger cabinet. As in the first mold assembly, Crucible metallurgists recommended Plastic CSM2 Mold Steel. The large cavity section of the 16,000-pound mold assembly required a mold steel forging that measured 41″x54″x20″ . . . and weighed 9300 pounds. This is one of the largest tool steel forgings ever made!

Two molds were built so that the 2500-ton hydraulic press could form two cabinets every five minutes.

The illustrations serve to show the size of the hydraulic press, the action of the plunger on the cavity, and the quality of the finished product. Compression molding as performed in the mold assembly is applied to a 40-pound plastic charge in each section of the cavity. The cabinet is molded in one piece including center shelving to support the television chassis. The power supply rests on the bottom of the cabinet. The speaker grille is integrally molded. Cored-in openings for the television window and controls, as well as cored studs for mounting are all part of this one operation.

8-ton mold assembly in action

It is a credit to Crucible Plastic CSM2 Mold Steel that this forging working around-the-clock has shown little wear . . . and maintained durable, uniform cabinets with few rejects.

Preparing for 40 lb. plastic charge. This is Crucible's 9300-lb. CSM2 forging.

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Our metallurgists can help you apply Crucible plastic mold steels to your requirements. Write for literature. Crucible Steel Company of America, Chrysler Building, New York 17, N. Y.

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SCIENTIFIC AMERICAN

MARCH 1951 VOL. 184, NO. 3

Operations Research

It is the application of scientific method to broad problems in war, government and business. First developed by the British during World War II, it is now beginning to flower in the U. S.

by Horace C. Levinson and Arthur A. Brown

WORLD WAR II developed a new military use of science, christened operations research (in the U. S.) or operational research (in Britain). Unlike all previous applications of science to warfare, which were concerned almost entirely with the development of weapons, operations research is concerned with the use of weapons. Its province is the tactical and strategical aspects of military operations: it deals with methods of locating enemy submarines, for example, rather than with the technology of the torpedo or the bomb. What it does is to apply scientific method, including mathematical techniques, to the analysis of situations and of the efficiency of various systems of organization for coping with them.

Obviously this approach can be applied to business and governmental organizations just as well as to military ones, and since the war it has been used fruitfully to solve some business and industrial problems. In Britain the Government has made considerable use of it, and workers in the field have formed an Operational Research Club. In the U. S. there is now a Committee on Operations Research, organized by the National Research Council to further the development and use of operations research for nonmilitary purposes. Since 1948 a course on nonmilitary uses of it has been given at the Massachusetts Institute of Technology in collaboration with the Navy. On the military side, the Army, the Navy, the Air Force and the Joint Chiefs of Staff all have operations research organizations.

OPERATIONS research was born in the Battle of Britain. The British Government was exploring every available means to defend the country against the disastrous German bombings. The British had a skillful but small air force and they had radar. Could radar make up for the smallness of the Royal Air Force? How could the radar interception system be used to maximum advantage; how should the antennas be distributed, the signals organized, and so on? The Government called in half a dozen scientists of various disciplines to answer these questions. By collecting the relevant facts and analyzing them with the general methodology of science, these men devised a new operating technique that doubled the effectiveness of the air defense system.

Impressed with this spectacular success, Britain organized similar teams to tackle many other military problems. The U. S. armed forces likewise put operations research groups to work soon after this nation entered the war. The work of these teams in both countries paid high dividends in deciding such questions as the most effective altitudes at which planes should fly in hunting submarines, the best payload division between fuel, instruments and armament, the best search pattern. One short operations research study showed that planes attacking submarines could increase their effectiveness fivefold by changing the depth at which depth charges were set to go off. In the famous Allied anti-submarine campaign in the Bay of Biscay, British and U. S. operations research teams working together designed a patrol system which succeeded in sighting practically every submarine that came in or out of the Bay and sank about a quarter of those it attacked.

Operations research can handle very diverse problems, but to be eligible for solution the problem must satisfy two conditions: 1) it must be expressible in numbers or quantities, and 2) the data must be adaptable to the available techniques. If the data are statistical, for example, they must come from operations that are roughly similar and must be extensive enough to permit some sort of statistical regularity or law to show itself. Let us consider a couple of actual military examples.

Early in the war it was the conventional military view that in an airplane squadron it was most important to have as many planes as possible in fit condition to take to the air at all times. The RAF had set as a standard that no less than 70 per cent of a squadron's planes should be fit to fly; this percentage was called the maintenance efficiency. Since it was very difficult to keep up to this standard, the problem was given for study to Cecil Gordon, a member of an operations research team.

Gordon took a completely fresh approach. He was a biologist, and he decided there was a usable analogy between the life cycles of human beings and of aircraft. Flying, he reasoned, breeds disrepair and the necessity for repair; repair breeds readiness for flight; readiness for flight, given the opportunity, breeds flying, and so the cycle starts again. But in a military squadron it is not readiness for flight that you want: you want flying. An airplane on the ground is only potentially valuable—useless until you need to fly it.

Gordon lived with the squadron for a while, determined the rate at which flying time generated repair time and assimilated every significant feature of the squadron's operations and the life cycle of a plane. As the result of all this he came to a startling conclusion: the old criterion of maintenance efficiency was wrong. What counted was the percentage of demand for flying met by the planes and the amount of flying accomplished per maintenance man-hour. The upshot was that the target percentage of aircraft kept fit for flying was cut from 70 per cent to around 35 per cent, with a large increase in battle time and squadron efficiency.

The other example concerns the problem of the Japanese Kamikazes (suicide planes) that threatened our ships in the Pacific. The question was whether a ship should maneuver violently to spoil the aim of the diving Kamikaze or keep steady to improve the aim of its own defensive anti-aircraft fire. The operations research group that undertook to find the answer had the records of 477 attacks to study. In 172 cases the suicide plane had succeeded in hitting the ship, and in 27 cases the ship had been sunk. The scientists discovered that the effectiveness of the two types of defensive tactics depended on the size of the ship. Violent evasive maneuvers obviously have only a slight effect on the aim of anti-aircraft gunners in the case of a large ship but a very pronounced effect on their aim in a small ship. What is the net result when the effects on the aim of attacking Kamikazes are taken into account? After considerable study the group concluded that a large ship, when attacked by a diving Kamikaze, should change course violently and a small ship slowly. It also found that a ship should present its beam to an attacking plane that came in from a high dive and turn its bow or stern to a plane diving from a low altitude. In presenting its beam to a Kamikaze a ship could concentrate more anti-aircraft fire on it, but in the case of a low-diving plane the effect of the increased fire power was more than offset, the study showed, by the larger target offered by the ship. The operations research team's recommendations later proved their value in battle: ships that followed its suggestions were hit about 29 per cent of the time when attacked and those that did not observe these rules were hit about 47 per cent of the time.

OPERATIONS research makes use of such mathematical and statistical concepts as the variable, the statistical constant, the function and probability. Its military applications also introduced a number of new concepts, examples of which are exchange rate and sweep rate. The exchange rate of course is the ratio of one's own losses to those of the enemy, but when the losses are not in directly comparable units, a complex analysis may be necessary to determine the true value of an operation in the over-all picture.

The notion of sweep rate grew out of the problem of searching for enemy ships or submarines. Any search tool (a broom, a rake, a flashlight beam, a radar beam) essentially explores a field of targets whose exact locations are unknown. Its effectiveness is measured by its sweep width and its sweep rate. It has a certain probability, depending on these factors, of picking up a target at any given point. A new broom, which "sweeps clean," has a sweep width equal to its actual width, and the probability that it will pick up an object within these limits is 1, representing certainty. A rake swept over an area of small leaves has an irregular detection probability curve, and a man hunting a target at night with sweeps of a flashlight may have still another probability pattern.

Suppose that a plane, flying back and forth at a given speed without crossing its own path, is searching an area of ocean for submarines. To compute the sweep width you multiply the number of submarines assumed to be in the area by the distance flown by the plane, and then divide this product into the product of the number of submarines actually detected and the total number of square miles searched. This number, the sweep width, multiplied by the speed of the plane, gives the sweep rate.

This seems a lot of computing, and one is inclined to ask what is accomplished by it. The answer is that sweep rates are sensitive measures of the efficiency of the searching operation. If the sweep rate of a command of airplanes searching an area for submarines drops sharply, it is a signal to the command that something has gone wrong.

These concepts can also be applied to some business problems, for there are close analogies between military and business operations. In fact, a rough dictionary can be constructed that will translate one into the other. For "weapons" read "materials"; for "command" read "management" or "executive"; for "enemy" read "competitor" or, curiously enough, "customer"; for "destroy" read "out-compete" or "acquire"; for "enemy losses" read "own gains," and so on. The notion of exchange rate becomes, in business, the ratio of gains to expenditures. The notion of sweep rate is directly applicable to the search for customers.

THE use of operations research in business is not entirely new. Under such names as "business analysis" or "business research" sporadic activities of this kind have been conducted for a long time by some firms. What the operations research of World War II introduced was the development of systematic techniques and the enlistment of groups of trained scientists in such work.

To illustrate how operations research may be used in business let us take a study that was actually made of the effectiveness of department-store newspaper advertising. The particular type of advertising analyzed was the kind designed to produce immediate sales—what may be called "quick response" advertising. Since department stores spend millions of dollars each year on this "QR" advertising, the scientific measurement of its results is evidently a worth-while project.

The success of such advertising cannot be measured simply by the amount of extra sales of the particular goods advertised. The advertising is intended to attract customers to the store and increase the total sales. It is not effective if it merely increases the sales of one department at the expense of other departments in the store or of future sales of this department itself. For example, suppose a store advertises a coat that has been selling for $30 at a reduced price of $24. This will naturally attract a lot of quick sales. But how many of these sales are to customers who would have bought the coat anyway at its normal price of $30, either at the time or later on, if the advertisement had not been run? In how many cases did this $24 purchase take the place of purchases that would have been made in other departments of the store? How many customers attracted by the coat bargain also made spur-of-the-moment purchases elsewhere in the store? And finally, how much business did this advertisement bring to the store that would otherwise have gone to competing stores?

It is clear that to assess the net returns from this type of advertising the study must cover the store's total sales and all QR advertising over a considerable period of time. Its goal must be to determine the "true plus volume," that is, the extra volume of sales for the store as a whole which would not have been obtained if the advertising had not been run. Such a study was conducted some years ago by the research director of a certain department store. He made a week-by-week comparison of the QR advertising and total sales of this store with those of the competing department stores in the same city. His analysis of these data was then based on the following reasoning: Of the total sales in a given week a certain percentage is due to QR advertising. This fraction changes from week to week, both for the store and for the competing group, due to fluctuations in their respective QR expenditures. Moreover, the fluctuations in advertising by this store do not parallel those for the competing group: in some weeks it does relatively more advertising, in others relatively less. Consequently there should be corresponding fluctuations in the ratio of total sales by the store to total sales by the competing group, reflecting the variations in advertising ratio. The problem was to isolate these fluctuations.

In order to do so the research director

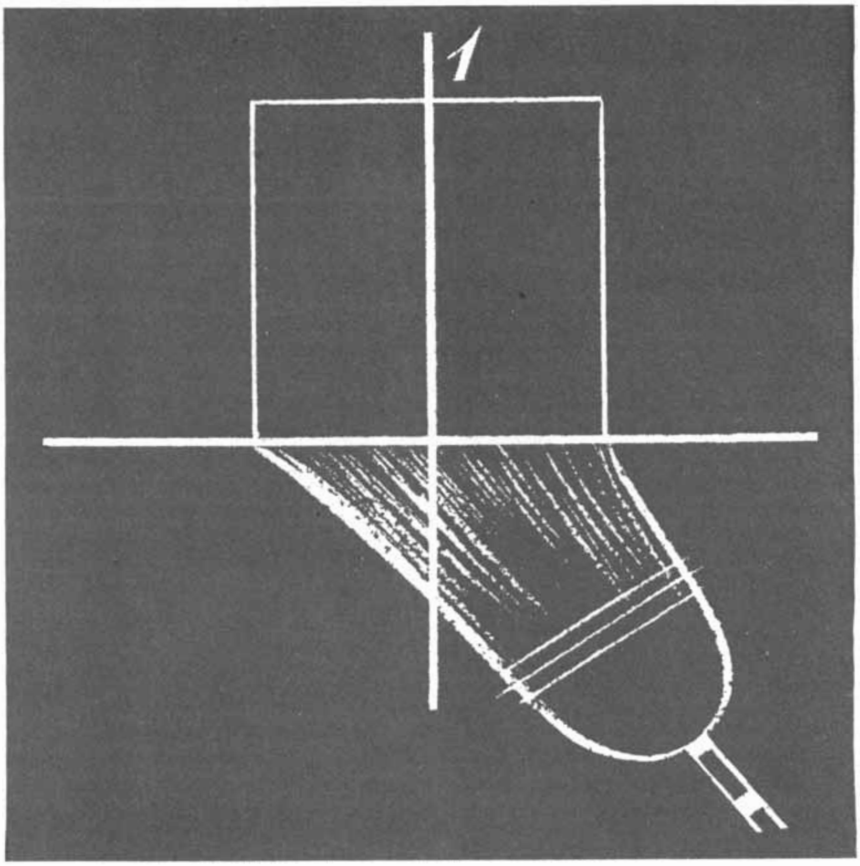
resorted to mathematics. Let S represent the portion of the store's sales volume that does not include the sales attributable to QR advertising, in other words, the total sales minus the QR sales for a week. Let O represent the corresponding sales of the competing group. It is reasonable to assume that the ratio S/O is a statistical constant over an extended period, since sales due to the variable factor of QR advertising are eliminated and the effects of weather and of economic changes, if not too violent, will be uniform for all the stores. This assumption is the key to the solution, for it leads to a set of equations which, using the known figures on total sales and QR advertising expenditures, can be solved numerically to determine the unknown statistical constant and the pulling power of the advertising.

This study yielded the following conclusions, among others: 1) the QR advertising produced a large true plus volume; 2) the amount of true plus volume depended sensitively on price reductions of the advertised goods; 3) the average pulling power of the advertising remained practically constant over a period of several months, although individual advertisements varied greatly in effectiveness. The analysis also had important by-products not involving advertising: it threw much light on some phases of the store's operations and led to improvements in efficiency.

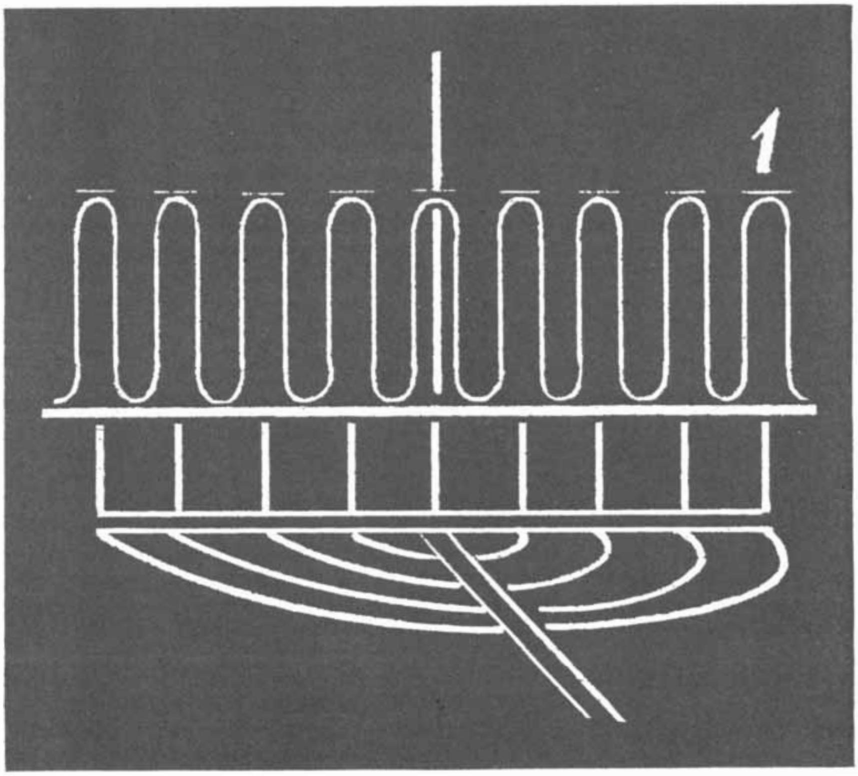
THE peacetime applications of operations research have included the analysis of such problems as the proper use of equipment and manpower, operating procedures in factories and public utilities, the planning of government projects. One operations research study of the laying of road surface materials in Britain, for example, resulted in an annual saving of a million pounds sterling.

Operations research is already a machine of great power. Like a farm tractor it must be expertly manned. One of the main objectives of the Committee on Operations Research in the U. S. is to create a supply of trained workers in this field. The Committee believes that operations research is particularly important and urgent during the present national emergency. To the extent that nonmilitary operations research is successful in increasing the efficiency of U. S. industry, it will contribute to reducing the critical shortage of manpower. And the more young scientists are trained in operations research, the greater will be the supply available to the armed forces in case of necessity.

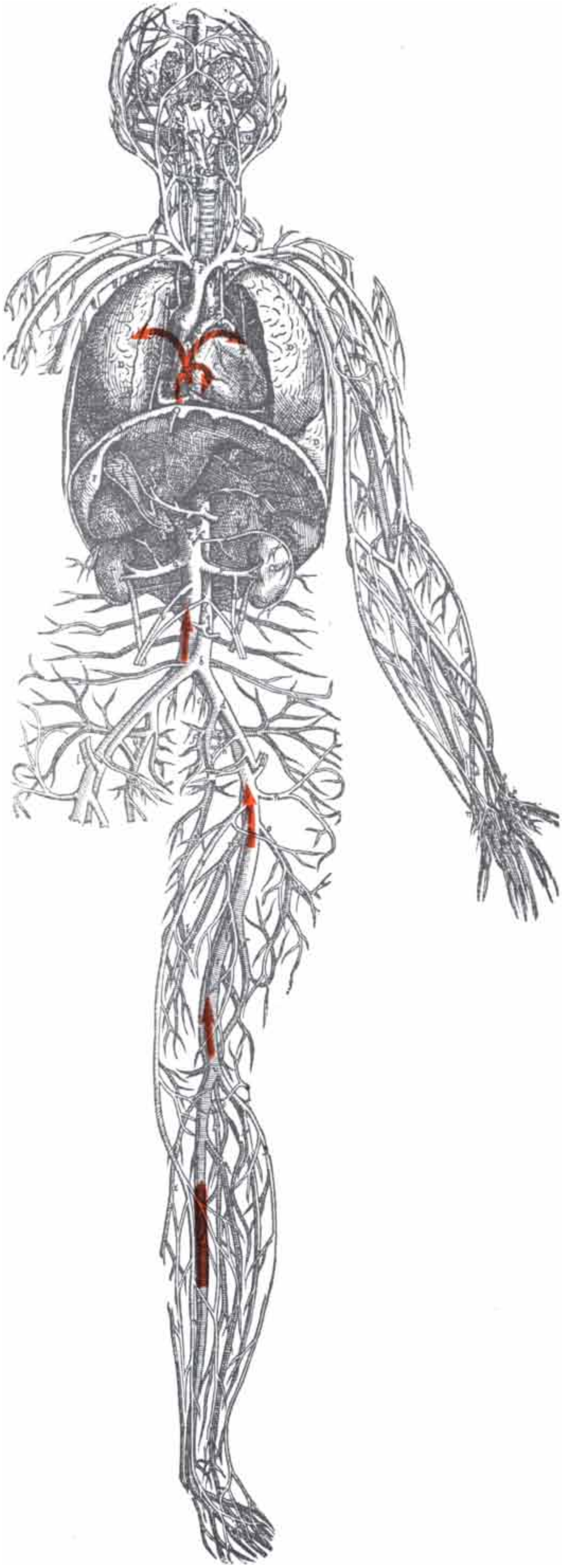
Horace C. Levinson is chairman of the National Research Council's Operations Research Committee. Arthur A. Brown is Deputy Director of the Navy's Operations Evaluation Group.



NEW BROOM has an effectiveness measured by its sweep width (*horizontal coordinate*) and its sweep rate (*vertical coordinate*). The probability that the broom will encounter an object in its path is 1, or certainty.



GARDEN RAKE obviously has less effectiveness than a broom. The probability that a tooth will encounter an object in its path is 1, but the probability that an object between the teeth will be encountered is 0.



The

TO CLOT when shed: this is a fundamental property of all mammalian blood. When, because of injury, illness or some disorder of metabolism, blood does not clot readily enough, the danger is obvious. Hemorrhage within the body can be disastrous, especially if it involves important structures like the brain. And hemorrhagic diseases have always been the center of interest among physicians. The spectacle of blood spurting from the body possesses an intrinsic drama which belongs among the most ancient of human traditions. It symbolizes disaster; it is synonymous with pain. It is one of the few universal experiences.

This preoccupation with blood that flows too freely is, however, misplaced, so far as human welfare is concerned. Blood that does not flow freely enough should concern us far more. The disorders of pathological clotting in the blood vessels—called, as a group, thromboembolic diseases—far outweigh in importance those of hemorrhage. Thromboembolism is very common in occurrence, has a high mortality rate and even when death does not occur may produce serious disabling symptoms.

Among patients over 55 years of age more lives are ended by a thrombotic episode than by any other single disorder. Of the 1,500,000 deaths in the U. S. in 1948, 637,000 were of cardiovascular origin, and among these the thromboembolic ailments were undoubtedly a majority. Coronary thrombosis alone claims about 200,000 lives annually; blood-vessel diseases of the brain, 125,000; pulmonary embolism, 33,000. In the two years between 1946 and 1948 the coro-

LUNG EMBOLISM can result from a blood clot in a leg vein. Superimposed on this woodcut from the *Epitome* of Vesalius is the leg clot (*bottom*). The embolism occurs when pieces of the clot break off and pass through the heart into the lungs.

Control of Blood Clots

The mechanism that prevents hemorrhage can also cause internal catastrophes. New agents and tests show promise of forestalling them

by Shepard Shapiro

nary death rate in the U. S. rose from 98 to 109.9 per 100,000 population.

AGAINST this background, few medical advances in our time have been more important than the recent development of anticoagulant therapy, which has provided a practical means of controlling abnormal clotting and saving lives. The advance is the more remarkable because only a little more than a decade ago there was literally almost nothing a physician could do to prevent or stop a thromboembolic disaster.

The formation of a pathological blood clot, or thrombus, is most dangerous when it occurs in the arteries—the supply line of oxygen and nourishment to the tissues. Obstruction of the flow of arterial blood may introduce a chain of changes that threatens quick death to the affected part or the whole organism. A dramatic and familiar example is blockage of the great heart artery in coronary thrombosis.

But a thrombus may have serious or fatal consequences in any blood vessel. When it obstructs a vein, the body may compensate by using alternate routes for passage of the venous blood. However, the obstruction in the vein causes blood and other fluids, as well as waste products, to accumulate in the surrounding tissues. This in itself may produce serious results. In addition, the thrombus may release a clot fragment, called an embolus, which travels in the bloodstream and may block another vessel. Venous thrombosis often leads to the dreaded blockage of a lung artery that is called pulmonary embolism. The embolus from the vein is carried through the right side of the heart and thence reaches the lung. Eventually it passes into a lung artery of caliber too small to permit farther passage and plugs the vessel. One out of every five or six patients to whom this occurs dies instantly or very soon. If it does not kill the patient, the embolism may initiate a massive destruction of the affected lung area. In some cases, on the other hand, its effects may be slight. But such attacks rarely come singly. One pulmonary embolism generally portends a series to follow, any one of which may be disastrous.

The worst of thromboembolism is the indiscriminate way in which it tends to accompany almost any other illness or shock. Two thirds of all hospital patients apparently develop thrombi. Victims of heart and circulatory disease, especially older people, tend to a high proportion of venous thrombosis and consequent embolism to the lung. At least 1 to 9 per cent of all hospital surgical patients, depending on the kind of operation, develop venous thrombosis after the operation. About half of these have pulmonary embolism, with a mortality of some 20 per cent.

THE beginning of a better outlook for the control of these dreaded disorders came one blue February morning in 1934. On that morning occurred one of those marvelous coincidences that sometimes fertilize scientific growth at a critical point. On the campus of the University of Wisconsin at Madison, an angry farmer trudged from building to building trying unsuccessfully to interest someone in two buckets of cow blood he was carrying and in the carcass of a cow in his truck parked outside. His herd was dying of hemorrhage. He wanted help, but no one would listen to his trouble. There was one last place he saw to try: the Medical School. While looking for it he stumbled into the biochemistry building of the Agricultural Experiment Station at the south end of the campus. Inside, as it happened, Professor Karl Paul Link had just finished a staff seminar concerning the Station's current study of the role that sweet clover was believed to play in hemorrhagic diseases of cattle. As the frustrated farmer entered the building, he ran head-on into Professor Link.

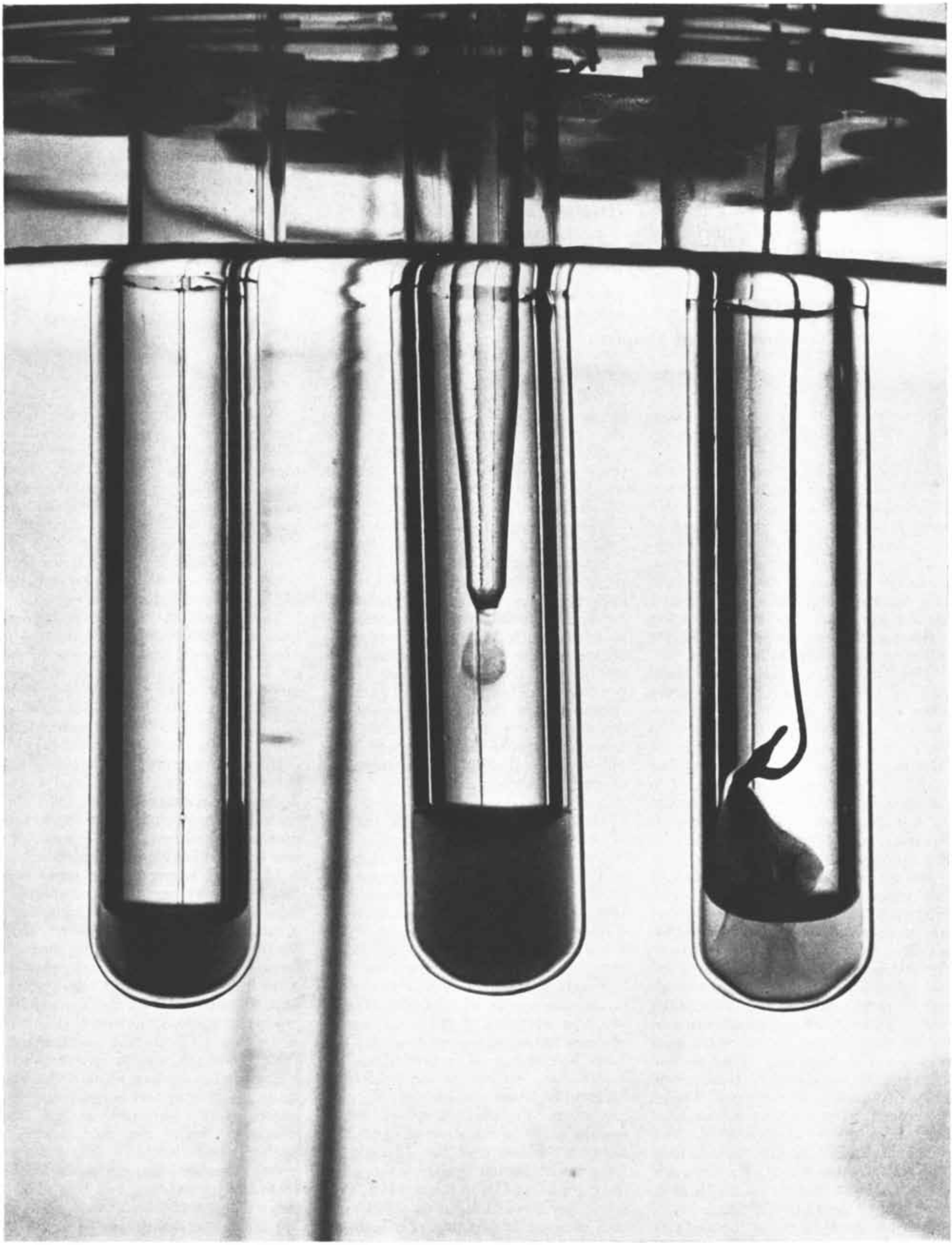
Within a matter of minutes the farmer was a prodigal son, his wrath allayed by plenty of attention and laboratory homebrew. When the conversation ended hours later, Link had accepted the dairyman's buckets of blood for study and had already sketched the first steps of extended and brilliant investigations that were to lead finally to the discovery of the anticoagulant substance responsible for the sweet-clover disease.

The disease that had hit the farmer's herd had been an epidemic plague for years over large areas of the northwestern U. S. and Canada. Its cause had been identified after the first World War by two veterinarians, F. W. Schofield of Canada and Lee Miles Roderick of North Dakota. They had traced it to the continued ingestion of spoiled sweet-clover hay in improperly dried silage. Roderick had announced in 1931 that the cattle's hemorrhage was due to suppression of prothrombin, a plasma protein essential for blood coagulation.

Link had suspected for some time that the guilty agent was coumarin, a substance contained in all leguminous plants, including sweet clover. Coumarin, though it has a bitter taste, is the source of clover's typical sweet smell. After his encounter with the farmer, Link started a quest for the hemorrhage-producing agent. Coumarin is the name of a chemical family; the question was: Which coumarin was the anticoagulant?

Early in the morning of June 28, 1939, while the rest of the campus was still asleep, H. A. Campbell of the Link laboratory finally ran the answer to earth. He had isolated crystals of a compound identified as 3,3′-methylenebis (4-hydroxycoumarin), and was able to prove that it was the hemorrhagic agent in the sweet-clover disease of cattle. By the next year the Wisconsin chemists had succeeded in analyzing and synthesizing this anticoagulant substance. They named it Dicumarol.

Meanwhile two other groups of



BLOOD CLOTTING TIME of a patient can be measured by prothrombin test using the reagent Simplastin. Here three small test tubes are suspended in a bath of warm water. The first tube contains plasma from the patient; the second, Simplastin. When the plasma is dropped into the Simplastin (*second tube*), a clot forms (*third tube*). The length of time it takes the clot to form is a measure of the patient's blood-clotting time.

workers had made a beginning in anticoagulant therapy with an entirely different substance. This was heparin, a compound obtained mainly from liver. A group led by Clarence Crafoord and J. E. Jorpes in Sweden, and one led by Gordon Murray and Charles H. Best (co-discoverer of insulin) in Toronto, showed that heparin could prevent and control thromboses and embolisms. In clinical tests they succeeded in reducing fatalities from pulmonary embolism almost to zero. But the high cost of heparin and the complexity of the method of administering it restricted its practical usefulness.

Late in 1940 Dicumarol became available for clinical trial. Link and his students had found in preliminary experiments in animals that Dicumarol, given by mouth, took 24 hours to act. It caused a pronounced reduction of the clotting ability of the blood. If the doses were continued, the animals showed a tendency to bleed even from a slight scratch, and further doses produced spontaneous hemorrhages. But if given in proper doses, Dicumarol could maintain blood in a state of low coagulability for a considerable time without hazard of hemorrhage. These changes in coagulability were reversible and involved no organic damage.

The first clinical trials were disappointing. Some investigators reported an alarming amount of hemorrhage in their patients. But this proved to be the result of initial inexperience and ineptitude in the use of the drug. It was eventually demonstrated incontestably that there was an ample margin of safety between the helpful and toxic doses.

Dicumarol interferes in some way with the formation of prothrombin, which is manufactured in the liver. Prothrombin is a precursor of thrombin, which plays a key role in the clotting of blood. As the active agent that causes clotting, thrombin itself obviously is not present in normal freely circulating blood. But its precursor, prothrombin, is. The chain of events that leads to clotting is this: The initial stimulus, such as the cutting of a blood vessel or some biochemical disorder, causes the tissues to liberate thromboplastin, a lipoprotein, into the blood, possibly with the aid of the minute bodies in the blood called platelets. Thromboplastin in turn acts in the presence of ionic calcium contained in the blood to convert the prothrombin in the plasma into thrombin. Thrombin then acts on fibrinogen, a soluble plasma protein, to transform it into a relatively insoluble gel called fibrin—the clot. Now each step in this chain of events depends on the one before. The chain can be broken at any point. Accordingly, to depress prothrombin supply or activity is to reduce thrombin activity and to delay clot formation.

This, then, is the way Dicumarol works: it cuts the supply of prothrombin and nips clotting in the bud, so to speak. Obviously it is a potent and potentially dangerous preparation. Fortunately there is an antidote. This is vitamin K, which promotes the liver's synthesis of prothrombin. The author and his associates were able to show in 1943 that in man the administration of relatively large quantities of vitamin K can neutralize a moderate dose of Dicumarol.

Heparin is a natural anticoagulant that acts directly on the blood and produces its effect more rapidly. Its effect, however, is also more short-lived. Since Dicumarol usually takes at least 24 hours to show results, the two drugs are commonly given together—Dicumarol by mouth and heparin by injection. After the action of the Dicumarol becomes manifest, heparin is discontinued.

Recently two other coumarins like Dicumarol have been developed: Tromexan and Link's Compound No. 63. They are now undergoing clinical evaluation.

ANTICOAGULANT therapy, despite its spectacular effectiveness, has been slow to spread into general use. A survey not long ago showed, for instance, that only half of the hospitals on the Eastern Seaboard were willing to offer this treatment, and individual physicians of course were even less able to provide it. The problem was that it was very difficult to determine the proper dose for an individual patient: too little anticoagulant might fail to save the patient and too much might cause hemorrhage. Because Dicumarol operates *via* a circuitous route, its effects are unpredictable as to intensity and duration. And the tests for a patient's response to it were time-consuming and unreliable.

Within the past year, however, a simple, quick and inexpensive test has been perfected. It employs a thromboplastin reagent, called Simplastin, to determine a patient's prothrombin activity, which in turn indicates the proper dose of Dicumarol. The test is so simple and rapid that it can be performed in any physician's office. The method was initiated by Armand J. Quick of Marquette University and was further developed into a procedure known as the Link-Shapiro technique.

Already there is a great mass of evidence testifying to the dramatic ability of the anticoagulants to subdue thrombosis and embolism. At the Mayo Clinic the effectiveness of Dicumarol was studied in a series of 2,307 patients, 1,513 of whom had undergone operations. Of these patients 352 developed clots in the veins after the surgery. Treatment with Dicumarol held the further development of venous thrombosis in the afflicted patients to 3 per cent, instead of the normal expectation of 25 per cent, and it cut fatalities from an expected 6 per cent to none. In the same series 329 patients developed pulmonary embolism. Dicumarol limited further development of the embolism to 1 per cent, instead of the usual 43 per cent, and it reduced deaths from 18 per cent to 1 per cent. In another project sponsored by the American Heart Association, some 1,000 patients with coronary thrombosis were divided into two equal groups that received the same treatment in every respect except that one-half received Dicumarol and the other did not. In the group not treated with Dicumarol, 23.5 per cent died; in the treated group, 16 per cent—a reduction in mortality of one-third. The Dicumarol treatment also reduced thromboembolic complications in the surviving patients; 42 per cent of the untreated patients had complications but only 13 per cent of the treated. The results of this test are borne out by the routine experience of a large clinic, which reports that it has cut the mortality rate among its coronary thrombosis patients from 25 per cent to 15 per cent by using Dicumarol.

As often happens in medicine, the development of the new anticoagulant therapy has brought us to a much keener realization of the magnitude of the need for it. Only during the past decade, as the anticoagulants have come into use, have we begun to learn how prevalent thrombosis is, particularly among the bedridden. One hospital, for example, found in post-mortem examinations of a very large number of patients who had died of various diseases that 52.5 per cent had thromboses in the leg veins—in most cases unsuspected before their deaths. As a result of such findings, many hospitals now require surgical patients to get out of bed and walk within 24 hours after leaving the operating table, in order to stimulate circulation and prevent thrombosis.

THE way has now been opened for a successful general offensive against the deadly thromboembolic diseases. However, although the basic scientific and clinical work on anticoagulant therapy was completed some years ago, it has not yet been available to the numbers who might be helped by it. The problem now is to make all physicians aware of thrombotic complications so that they recognize the conditions in the initial stages, and to provide reliable laboratory control of the therapy so that the treatment can be administered with a minimum hazard of hemorrhage.

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THE STRUCTURE OF THE NUCLEUS

The electrons in an atom tend to occupy distinct shells. What about particles in the nucleus? The "magic numbers" of the isotope chart suggest that they also have a shell arrangement

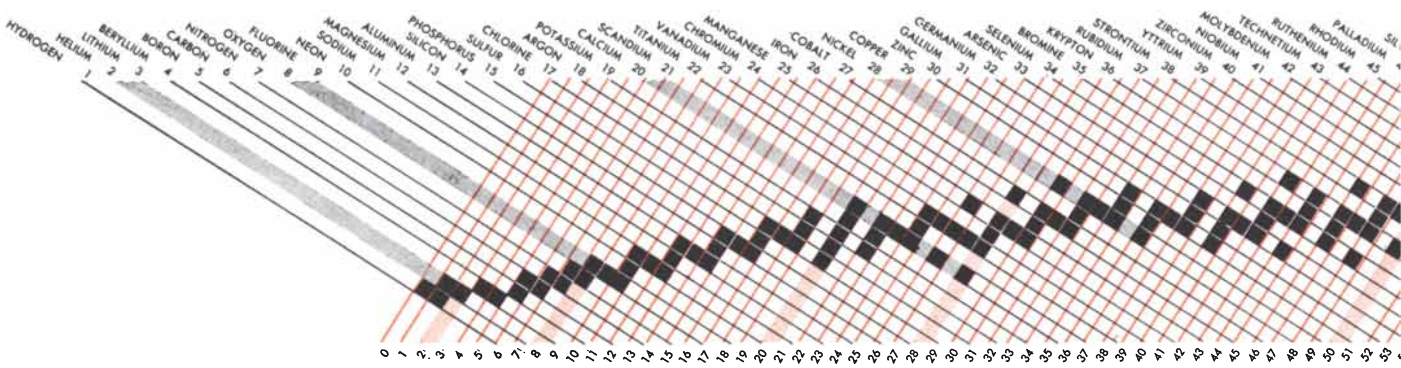
by Maria G. Mayer

NO one has ever seen, nor probably ever will see, an atom, but that does not deter the physicist from trying to draw a plan of it, with the aid of such clues to its structure as he has. He needs to construct at least a rough hypothetical model of the atom as a starting point for attempting to understand its behavior. For the atom as a whole modern physicists have developed a useful model based on our planetary system: it consists of a central nucleus, corresponding to the sun, and satellite electrons revolving around it, like planets, in certain orbits. This model, although it leaves many questions still unanswered, has been helpful in accounting for much of the observed behavior of the electrons. The nucleus itself, however, is very poorly understood. Even the question of how the particles of the nucleus are held together has not received a satisfactory answer.

Recently several physicists, including the author, have independently suggested a very simple model for the nucleus. It pictures the nucleus as having a shell structure like that of the atom as a whole, with the nuclear protons and neutrons grouped in certain orbits, or shells, like those in which the satellite electrons are bound to the atom. This model is capable of explaining a surprisingly large number of the known facts about the composition of nuclei and the behavior of their particles.

Let us consider first the shell structure of the electrons, from which our nuclear model derives. The modern exploration of the atom began with the experiments of Ernest Rutherford at Cambridge University early in this century. Rutherford's main experiment consisted in shooting high-speed alpha particles, the nuclei of helium atoms, through metal foils. The physicist-writer George Gamow has likened this experiment to the strategy of an overworked South American customs inspector who adopted the expedient of shooting revolver bullets into bales of cotton as a quick method of finding out whether they contained contraband arms. (His bullets must have been shot from a revolver of very high muzzle velocity to penetrate the bales, but this small detail hardly destroys the analogy.) If the bale contained only cotton, the bullets would pass through in approximately a straight line. If, however, the bale contained metal arms, some bullets would ricochet off them and be deflected at a wide angle. Rutherford found in his experiment that most of the alpha particles passed through the metal foil with no appreciable deflection in angle, though of course they were slowed down. But a certain small proportion of his projectiles were markedly deflected. From this it could be concluded that the greater part of the metal foil consisted of light cottonlike material, and that the foil also contained some heavy small targets capable of exerting very strong forces on the alpha particles.

It was essentially from this experiment that the modern concept of the planetary atom emerged. The heavy targets that deflected some of Rutherford's projectiles were the nuclei of atoms. Almost all the mass of an atom is concentrated in this small, positively-charged nucleus. The diameter of the nucleus is only about a hundred thousandth that of the whole atom. The remaining space in the atom is almost empty, and in this space the electrons move in their orbits. Most of Rutherford's alpha particles



THE CHART OF THE ISOTOPES reveals seven "magic numbers" (*rows shaded red and black*). Each isotope is represented by a black square. Each row outlined by black lines includes nuclei with the same number of protons, *i.e.*, isotopes; each row enclosed in red lines shows nuclei with same number of neutrons. Since never came close to a nucleus, but they encountered many of the light electrons as they passed through the outer spaces of the atoms and were thereby slowed down.

WITH the leads furnished by Rutherford's experiments and by the quantum theory, Niels Bohr and other physicists went on to establish the fundamental laws governing the motion of the electrons around the nucleus. In these studies they worked with the simple hydrogen atom, which has only a single positive charge on its nucleus and a single electron. The hydrogen atom's electron may move in any one of a discrete series of elliptical orbits about the nucleus. Under the quantum rule only these specific orbits are stable, or "permitted," for the electron. The most stable of the allowed orbits is that of lowest energy; in this orbit the electron keeps within about one Angstrom unit (1/100,000,000 of a centimeter) of the nucleus. Here its "angular momentum" is zero. Angular momentum is a measure of the amount of rotation of a particle in an orbit; for a circular orbit it is computed as the mass times the velocity times the radius of the orbit. When measured in appropriate units ($h/2\pi$, with h representing Planck's constant), the angular momentum of a permitted Bohr orbit is always a whole number. At the next higher level of energy an electron is allowed any one of four possible orbits. One of these has zero angular momentum; the other three all have an angular momentum of one unit but differ in the direction of the angular momentum vector. At still higher energy levels the electron may have more than four allowed orbits.

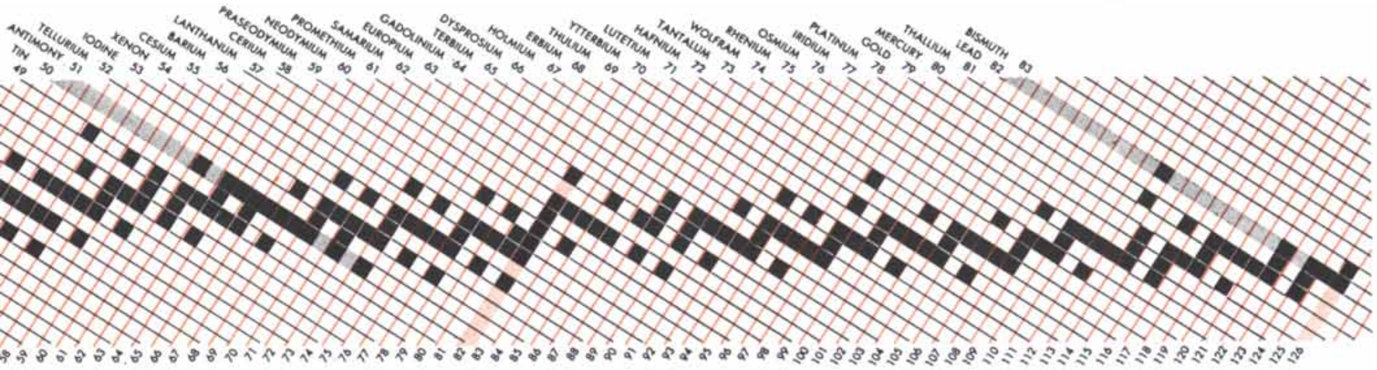
Besides revolving around the nucleus, the electron also spins on its own axis, just as the earth has a daily rotation in addition to its motion around the sun. The electron's spin can take one of two directions. This effectively doubles the number of permitted motions, or kinds of orbit, for an electron, since in any given orbit it may spin in one direction or the other. The angular momentum of the electron's own spin is a half-unit.

In an atom heavier than hydrogen, *i.e.*, with more than one electron, the electrons' motions are of course more complicated. Just as the orbit of the earth around the sun is distorted from a perfect ellipse by the gravitational effects of the other planets, so the motion of each electron around the nucleus of a heavy atom is influenced by the presence of the other electrons. To some extent, however, these effects can be averaged and the motion of a single electron can be considered to be governed by the averaged field of force from the nucleus and the other electrons. A further factor that must be noted is the famous Pauli exclusion principle: namely, that two electrons can never exist in exactly the same orbit of the same magnitude and direction of orbital angular momentum and with their spins in the same direction.

WE might liken the electronic structure of an atom to that of an apartment house. The ground floor, or orbit of lowest energy, which is the most desirable from the electron's point of view, has a single apartment. Two electrons of opposite spin can occupy it. The second floor contains four apartments, one of which is at a slightly lower level than the others. This one has zero angular momentum, while the other three have one unit of angular momentum. Each of these four apartments likewise can be occupied by two electrons of opposite spin. Thus the apartment house rises, level by level, with a certain number of apartments at each level, each available for occupancy by a pair of electrons. The atomic physicist has designated the levels (or orbits or shells or whatever one pleases to call them) by a system of numbers and letters: the letters represent the energy levels in terms of angular momentum. The letter s stands for zero angular momentum; p for one unit of angular momentum, d for 2, f for 3, and so on. Thus the ground floor, the lowest orbit that can be occupied by the hydrogen atom's electron, with zero angular momentum, is called 1s; the next orbit, that of the depressed second-floor apartment with zero angular momentum, is 2s; the next, occupied by the three second-floor apartments with one unit of angular momentum, is 2p, and similarly up through the higher orbits.

Now it turns out that atoms are happiest and most stable when all the apartments at a given level are fully occupied by electrons; they do not like vacancies. For example, the single electron of the hydrogen atom is lonely and restless in its 1s apartment, which as we have seen has room for two electrons. Hydrogen readily loses its electron, thereby becoming a positive ion, or picks up a roommate for its lone electron, forming a negative ion. Hydrogen, in other words, is a very reactive element; it easily enters into chemical combinations with other atoms. In contrast, the helium atom, with two electrons, is extremely stable. Its two electrons fill the 1s apartment and form a closed system. There is no room for more electrons in this orbit, and the two electrons are held so tightly by the two positive charges in the atom's nucleus that they are not easily separated from it. As a result helium does not react or combine with other elements. The same is true of the four other "noble" gases in the periodic table of elements—neon, argon, krypton and xenon. Each of these has a closed outer shell, fully occupied by electrons, and does not form ions easily or enter into chemical combinations. Indeed, the stability of the five noble gases is so remarkable that their atomic numbers—2, 10, 18, 36 and 54—may be called the "magic numbers" of the periodic table.

This picture of the atom's electronic structure has been enormously useful to chemistry; by means of it chemists have been able to group the elements in families and predict their chemical behavior. But it tells us little or nothing about the structure of the nucleus. The only piece of information an atom's chemical activity gives us about its nucleus is the number of positive charges, or protons, it contains. The chemical nature of the atom is determined by the number of its electrons. We know that if an atom has



the number of protons is the same as the atomic number, the name of each element is given above the number of protons. The nuclei that contain 2, 8, 20, 28, 50, 82 or 126 protons *or* neutrons are unusually stable: these are the magic numbers. The chart is not carried beyond bismuth: that is the last element to which magic numbers apply.

ORBITAL ANGULAR MOMENTUM	SHELL	NUMBER OF NUCLEONS IN A LEVEL	NUMBER OF NUCLEONS UP TO A LEVEL
0	1s	2	
			2
1	1p	6	
			8
2	1d	10	
0	2s	2	
			20
3	1f	14	
1	2p	6	
			40
4	1g	18	
2	2d	10	
0	3s	2	
			70
5	1h	22	
3	2f	14	
1	3p	6	
			112
6	1i	26	
4	2g	18	
2	3d	10	
0	4s	2	
			168

MARGENAU CHART of nuclear energy levels supports the shell-structure hypothesis in part. The first three numbers in column at right match the magic numbers. The next four do not; at this point the scheme breaks down.

ORBITAL ANGULAR MOMENTUM	SHELL	TOTAL ANGULAR MOMENTUM	NUMBER OF NUCLEONS IN A LEVEL	NUMBER OF NUCLEONS UP TO A LEVEL
0	1s	1/2	2	
				2
		3/2	4	
1	1p	1/2	2	
				8
		5/2	6	
2	1d	3/2	4	
0	2s	1/2	2	
				20
		7/2	8	
		↕		28
3	1f	5/2	6	
		3/2	4	
1	2p	1/2	2	
		9/2	10	
		↕		50
4	1g	7/2	8	
		5/2	6	
2	2d	3/2	4	
0	3s	1/2	2	
		11/2	12	
		↕		82
5	1h	9/2	10	
		7/2	8	
3	2f	5/2	6	
		3/2	4	
1	3p	1/2	2	
		13/2	14	
		↕		126
6	1i	11/2	12	

MAYER CHART accounts for the discrepancies by introducing the spins of nuclei (*fractions in the center column*). "Spin-orbit coupling" splits the close-lying levels apart and creates energy gaps where the magic numbers occur.

a certain number of electrons, it must have the same number of protons in its nucleus to hold them. But how the protons themselves are held together, how they interact with one another and with the uncharged neutrons also present in the nucleus—these are the great mysteries of nuclear physics.

The forces that bind the nucleus together are very great—millions of times greater than those that bind electrons to the nucleus. We do not know how these forces are created. And even if we understood them completely, we would still be confronted with the tremendous difficulty of solving a many-body problem, *i.e.*, calculating the results of these forces upon a large number of protons and neutrons that interact with one another strongly and at extremely short range within the nucleus. The problem has seemed so hopeless that nuclear physicists have preferred to treat the nucleus as a "liquid drop," in which the protons and neutrons essentially lose their identity. (This approach has been very fruitful, particularly in studying high-energy phenomena in the nucleus.)

Yet it is possible to discern some rather remarkable patterns in the properties of particular combinations of protons and neutrons, and it is these patterns that suggest our shell model for the nucleus. One of these remarkable coincidences is the fact that the nuclear particles, like electrons, favor certain "magic numbers."

EVERY nucleus (except hydrogen, which consists of but one proton) is characterized by two numbers: the number of protons and the number of neutrons. The sum of the two is the atomic weight of the nucleus. The number of protons determines the nature of the atom; thus a nucleus with two protons is always helium, one with three protons is lithium, and so on. A given number of protons may, however, be combined with varying numbers of neutrons, forming several isotopes of the same element. Some isotopes are stable; others decay by radioactivity. Some of the stable isotopes readily add a neutron; others are much less inclined to do so.

Now it is a very interesting fact that protons and neutrons favor even-numbered combinations; in other words, both protons and neutrons, like electrons, show a strong tendency to pair. In the entire list of some 1,000 isotopes of the known elements, there are no more than six stable nuclei made up of an odd number of protons and an odd number of neutrons. The other odd-odd nuclei break down radioactively by emitting a negative or positive electron; this change in charge transforms a neutron into a proton or a proton into a neutron and creates a more stable even-even combination of protons and neutrons.

Moreover, certain even-numbered aggregations of protons or neutrons are particularly stable. One of these magic numbers is 2. The helium nucleus, with 2 protons and 2 neutrons, is one of the most stable nuclei known. The next magic number is 8, representing oxygen, whose common isotope has 8 protons and 8 neutrons and is remarkably stable. The next magic number is 20, that of calcium. Calcium, with 20 protons, has 6 stable isotopes, ranging in neutron number from 20 to 28. This is an unusually large number of stable isotopes for the lower region of the periodic table.

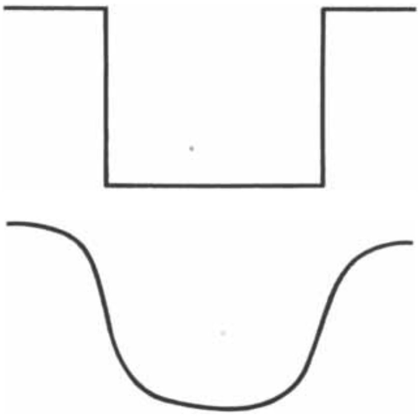
Among these light elements the relative stability can be determined very accurately in terms of binding energy. The net mass of a nucleus is always smaller than the combined masses of the protons and neutrons of which it is composed. The binding energy is calculated from this "mass defect" by means of Einstein's famous relation $E=mc^2$, with m representing the mass defect and c the velocity of light. Such calculations show conclusively that the nuclei with the magic numbers 2, 8 and 20 have much greater binding energies than their neighbors. But for the heavier elements above calcium the binding energies are not accurately determined, and we must judge their relative stability by indirect evidence. One such piece of evidence is the number of stable (*i.e.*, nonradioactive) nuclei that are found to exist with a given number of protons or neutrons. Another is the relative abundance of a given nucleus in the universe, since it seems reasonable to assume that the most abundant isotopes are the most stable.

By these tests the number 50 joins the list of magic numbers. Tin, with 50 protons, has 10 stable isotopes, more than any other element, and it is much more abundant than neighboring elements in the periodic table. The same is true, to a somewhat lesser degree, of the number 28. Another magic number is 126: an isotope with 126 neutrons holds them much more strongly than one with 127 or 128. Perhaps the most remarkable magic number of all is 82. There are 7 stable nuclei containing 82 neutrons, ranging from isotopes of xenon to samarium. The barium isotope with 82 neutrons accounts for 72 per cent of the abundance of that element, and cerium's 82-neutron isotope represents 88 per cent of all the cerium. Finally, 82 protons means lead, and lead is the stable end-product of the decay of all the heavy radioactive elements that may be found in nature.

There are other indications of the special stability of these magic numbers. For instance, nuclei containing 50, 82 or 126 neutrons do not like to add an extra neutron: their absorption cross-sections for fast neutrons are smaller by several factors of 10 than those of an average nucleus of nearly the same weight.

THE list of magic numbers, then, is: 2, 8, 20, 28, 50, 82 and 126. Nuclei with these numbers of protons *or* neutrons have unusual stability. It is tempting to assume that these magic numbers represent closed shells in the nucleus, like the electronic shells in the outer part of the atom. To be sure, the electronic shells form a more distinct dividing line than those in the nucleus: the last electron in a closed shell is held to the atom at least three times as strongly as the last electron in an unfilled shell, whereas in nuclei the energy difference is at most 50 per cent. Yet the situations seem sufficiently similar to justify exploring the possibility that the nucleus may be tied together in much the same kind of shell structure as the electrons.

There is another kind of evidence that



NUCLEAR POTENTIALS are represented as "wells." A well with round edges agrees with magic numbers better than one with square.

supports this shell-structure hypothesis. It has to do with the spin of the nucleus. Many nuclei apparently spin about their axes like a top, just as the earth and electrons do. Since the nucleus carries a charge, its rotation corresponds to an electric current, and it behaves like a tiny magnet. The result is known as the magnetic moment of the spinning body. The spins and the magnetic moments of nuclei and of their building blocks, the neutron and proton, can be measured. It turns out that the spin of nuclei, like that of electrons, is "quantized": that is, when measured in the same units ($h/2\pi$) it is always a whole number or half a whole number. The spin of the proton and of the neutron has been determined to be 1/2-unit. Their magnetic moments, measured in units called nuclear magnetons, also have been accurately determined. The spins of nuclei with an odd number of particles are all half of some whole odd number (*e.g.*, 1/2, 3/2, 5/2 and so on), and the spins and magnetic moments of nuclei with an even number of protons and of neutrons are zero.

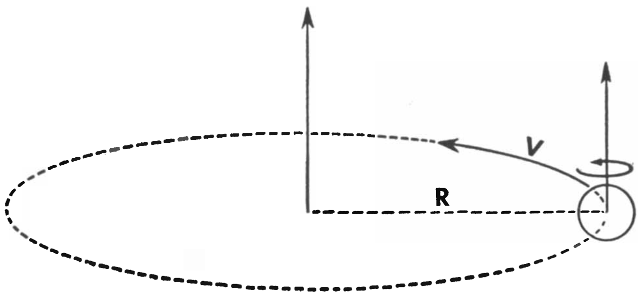
Now it is a very surprising fact, not expected from the general theory of the nucleus, that two isotopes with the same odd number of protons but different even numbers of neutrons behave very similarly. They have the same spins, nearly the same magnetic moments and frequently the same kinds of excited states. Take, for example, the 2 isotopes indium 113 and indium 115. Each has 49 protons, but one has 2 neutrons more than the other. Yet both have spins of 9/2, and their magnetic moments are very close in value—5.461 and 5.475 nuclear magnetons, respectively. The extra pair of neutrons in the second isotope does not seem to affect these nuclear properties; in other words, the spins and magnetic moments in this case appear to be due only to the protons. On the other hand, a nucleus with 49 neutrons and an even number of protons (*e.g.*, strontium-87) also has a spin of 9/2, though not the same magnetic moment. As far as nuclear spin goes, 49 neutrons behave just like 49 protons. This seems to be the general rule for the lighter isotopes of mass number less than 120.

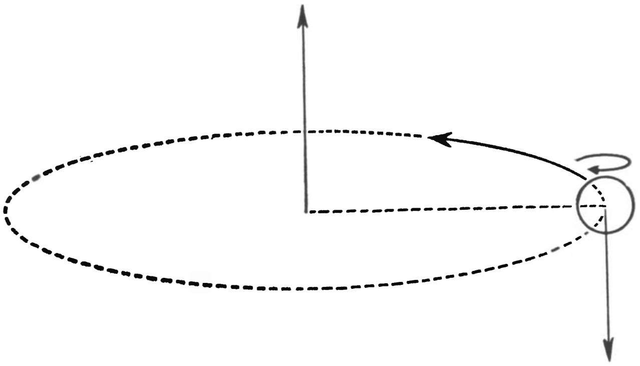
On the basis of these observations the German physicist T. Schmidt many years ago made the radical suggestion that it is not the nucleus as a whole that spins. Instead, in nuclei with an odd number of particles the properties of spin and magnetic moment are due entirely to the last odd particle, be it a proton or a neutron. The structure of odd nuclei is thus pictured very simply. The nucleus has a spherically symmetrical core of an even number of neutrons and protons. The core has no spin. Around it revolves the last odd particle. Its motion alone determines the spin and magnetic moment of the nucleus.

It is curious to find that, as the evidence of the magic numbers and of the nuclear spins suggests, protons and neutrons behave with considerable independence of each other in the nucleus. Such independence is unexpected from the standpoint of current nuclear theory.

The angular momentum of a particle's orbit alone is always a whole number. But the particle's total angular momentum is the sum of its orbital momentum and its own spin. Hence the total angular momentum of a nucleus always has a half-integer value, since protons and neutrons, just as electrons, spin about their own axes with an angular momentum of 1/2. This spin can be parallel or anti-parallel to the orbital angular momentum; that is, it can be directed so as to add 1/2 or to subtract 1/2 from the orbital angular momentum. Consequently a measured spin can correspond to either of two different orbits.

That such a picture is not too far from the truth is borne out by the measured values of magnetic moments. From this





SPIN and orbital angular momentum are depicted in this diagram. The spin is indicated by the circular arrow above the particle. The orbital angular momentum is the mass of the particle times R times V.

simple model it is possible to compute the theoretical magnetic moment of a given nucleus. The agreement between the predicted and measured magnetic moments is reasonably good.

THUS the spins and magnetic moments lead to a description of the nucleus in terms of orbits of single particles. One can then picture the building of the structure of the nucleus as the gradual filling up of single-particle orbits by neutrons and protons, in the same way as electrons build the atom. The single-particle orbits for one nuclear particle are determined by the average field of the others. The orbits can be described by the letters used to designate the quantized orbital angular momentum of electrons: s=0, p=1, d=2, f=3, g=4, h=5, i=6. Since neutrons and protons obey the Pauli principle, the s level has room for just two protons and two neutrons, as in the case of electron orbits; the p level has room for six, and so on. In this scheme the magic numbers should correspond to closed shells; that is, they should indicate the boundaries where one level is filled and the next level is appreciably higher.

The order of levels, or the number of particles in a level, depends on the form of the nuclear potential. The simplest guess we can make about the potential is to compare it to a well: no force is acting on a particle outside the well (*i.e.,* outside the spherical nucleus), and none inside. But at the edge of the well (at the surface of a spherical shell) a strong attraction takes place. The change in attraction may be more or less abrupt. A series of very abrupt transitions would be represented by a well with square edges; a more gradual transition by a well with rounded edges.

The structure of levels that would obtain if the well had square edges has been calculated by the Yale University physicist Henry Margenau. The result is shown in the table at the top of page 24. The table gives the number of neutrons or protons each level can hold and the cumulative numbers that fill all the levels up to a given point. The same type of calculation for wells with rounded edges divides each level into two or more levels of the same or nearly equal energy; in the table these closely adjacent levels are grouped together, with breaks between the gaps.

This scheme explains perfectly the smaller magic numbers, up to 20. The lowest level can contain no more than two particles. The next level, or p-shell with angular momentum 1, has three different orbits, each of which can be occupied by two nuclear particles with opposite spin. These six particles in the p-shell, plus the two in the ground state, correspond to the stable form of oxygen with eight neutrons and eight protons. The next two levels, 1d and 2s, which lie close together, have room for 12 more nuclear particles, and these bring us to the magic number 20.

From here on the scheme seems to break down. In this table there is no sign of the magic numbers 28, 50, 82 and 126. It is possible, however, to arrive at them by taking into account an effect which is very small and unimportant for electrons but apparently not for nuclear particles.

A nuclear particle can align its own 1/2-unit spin parallel or anti-parallel with the angular momentum of its orbit. Thus its total angular momentum can be the orbital angular momentum plus 1/2 or minus 1/2. This splits its orbit into two possible levels. There is a considerable difference of energy between these two levels, brought about by what is called "spin-orbit coupling." The strength of the coupling increases with increasing angular momentum, and one would expect it to decrease with increasing size of the nucleus. Consequently the greatest split in such a pair of levels should occur at the beginning of a group of closely adjacent shells, where relatively high angular momentum is combined with a relatively small nucleus. Suppose that a wide split of this kind occurs at the 1g level. Then it is no longer correct to treat the 1g level as a single level with room for 18 particles. Instead, it will divide into two levels with room for 10 particles in its lower level. This lower level will be depressed toward the next lower group, consisting of the 1f and 2p shells, as listed in the Margenau table. The 10 particles, added to the 40 up to that point, make the magic number 50. Above this there is an energy gap, created by the spin-orbit coupling.

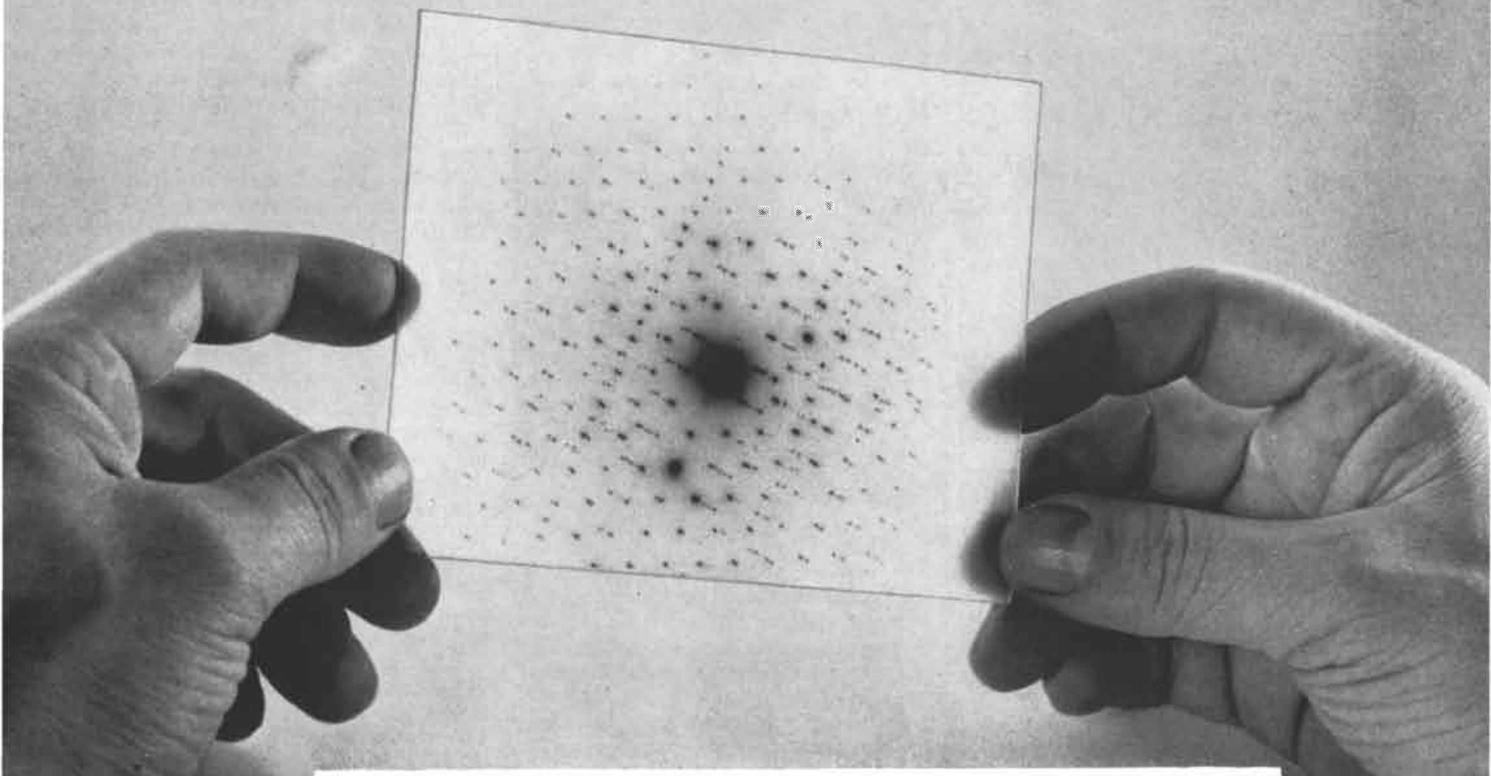
The table at the bottom of page 24 shows how the various levels are revised when allowance is made for spin-orbit coupling. Now the larger magic numbers come into the scheme: they all occur at the places where spin-orbit coupling has its greatest effect.

This level scheme is in excellent agreement with the observed spins and magnetic moments of odd-numbered nuclei. Among the approximately 90 spins and 73 magnetic moments that have been measured so far there are only four serious disagreements with the theory.

THE shell model can explain other features of nuclear behavior, including the phenomenon known as isomerism, which is the existence of long-lived excited states in nuclei. Perhaps the most important application of the model is in the study of beta-decay, *i.e.,* emission of an electron by a nucleus. The lifetime of a nucleus that is capable of emitting an electron depends on the change of spin it must undergo to release the electron. Present theories of beta-decay are not in a very satisfactory state, and it is not easy to check on these theories because only in a few cases are the states of radioactive nuclei known. The shell model can help in this situation, for it is capable of predicting spins in cases in which they have not been measured.

Certainly the simple model described here falls short of giving a complete and exact description of the structure of the nucleus. Nonetheless, the success of the model in describing so many features of nuclei indicates that it is not a bad approximation of the truth.

Maria G. Mayer is a physicist with Argonne National Laboratory and the Institute of Nuclear Studies at the University of Chicago.



The electrons landed here . . .

. . . and the diffraction pattern they left on this plate measures the splitting of the laminae in a 1000-Angstrom-unit-thick sheet of bent mica through which they passed.

For industry, electron diffraction patterns are revealing and identifying oxides on non-ferrous metals, the faint beginnings of corrosion on steel, scale in distillation equipment, crystal formations in chemical processes—thin films of all kinds.

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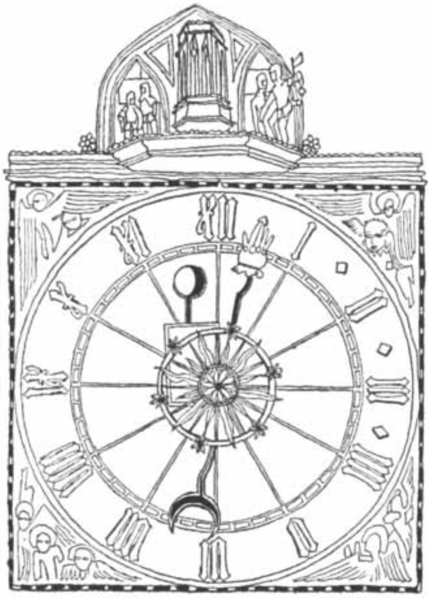


Blasts and Reports

LAST month the Atomic Energy Commission simultaneously issued its Ninth Semiannual Report and set off a series of nuclear explosions on its new testing range near Las Vegas, Nev. The explosions were highly secret; the AEC described them only as "nuclear detonations," and Chairman Gordon Dean added mystifyingly, "I don't think it would be fair to call them bombs." Flashes of light were observed as far as Boise, Idaho, 500 miles away. Within a few days observers in the eastern U. S. and Canada, 2,300 miles from the testing range, began to report a slight increase in the radioactivity of the atmosphere.

The first explosion, coming without warning, caused some to think that "the Russians were bombing Hoover Dam"; by the third, the citizens of Las Vegas were becoming hardened. But the fourth, obviously greater than the preceding ones, shook the town like an earthquake and broke some windows. The AEC issued a general alert to Las Vegans to stay away from windows at dawn, the chosen time for the tests. On February 6 came the fifth and most powerful blast of the series. Cameras stationed on Mount Wilson, near Pasadena, Calif., recorded the flash on television. The AEC announced that for the time being it had concluded its tests.

The Commission's Semiannual Report announced a continuing rise in the production and improvement of atomic weapons. It disclosed that the Experimental Breeder Reactor at Arco, Idaho, is expected to begin operating by spring; the reactor will operate a small turbogenerator and produce the first nuclear-fueled electricity. In a separate announcement the AEC also said it had started a study of ways and means to permit private industry to build power reactors. The tentative plan is for the AEC to provide the fissionable fuel, the companies to produce power and plutonium, and the AEC to buy the plutonium. Companies equipped to handle the job were invited to take part in the study.

The Semiannual Report briefly described several new research findings in AEC laboratories. One new development is the acceleration of carbon nuclei as projectiles for bombarding other nuclei; previously the largest projectile used had been the alpha particle, or helium nucleus. The University of California's 60-inch cyclotron accelerated nuclei of carbon 12 and 13 to energies of over 100 million electron volts. Bombardment of elements with these heavy particles transmuted them into considerably heavier ones in a single step: thus the carbon bombardment changed gold 197 into astatine 205 and aluminum 27 into chlorine 34. The application of this technique to uranium may make possible the production of larger amounts of the synthetic elements americium, curium, berkelium and californium.

AEC physicists have also succeeded in fissioning several medium-weight elements, such as copper, bromine and silver. The report says that apparently any element can be split if it is bombarded energetically enough, but such fissions do not yield energy; they absorb more than they produce. The fission products include a wide range of fragments, from neutrons and protons to nuclei of chlorine and sodium.

The bulk of the report is devoted to the Commission's forms of contract and relations with contractors. In a brief section on security investigations, it announces that 200,000 employees and candidates for employment have been loyalty-checked since January, 1947. Of these 1,600 were denied clearance or quit their jobs while being investigated.

Another development in the field of atomic energy was an announcement that Canada is preparing to build a new heavy-water atomic pile much larger and more powerful than the present reactor at Chalk River. The new pile, costing $30 million, will be used to study breeding of fissionable materials and power production, and to produce more radioisotopes for therapy and research.

Light Without Glare

A NEW principle of lighting has been developed by engineers of Sylvania Electric Products, Inc. It provides an area source of light, instead of the point source of the incandescent lamp or the line source of the fluorescent tube.

The new system uses the phenomenon of electroluminescence. A fluctuating electric field is applied to a phosphor to make it glow. This direct conversion of electricity into light permits great simplicity of design. There is no sealed bulb or tube. The phosphor may simply be incorporated into a nonconducting film which is laid down on a sheet of conducting glass with a metal backing. The lamp can be made of any size and shape; any surface from a clock face to a whole ceiling may be rendered luminous.

The engineers who are developing the technique say one of its great advantages is that it can give light without glare, since luminescence spread over a large area can provide the same total illumination as a conventional lamp with much less brightness per unit area.

Weather Improvers

A GROUP of Western ranchers and farmers have banded together to form the National Weather Improvement Association, under the slogan, "Everybody talks about the weather, but we do something about it." Their chief tool is cloud-seeding. At their founding convention two months ago in Fort Collins, Col., they exchanged experiences and agreed that the weather can certainly be improved.

Leo Horrigan, a wheat grower who is also president of the Horse Heaven Water Development Corp., said: "We're pioneering a brand new science." He cited two storms that had taken place on his ranch in the state of Washington within two weeks. The first storm was seeded with crystals while it was developing; the second was not. "The seeded storm," reported Horrigan, "gave us a gentle, even rain over the whole area. The other produced only about .02 inches of rain at our ranch house, but when I went down to the lower end of the ranch, I found everything under water, crops ruined, and half a mile of road washed out that cost the county several thousand dollars to rebuild. Next time a storm like that comes up, you may be sure we will seed it."

This spring and summer various groups will sponsor cloud-seeding projects covering a total of more than 100 million acres of the U. S. The Association voted to raise money to help its members fight possible lawsuits "in which, because of ignorance, artificial nucleation gets blamed for violence committed by nature."

The Third Wave

MOST of the seismologist's information about earthquakes has come from study of two types of waves, known as the preliminary and the surface waves, which travel through the earth at speeds of five miles and three and a half miles per second respectively. In 1935 L. Don Leet of the Harvard Seismograph Station discovered a third wave that trails after the first two at only one mile a second, but its route was a mystery. Now Leet and two associates have located its pathway: it travels along the sediment on the ocean floor, bouncing back and forth between the roof of the sediment and the underlying rock. Leet believes that investigation of the third wave may yield new information on the contours of the ocean floors.

Housewives' Fatigue

DISHPAN hands and the other occupational hazards of housework are no joke. The American Medical Women's Association has recently collected the facts, and it reports grimly that housewives and domestic workers are subject to many occupational disabilities, ranging from sore feet to reproductive disorders and melancholia.

The Association obtained data from women doctors in 17 countries. One British study of 194 housewives disclosed that 34 per cent had frequent colds and coughs; 27 per cent had rheumatic pains; 15 per cent had severe headaches; 12 per cent had disabling varicose veins; 79 per cent complained of fatigue, anxiety and depression; and 78 per cent had flat feet, corns or bunions.

Injury to reproductive organs, usually caused by starting back to work too soon after childbirth, is common. Many women injure muscles and tendons by carrying too heavy bundles; many have deformed feet from too much standing and stooping and wearing the wrong kind of shoes. Long hours, overcrowding and lack of labor-saving devices are almost universal complaints. The poorest health is found in women who have to work both in the home and at outside jobs; they frequently suffer from "worry and melancholia."

In India only one third of the families surveyed had their own kitchens, and still fewer their own bathrooms. In many places "the water supply is restricted to certain hours of the day or night, the housewife having to get up at 4 a.m. in order to draw her day's water supply." Great Britain reported that "food patterns seemed to revolve around the breadwinner, and it was evident that if deficiencies were to be remedied and the housewife's dietary habits improved, the man would have to be converted to new ideas." Dr. Doris Odlum of Britain found that unnecessary work is one cause of frustration and dissatisfaction. "Many a young woman begins her married life by doing too much for her husband and children."

There is little protective legislation for domestic workers in any of the 17 countries. In Israel an 8- or 9-hour day and occasional vacations for housewives have been achieved by communal housekeeping; in the U. S. social security has just been extended to domestic workers. The physicians who took part in the symposium suggest that much could be done to improve the lot of houseworkers by providing them with training in efficient methods of work and the proper use of muscles. The Italian Association of Women Physicians proposes that women architects and houseworkers be consulted in the design of houses. Some urge that public health officials take a hand in the situation. Curiously, none of the consultants suggested that women seek relief by trying to get the man of the house to share the work.

Hormone Research

A TOTAL of $2.3 million of Federal funds will be spent this year for study of cortisone and ACTH, in an unprecedented program of concentrated medical research. More than $2 million of this has already been allocated in 129 separate grants to workers in hospitals, universities and other research institutions. Leonard A. Scheele, Surgeon General of the Public Health Service, announcing these grants, said: "It is likely that the most dramatic period of steroid therapy is about concluded and that we are now entering a period of basic research which may ultimately lead to a new era in medicine."

In the main the grants will be used for testing the hormones against diseases "which have always had a discouraging outlook." The tests fall into two categories: 1) appraisal of the drugs for illnesses such as leukemia, where preliminary results are hopeful but inconclusive; 2) follow-up work on conditions such as rheumatoid arthritis, rheumatic fever, asthma and ulcerative colitis, where the value of the drugs is proved, but more knowledge is needed to make treatment as effective as possible. This includes standardization of the best treatment schedule, prevention of undesirable effects and, above all, determining how and why the drugs work, with the ultimate goal of preventing the disorders.

"Many isolated answers will be forthcoming," said Dr. Scheele. "It can be said that one day all these answers will probably be correlated into the expression of a single unifying action which is central to the over-all problem of health and disease. If and when this occurs, medicine then may be practiced on the total organism rather than at the site of disease or disability."

Yogi

THE British medical journal *The Lancet*, which is not often carried away, recently published a report entitled "Remarkable Feat of Endurance by a Yogi Priest." It was an eyewitness account of a performance seen by an Indian doctor named Rustom Jal Vakil, a member of the Royal College of Physicians. Dr. Vakil wrote:

"On Wednesday, Feb. 15, 1950, at precisely 5 p.m., Shri Ramdasji, an emaciated *sadhu* of hyposthenic habitus and middle age, entered an airtight subterranean concrete cubicle on one of the main highways of Bombay city. The act was witnessed at close quarters by well over 10,000 spectators.

"The walls of the cubicle were constructed of slabs of concrete 7 in. thick firmly cemented at the edges to make the cubicle both airtight and watertight; the total air capacity of the cubicle worked out at 216 c. ft.; the lid was another slab 3 in. thick. All six walls of the concrete cubicle were studded internally with thousands of iron nails 3 in. long, most of them old and rusty.

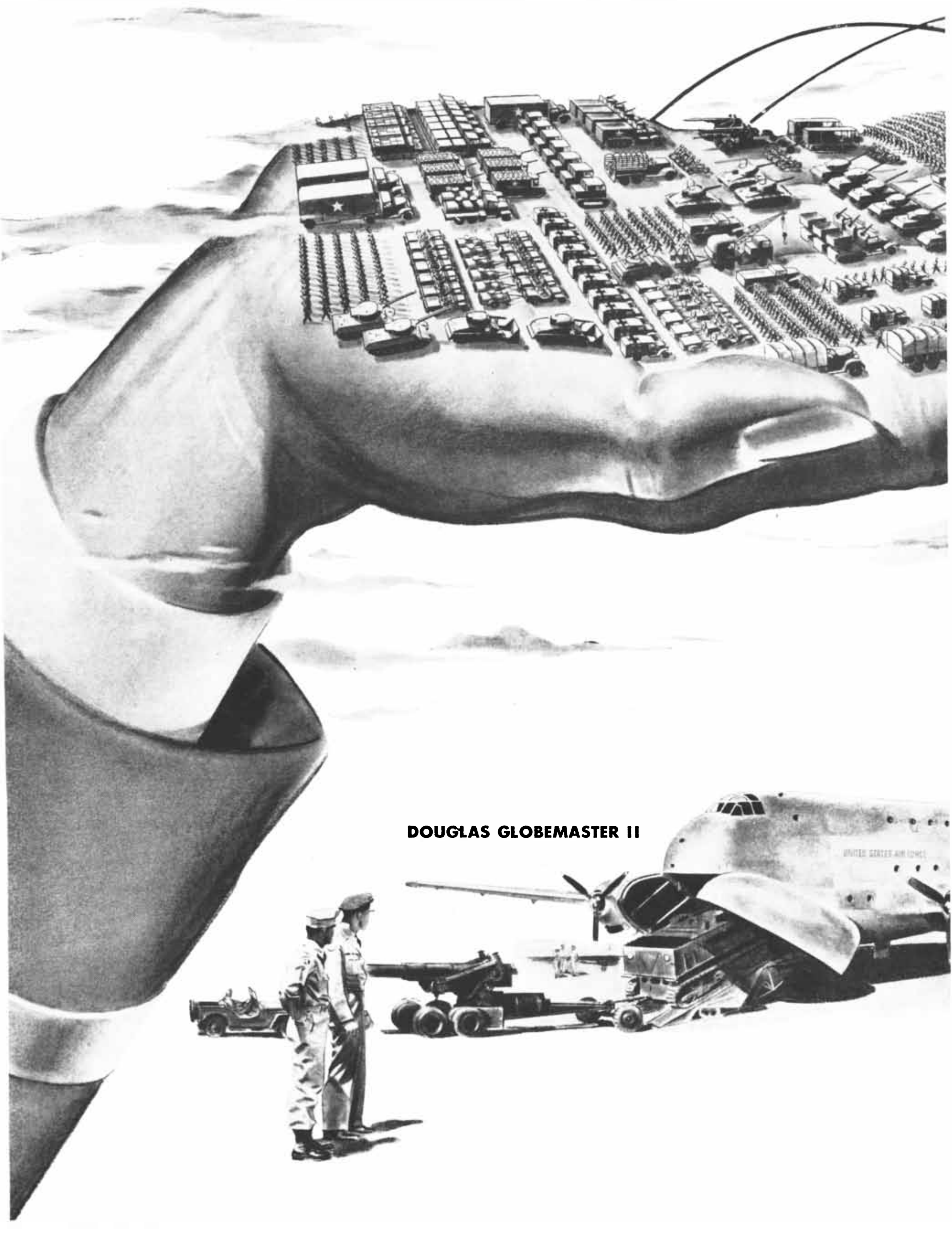
"After the *sadhu* had sat down with legs crossed in the subterranean chamber, the lid was put on and sealed with cement. . . .

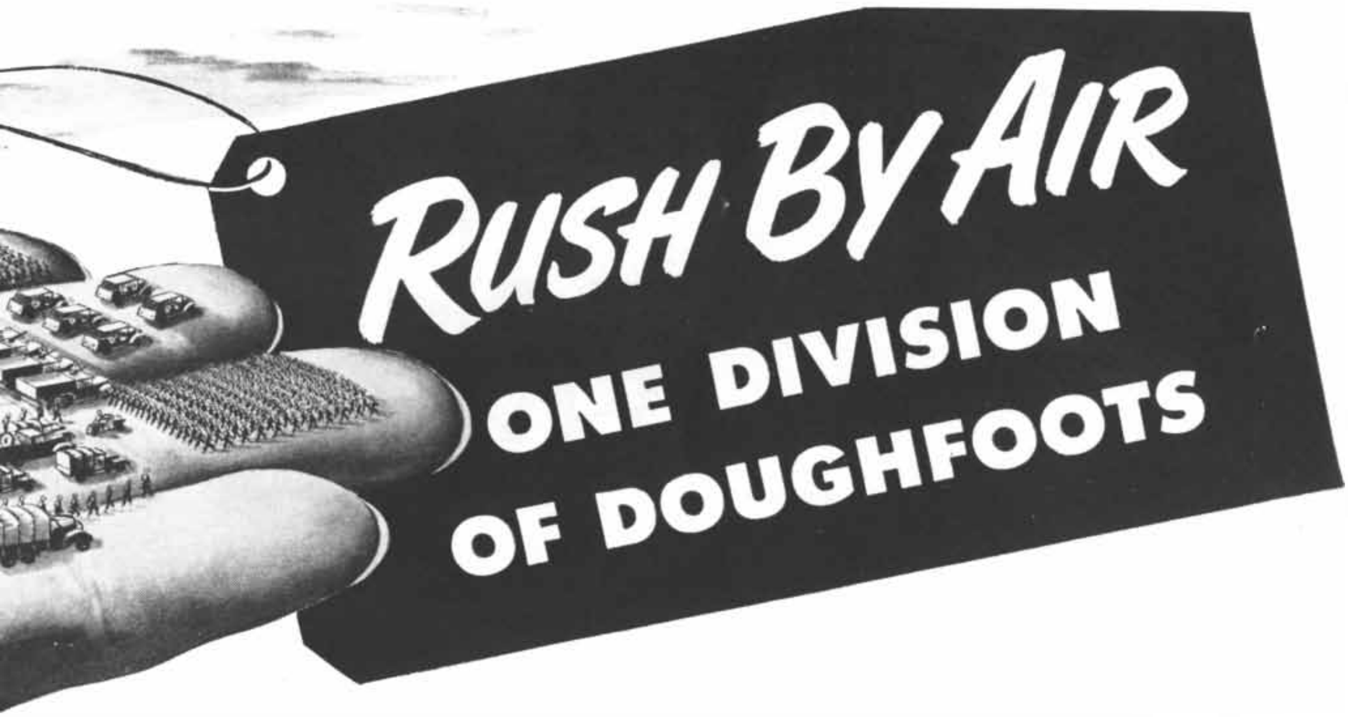
"Exactly 56 hours [later] a narrow opening was bored into the lid, and with the aid of a fire-hose about 1,400 gallons of water was introduced into the concrete cubicle, the narrow opening being subsequently sealed. . . . Then for about six and a half hours the *sadhu* remained within the cubicle in a state of almost complete immersion.

"At 8 a.m. on Sunday morning the concrete lid of the cubicle was detached and the yogi lifted out of the water . . . and immediately subjected to a clinical examination by me. He was in a state of semiconsciousness or stupor with closed eyes and flaccid limbs. The pupillary reflexes were present but sluggish. The pulse, whose rate was quite regular at 80 per minute, was of low volume. . . . The respirations were only 8 to 10 per minute and regular. After a few whiffs of smelling salts, the *sadhu* opened his eyes and took heed of his surroundings. Except for some scratches and cuts over the lower extremities and trunk he appeared none the worse for his gruelling experience. He had remained within the concrete cubicle for just over sixty-two hours."

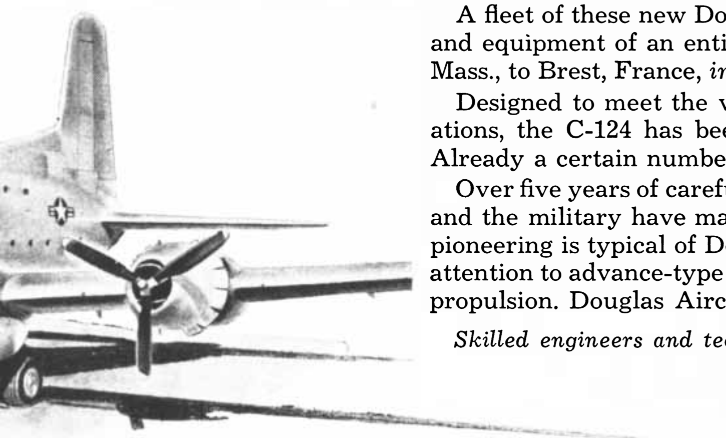
In trying to account for these remarkable events, Vakil recalled that J. B. S. Haldane, the British biologist, once enclosed himself in an airtight tank for an hour without sustaining any harm. Haldane calculated that a man lying perfectly still needs only 12 cubic feet of oxygen a day; on that basis the yogi could have held out for 86 hours instead of only 62. Nonetheless, Vakil found the feat startling enough.

Some of *The Lancet's* medical readers sniffed. Several correspondents promptly wrote to point out that 1,400 gallons will not go into a space of 216 cubic feet.


DOUGLAS GLOBEMASTER II



ONLY A FLEET OF C-124s COULD AIRLIFT AN ENTIRE INFANTRY DIVISION AND ALL ITS EQUIPMENT



Quickly the giant Globemaster II brakes to a stop. Its clamshell doors fold back. Down comes the self-contained ramp. And seconds later battle-ready troops are pouring out of her monstrous belly. Nearby other C-124s unload such divisional equipment as M-24 tanks, 155 mm. Long Toms, bulldozers, trucks and scrapers.

A fleet of these new Douglas transports could airlift all the personnel and equipment of an entire 16,000-man airborne division from Boston, Mass., to Brest, France, *in a single flight!*

Designed to meet the vital need for aircraft to support global operations, the C-124 has been ordered in quantity by the armed forces. Already a certain number are in active service.

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CHROMATOGRAPHY

Some 50 years ago a Russian botanist devised a way of separating the pigments of a green leaf. Now the method has been developed to fractionate a host of mixtures of subtly different substances

by William H. Stein and Stanford Moore

If a petroleum ether solution of chlorophyll is filtered through a column of an adsorbent (I use mainly calcium carbonate which is stamped firmly into a narrow glass tube), then the pigments, according to the adsorption sequence, are resolved from top to bottom into various colored zones.... Like light rays in the spectrum, so the different components of a pigment mixture are resolved on the calcium carbonate column according to a law and can be estimated on it qualitatively and quantitatively. Such a preparation I term a chromatogram, and the corresponding method, the chromatographic method. It is self-evident that the adsorption phenomena described are not restricted to the chlorophyll pigments, and one must assume that all kinds of colored and colorless chemical compounds are subject to the same laws.

IN THESE FEW words a 34-year-old Russian botanist named Michael Tswett in 1906 described a new technique which, to quote a later comment, "was destined to influence the life of man and beast the world over." As the author of this comment, H. H. Strain of the Carnegie Institution of Washington at Stanford University, went on to observe, Tswett's chromatographic technique provided scientists with a "particularly efficient procedure for the preparation of chemical compounds in a high state of purity. Isolation and identification of chemical substances, prerequisites to investigations of composition and molecular structure, were brought to a new state of perfection." Chromatography eventually made feasible the isolation of "numerous ephemeral substances" such as vitamins, drugs and pigments, and revealed "undreamed-of reactions" in living cells.

It would be pleasant to record that Michael Tswett received in his lifetime the acclaim warranted by his discovery. Such, however, is not the case. A quarter of a century elapsed before science began to make wide use of his findings. Since 1930, however, the applications of chromatography have been legion. By now literally thousands of papers have appeared describing investigations in which the method has been used in one way or another. This article will attempt to trace in broad outline the development and application of the technique.

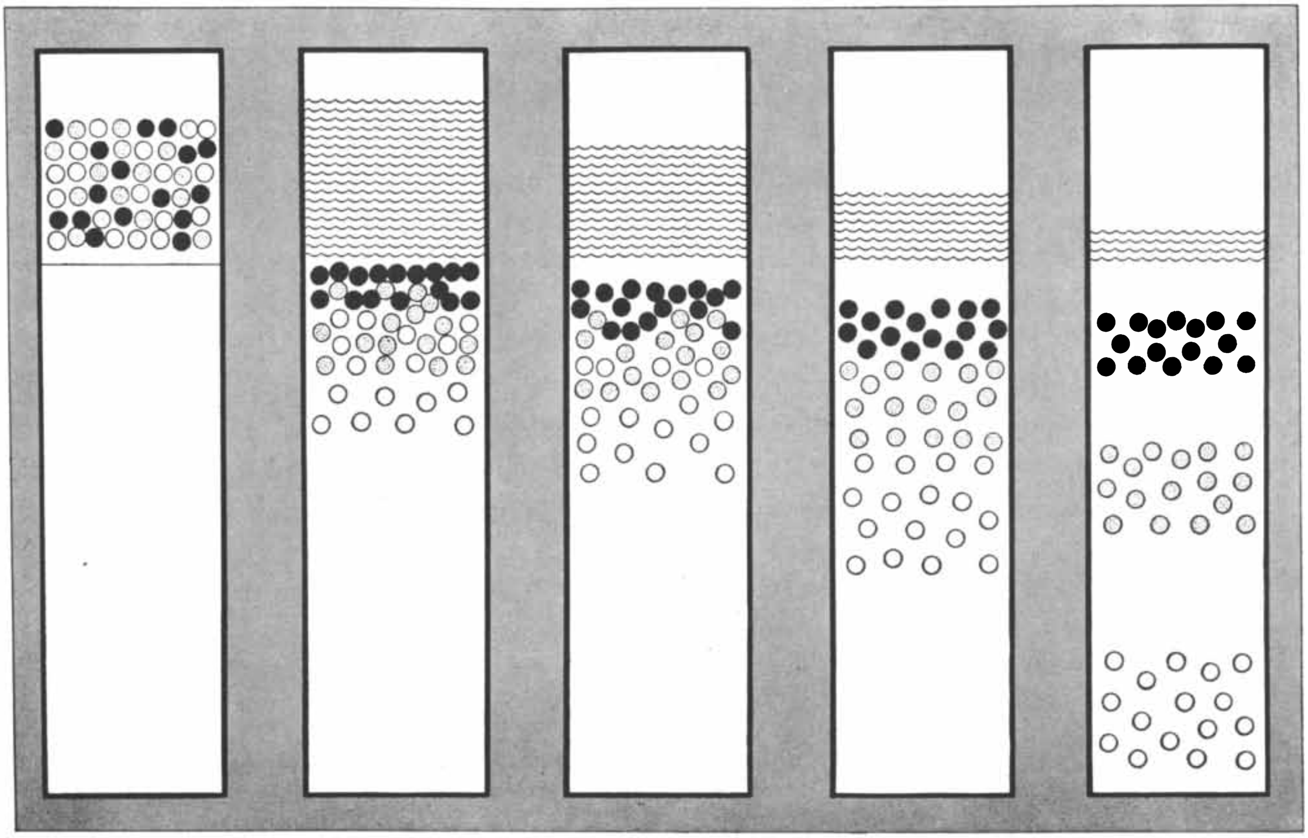
Chromatography utilizes the phenomenon of adsorption. This may be defined as the adhesion of a thin layer of molecules of a gas, a dissolved substance or a liquid to the surface of a solid body. Adsorption is well known as a method for removing impurities. For example, the common gas mask contains charcoal to adsorb the molecules of a noxious gas contaminating the air breathed in by the wearer. In the sugar industry charcoal is employed to remove colored impurities from concentrated cane-sugar solutions so that a clear white crystalline product may be obtained.

Adsorption is also frequently used for the concentration of a desired substance as, for example, in the isolation of the antibiotic drug streptomycin from its mold culture. The drug was adsorbed on charcoal, along with some other substances, and was separated from many of the unwanted products in the culture by simply filtering off the charcoal-streptomycin combination. The conditions were adjusted so that streptomycin would be almost completely adsorbed in a single "batch adsorption" step. A concentrated but still rather impure preparation was obtained when the drug was dissolved from the charcoal with a solvent. If only this batch method were employed, the operations of adsorption, filtration and elution (dissolving off) would have to be repeated many times, employing fresh adsorbent and fresh solvent each time, to obtain material of a high degree of purity.

Tswett's Column

The great value of Tswett's chromatogram is that it provides a very simple device for carrying out repeated adsorptions and elutions continuously. The chromatogram consists essentially of a glass tube filled with a specially prepared adsorbent. A solution of the material to be fractionated is added to the top of the column of adsorbent. After it has drained into the adsorbent, fresh solvent is percolated through the column. The granules of each layer of adsorbent, and the small volume of liquid that surrounds them, act as a single batch adsorption stage. As the solvent flows away from the first layer of granules and surrounds the granules of the next layer, a second batch adsorption occurs, and so on down the column to give the equivalent of hundreds or thousands of individual stages. In this manner a liquid flowing slowly through a packed column performs continuously a number of operations which would require an impossible amount of time and labor to perform individually.

One important difference should be noted between the single batch adsorption in the process we have described for the purification of streptomycin and a single adsorption stage in the chromatogram. Under these particular conditions the adsorption of streptomycin from the mold culture is essentially a one-way process. In order to dissolve the drug from the adsorbent, a solvent (acidic alcohol) that is different from the original medium is required. In the chromatogram, on the other hand, adsorption and elution frequently take place with the same solvent. Thus the molecules of a given compound in the solution are continuously shuttling back and forth in a reversible equilibrium between the flowing solvent and the stationary adsorbent. When the advancing front of solvent carries these molecules down to an unoccupied layer of adsorbent, the molecules leave the solution and are bound at the surface of the adsorbent. As soon as the influx of new solvent from above dilutes the dissolved material to less than a certain concentration, the adsorbed molecules are again released into solution. Thus a given compound travels down the chromatograph column as a zone, the leading edge of which is continuously inching



CHROMATOGRAPHIC SEPARATION is illustrated by schematic diagrams. In the first diagram a solution containing a mixture of three substances has been placed on top of an adsorbent packed into a glass tube. In the second the mixture has drained into the adsorbent and fresh solvent has been added. In the third, fourth and fifth the three substances have separated into zones as the solvent has percolated through the column.

ahead while the trailing edge is being gathered up.

The rate of travel of this zone is governed by the relative affinity of a given compound for the solvent and for the adsorbent. If the molecules in question have a great tendency to stick to the adsorbent, the zone will move slowly. If they greatly favor the flowing solvent, on the other hand, a rapidly moving zone will result. The degree of preference of a particular substance for either the solvent or the adsorbent can be measured quantitatively and given a numerical value known as the distribution coefficient. If the molecules of a substance tend to be distributed equally between the solvent and the adsorbent, the distribution coefficient is 1, and a moderately fast-moving zone results. If the coefficient is smaller than 1, the zone moves more slowly; if larger, it moves more rapidly. The actual value of the distribution coefficient depends upon the nature of the adsorbent and of the solvent as well as upon the chemical structure of the compound itself. For a given combination of adsorbent and solvent, however, the coefficient will vary only with the structure of the substance.

Sensitive Separations

It has been found that the magnitude of the coefficient is frequently very sensitive to slight differences in chemical structure, and it is for this reason that adsorption has been found so useful as a means for separating compounds. In the operation of the Tswett column very small differences in distribution coefficient are translated into appreciable differences in the rate of travel down the column. Thus various substances in a solution, even when very similar to one another chemically, may move down the column at different rates and form separate zones. Within recent years it has been shown that the behavior of zones on a chromatogram can be expressed in mathematical terms, and doubtless this is the "law" whose existence Tswett guessed and mentioned in his first paper.

After the pigments or other substances in a mixture have been separated into zones on the chromatogram, it is necessary to recover the material in each zone for chemical identification. Often this is done simply by pushing the column of adsorbent out of the chromatograph tube with a plunger. As each colored zone of adsorbent emerges from the glass tube, it is cut off with a knife. The segment cut off is then treated with a solvent that removes the desired pigment from the adsorbent, and this solution in turn is evaporated to yield the purified material. There are few more dramatic events in a laboratory than the crystallization of a much sought compound after this simple procedure.

In recent years the Swiss chemist Tadeus Reichstein, and others, have preferred to pass solvent through the column until the various zones emerge successively from the bottom in solution, instead of pushing the entire column out of the chromatographic tube. Each zone is collected as a separate fraction.

When pigments are being separated, forming zones of different colors, the process can easily be followed visually, as Tswett did in his pioneer experiments. Fortunately, as Tswett predicted, chromatography is not restricted to pigments. The technique works equally well for colorless substances, although some physical or chemical method must be employed to make them distinguishable. For example, some types of compounds show characteristic fluorescent colors when viewed under ultraviolet light. In other cases the fractions from the column, or the extruded column itself, may be treated with various chemical reagents that react with the material in the different zones to produce colors. A radioactive material can be located, after separation, with a Geiger counter; a biologically active fraction can be identified by bioassay, and so on. Actually there is a vast number of ways in which the progress of chromatographic fractionations can be followed, and new ones are continually being devised.

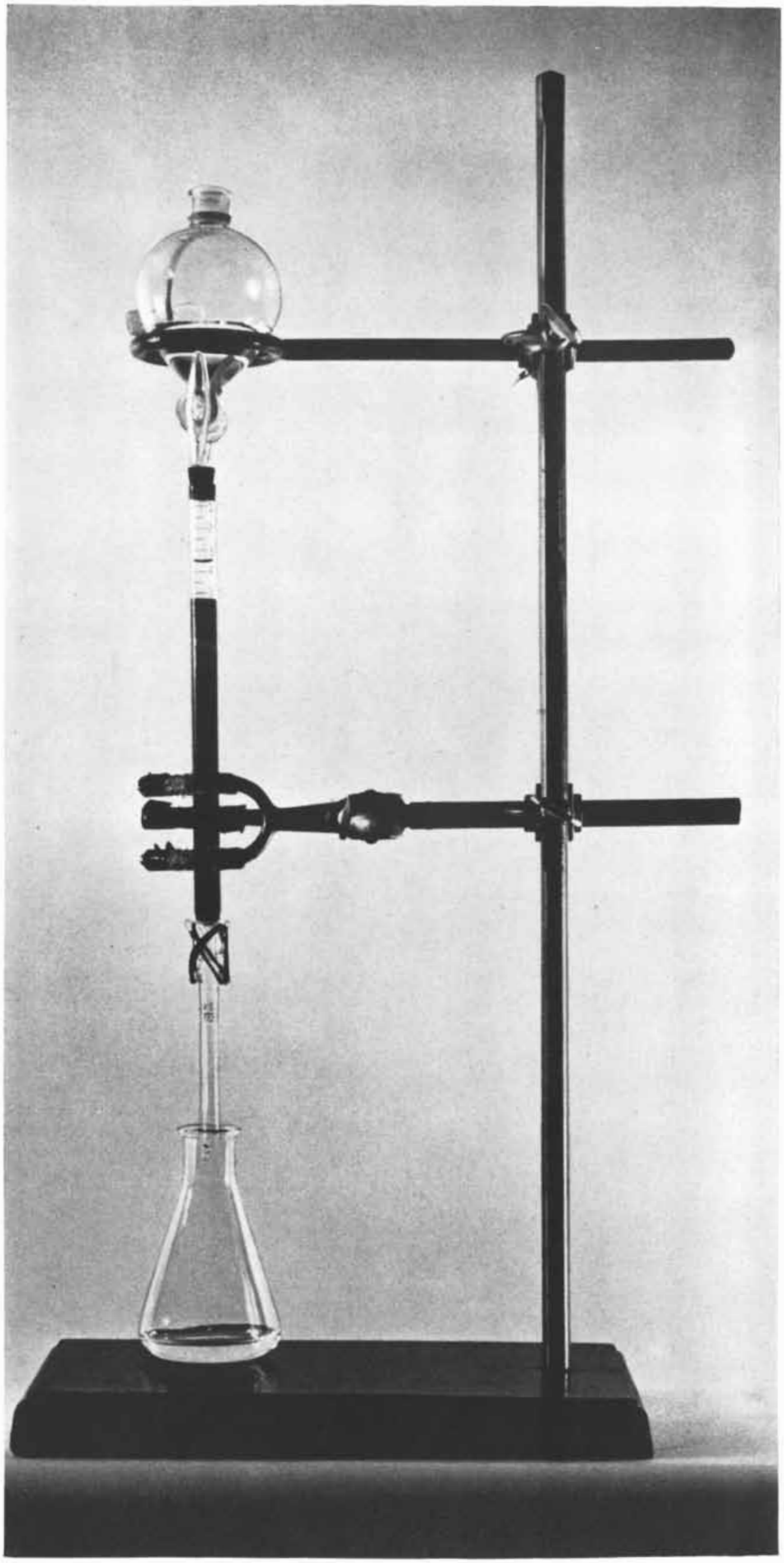
One of the advantages of chromatography is that it requires no elaborate or expensive equipment. All the essential items are readily available in any chemical laboratory. Much of the early and extremely useful work in chromatography was done simply with a long glass tube narrowed at one end and with a few flasks and beakers. Recently additional equipment and procedures have been devised that permit greater efficiency and ease of operation, but few of the modern innovations have modified in any fundamental manner the elegant simplicity of Tswett's original column.

Permutations and Computations

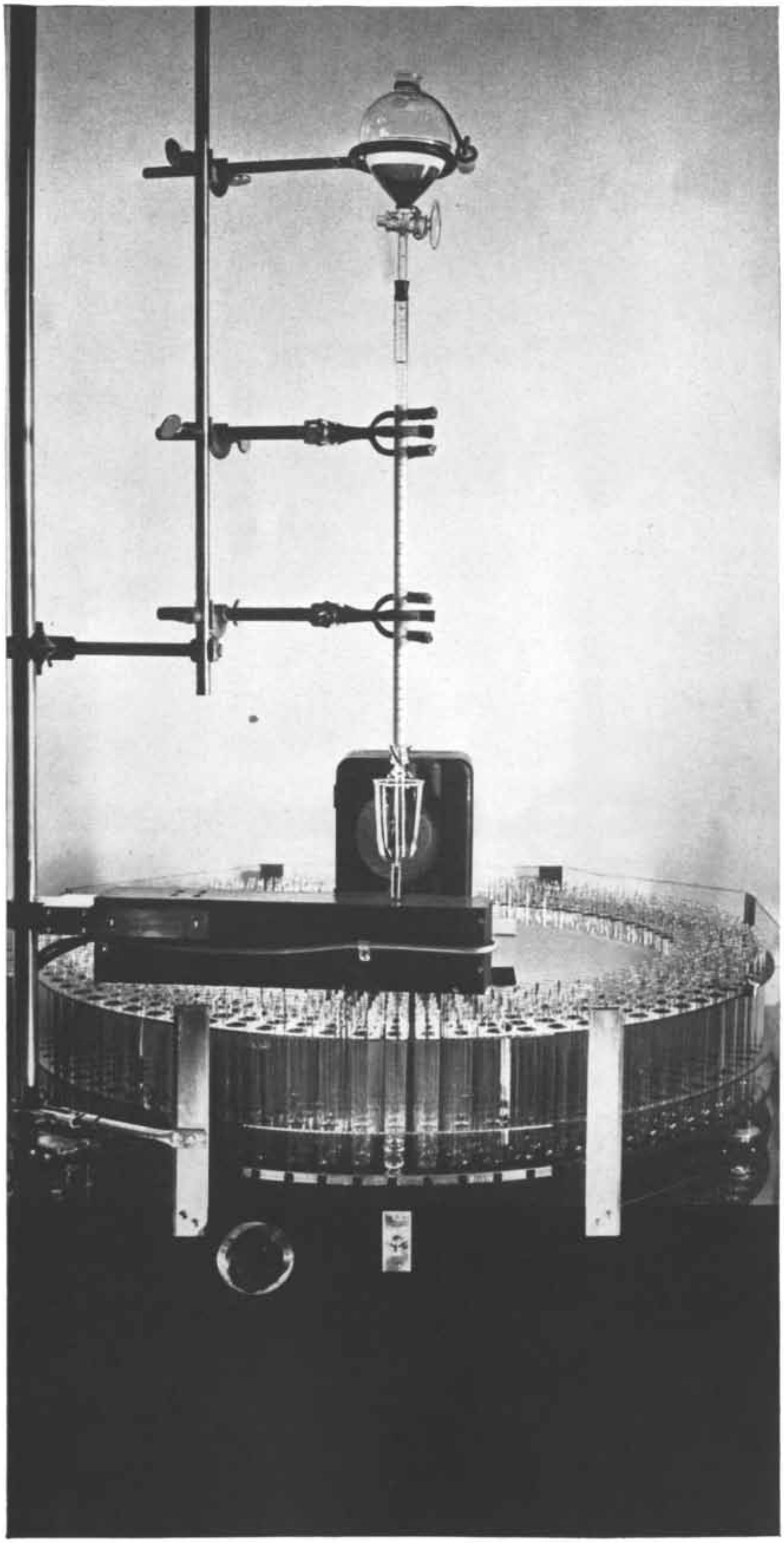
Chromatography is a versatile method. It can be used to fractionate mixtures of gases, liquids or dissolved solids. The method is also a mild one. Although occasionally compounds are altered chemically during the procedure, chromatography has been employed successfully for the separation of some of the most fragile and elusive of substances. It appears increasingly likely that it will eventually be possible to handle chromatographically any group of compounds that can be brought into solution. All that is required is the right combination of solvent and adsorbent.

But that is the difficulty: one of the prime shortcomings of chromatography is that it is not yet possible to predict with assurance what combination of solvent and adsorbent will prove suitable in any given case. The number of possible combinations of solvents and adsorbents is staggering. A partial list of the substances used as adsorbents includes the carbonates of calcium, magnesium and sodium; various forms of charcoal activated in special ways; fuller's earth, bentonite, Lloyd's reagent, talc and innumerable other clays and diatomaceous earths; alumina; silica gel, and a whole host of organic substances such as cellulose, starch, sucrose, inulin, benzoic acid and, more recently, ion-exchange resins. The solvents, too, form an imposing list: water; aqueous solutions of various acids, alkalies and salts; methyl, ethyl, benzyl, propyl, butyl and amyl alcohols; ketonic solvents such as acetone, methyl ethyl ketone and cyclohexanone; hydrocarbons such as benzene, toluene and hexane; the chlorinated hydrocarbons chloroform and carbon tetrachloride; various ethers; the newer derivatives of ethylene glycol, and countless more, alone or in combination.

It is not surprising that for a long time the choice of a chromatographic system was based largely on trial and error. Experience and a few general rules, such



CHROMATOGRAPH TUBE is a simple piece of apparatus that is made in a variety of sizes for different purposes. This small tube is filled with an ion-exchange resin as an adsorbent. At the top of the column is a reservoir of solvent. A small amount of the solvent may be seen on top of the adsorbent.



AUTOMATIC MACHINE is used to collect fractions containing the constituents of a complex mixture. The chromatograph column is in the center; solvent drips from it into collecting tubes on the turntable at the bottom. In the arm beneath the column is a photoelectric cell; when a given number of drops pass it, the turntable rotates and brings an empty tube into position.

as that like tends to adsorb like, have gradually provided some guidance in choosing adsorbent-solvent combinations, and progress is continually being made toward a less empirical procedure. The necessity for much tedious experimentation still is a basic difficulty, and is probably responsible for the fact that the development of the chromatographic method did not proceed more rapidly after Tswett's discovery in 1906.

Milestones

From 1906 until 1931 the Tswett column was used in only a few sporadic investigations. Then R. Kuhn and E. Lederer, two chemists working in Germany, found out with the help of chromatography that crystalline carotene, the yellow pigment of carrots, which for a century had been thought to be a pure substance, was in reality a mixture of two compounds. This important discovery focused attention upon chromatography as a laboratory tool.

Carotene is a precursor of vitamin A, and at that time chemists the world over were busily engaged in attempts to isolate and determine the structure of this and many other vitamins. Soon many investigators in the field of the carotenoids began to use the Tswett column. With its aid Paul Karrer and his associates in Switzerland made important progress in studying the chemistry of vitamin A, and Laszlo Zechmeister of Hungary (now at California Institute of Technology), working with L. Cholnoky, made significant contributions both to carotenoid chemistry and to chromatography. Strain at Stanford, whose comments were quoted at the beginning of this article, did pioneer work in the U. S. in the same fields.

Meanwhile the new tool was also producing major advances in the field of sterol chemistry. The sterols are a large group of substances that play key roles in the life processes of animals and plants. Within this group are found cholesterol, the bile acids, the male and female sex hormones, the plant sterols, vitamin D and the hormones of the adrenal cortex, including desoxycorticosterone and the now much sought cortisone. The sterols have a complicated structure that is capable of innumerable variations. To isolate them in pure form from the intricate mixtures in which they occur in the body, and to elucidate their chemical structure, presented a tremendous challenge to chemists. The eventual successful solution of the problem constitutes one of the truly brilliant chapters in modern chemistry. And in much of this work, destined to be of crucial importance to biochemistry, biology and medicine, the Tswett column was an indispensable aid.

These applications of chromatography all involved the fractionation of mix-

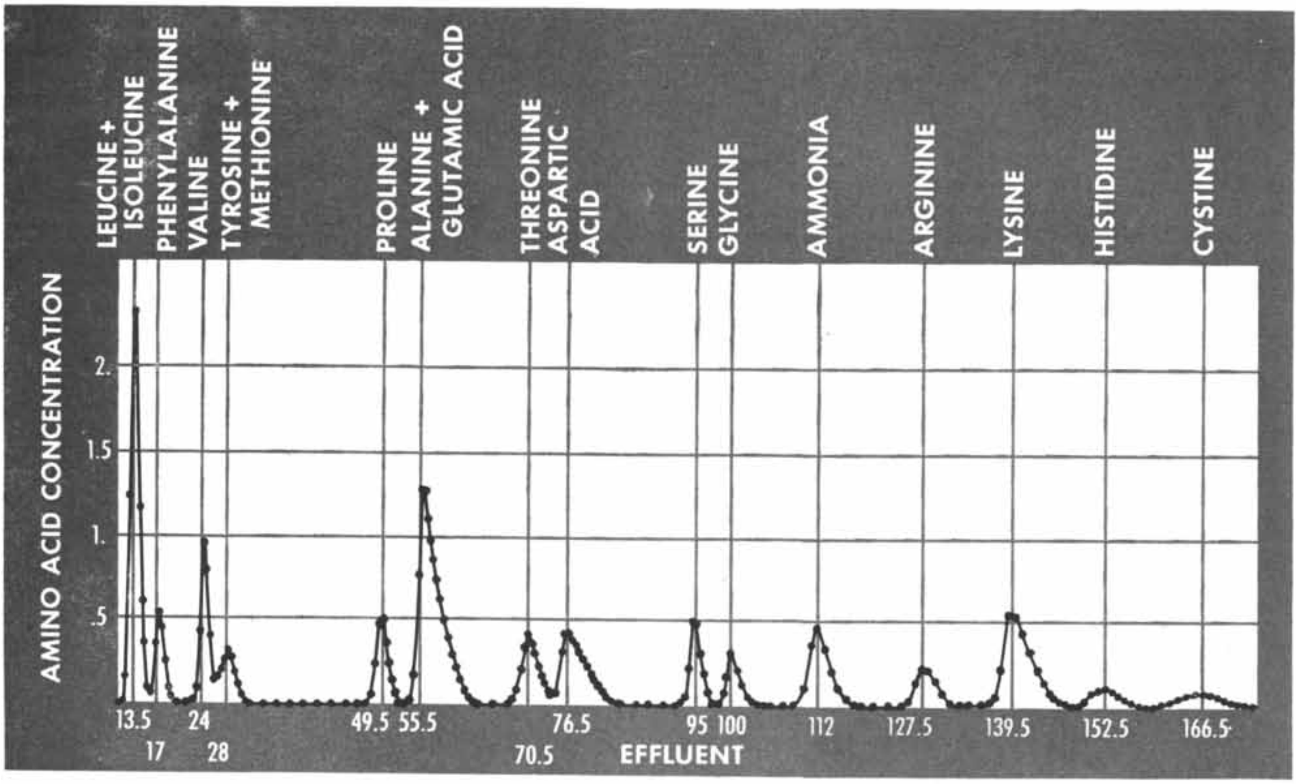


DIAGRAM shows the results of a fractionation by the machine on the opposite page. The mixture was composed of amino acids resulting from the breakdown of the protein bovine serum albumin. Each dot on the curve represents the concentration of one or more amino acids found in one collecting tube. The identity of the amino acids separated is indicated at the top of the page; their relative quantity is shown by the area under the peaks. The concentration of the amino acids is given in millimoles; the volume of effluent, in cubic centimeters.

tures of substances soluble in fat solvents. The widespread use of chromatography for the separation of compounds soluble in water constitutes another chapter in the history of the method. This chapter was opened about 10 years ago by two young British chemists, A. J. P. Martin and R. L. M. Synge, who devised a technique they have called "partition chromatography."

In partition chromatography the column is packed with a porous solid, such as silica gel, cellulose or starch, which is capable of holding water; the water is usually added to the solid before the chromatograph tube is packed. The substances to be separated are put through the column dissolved in a solvent, such as butyl alcohol, that does not mix with water. In such columns compounds separate into zones just as they do in the Tswett column. As Martin and Synge explained their principle, the compounds were separated by virtue of their distribution between the water, held within the pores of the packing as in a sponge, and the organic solvent flowing through the column. In other words, the water took the place of the adsorbent in the classical Tswett column. Hence the new process was called "liquid-liquid partition" chromatography, to distinguish it from the solid-liquid distribution operating in the Tswett column. Actually it now seems likely that the two processes do not differ as much as was first thought.

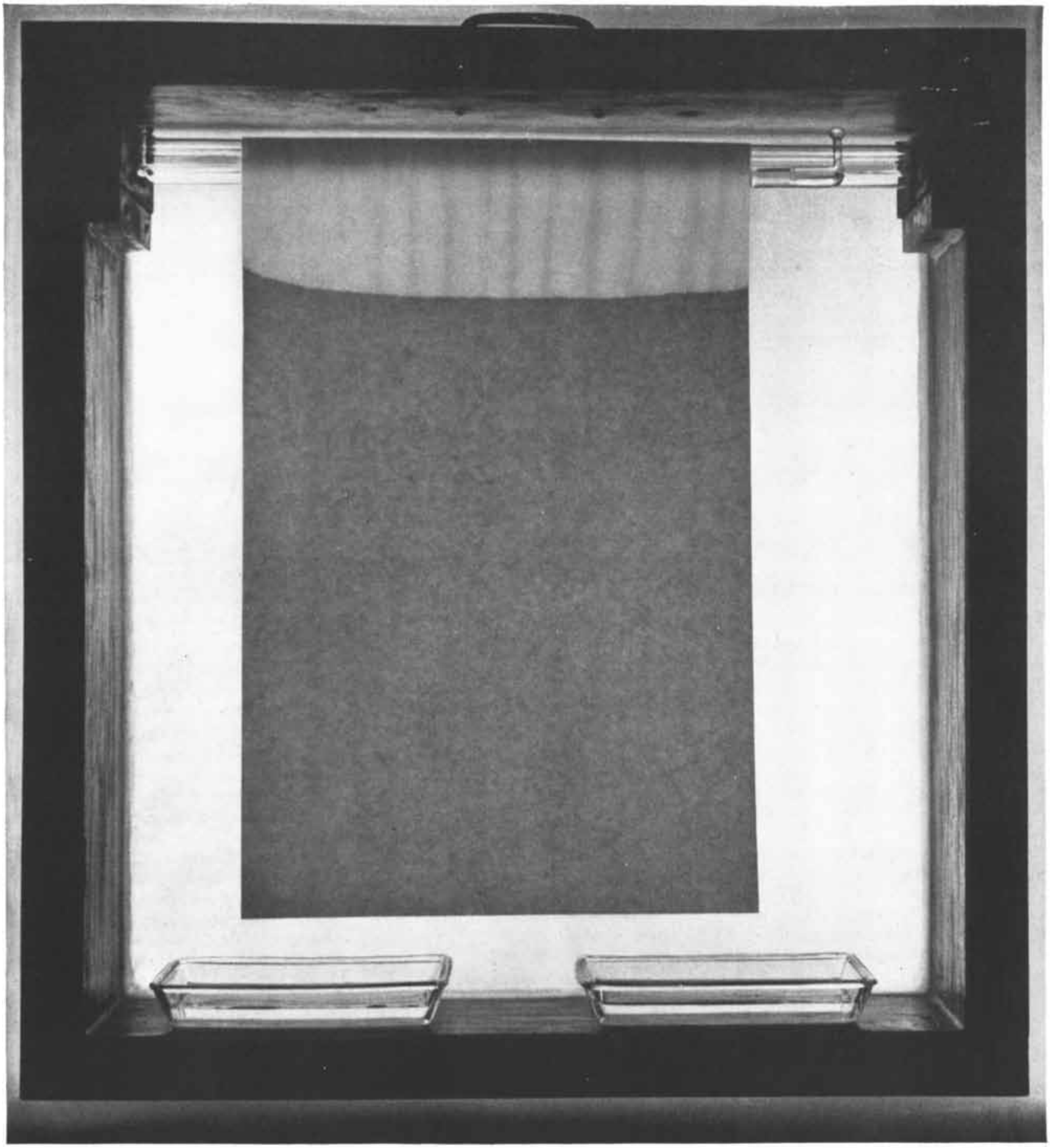
The application of this technique made it possible to separate a number of water-soluble compounds of particular interest to the biochemist, notably the carbohydrates and the amino acids. The new approach also led to improvements in methods for the separation of fat-soluble substances.

Paper Chromatography

Perhaps the most important development that has arisen from the concept of partition chromatography is the novel and simple technique of paper chromatography. In this method, developed by Martin and his colleagues R. Consden and A. H. Gordon, the separations are carried out on strips or sheets of paper instead of on an adsorbent in a glass tube. Chromatography on paper had been tried before, but the British investigators made it work so effectively that within a few years it has become by far the most popular of all chromatographic methods, and is now being used in chemical laboratories the world over.

An entire paper chromatogram can be carried out on a sheet of paper somewhat larger than a page of this magazine. This corresponds to the chromatographic column. A single drop of the solution to be fractionated is deposited on a corner of the sheet, and the sheet is then hung, with the drop at the top, in a closed box containing an atmosphere saturated with water vapor. The top edge of the paper is bent over to dip into a trough containing an organic solvent mixture (*see photograph on the next page*). The solvent creeps down the paper by capillarity. After the solvent has traveled the length of the paper, the compounds that were mixed together in the original drop of solution are separated and distributed as a series of spots in a vertical line along the edge of the paper. If, as is frequently the case, the spots still contain a mixture of compounds, making additional purification desirable, the paper may be turned around so that this edge is at the top and a new solvent is then allowed to flow down the sheet. Thus each spot serves as the starting point for a new chromatogram and may yield a series of spots across the sheet. The end result is a so-called "two dimensional" chromatogram, in which compounds are distributed more or less over the whole sheet. This procedure substantially increases the resolving power of the method.

A complex mixture of amino acids, for example, can be separated into spots which give the pattern shown in the background of the illustration on the cover of this issue. Here the spots have been treated with a reagent that reacts



PAPER CHROMATOGRAPHY uses paper in place of the chromatograph column. Here the paper is hung from a trough containing a solvent. As the solvent travels down the paper (*translucent area at top*), the constituents of a mixture placed near the top will be carried various distances. The paper is suspended in a glass-enclosed box. Within the box a saturated atmosphere is maintained by water and solvent in the dishes at the bottom.

with amino acids to produce a reddish blue color. This is the usual procedure when colorless substances are chromatographed; the paper is sprayed at the end of the experiment with a specific reagent that reacts with the particular class of compounds to yield colored products. Some types of compounds can be seen by examination of the paper under ultraviolet light. Sometimes the spots may be cut out and the separated compounds washed off the bits of paper for further tests.

How Chemists Use It

The great advantages of paper chromatography are its simplicity, rapidity and high resolving power. It is being applied to the study of the constituents of human blood and urine in health and disease, to the separation of antibiotics, to the discovery of new amino acids in bacteria and to a great variety of other chemical problems.

Recently paper chromatography has been employed by Melvin Calvin and

Andrew Benson at the University of California in very beautiful investigations of the mechanism of the fixation of carbon dioxide during photosynthesis. They exposed green algae to radioactive carbon dioxide and later chromatographed on paper the mixture of photosynthetic products extracted from the plant cells. The paper chromatogram was then covered with a sheet of X-ray film and left in a dark room for several days. Any products of photosynthesis that had taken up radioactive carbon dioxide would of course show their radioactivity by making spots on the film, which could be seen when the film was developed. From the positions of the spots on the film laid over the paper, the nature of the products that had taken up carbon dioxide could be inferred.

The ultramicro scale upon which paper chromatography can be performed is one of the factors contributing to its usefulness. With the expenditure of only a fraction of a milligram of material, an investigator can frequently obtain information of incalculable value. The small amounts involved mean that it is not possible to isolate a substance in sufficient quantity for identification by conventional chemical procedures. In paper chromatography, identification rests primarily upon the position of the compound upon the paper sheet. Control experiments are required to show that the position of an unknown substance matches exactly that of a known. For this reason paper chromatography cannot provide identification of a completely new compound never before handled by the investigator. Such a substance may appear as a spot in a position not normally occupied by any known compound. When that occurs, the chromatographer must resort to other methods, frequently column chromatography, to isolate and identify the substance. Paper chromatograms do not always provide quantitative results. Frequently they reveal the nature, but not the exact amounts, of the substances present in the mixture chromatographed.

Separation of Amino Acids

Within the past five years certain refinements in the techniques for column chromatography have been developed. These were stimulated by the longstanding need for quantitative work in the field of protein chemistry. They were touched upon in Joseph S. Fruton's article on the proteins in a recent issue of this magazine (SCIENTIFIC AMERICAN, June, 1950).

As Fruton pointed out, it is of great importance in protein chemistry to find out precisely the quantities of each of the 20-odd amino acids yielded by the breakdown of a protein. In the laboratory of the late Max Bergmann at the Rockefeller Institute for Medical Research the authors of the present article had been concerned with this problem for some time. In 1945 they undertook quantitative amino acid analysis with the aid of chromatography. The procedure finally evolved employed columns packed with potato starch and solvents composed of mixtures of certain alcohols with water or aqueous hydrochloric acid. After the amino acid mixture to be analyzed had been added to the prepared chromatograph column, the solvent was run through very slowly until the amino acids had progressed the length of the column and emerged in the effluent issuing from the bottom of the column. The effluent was collected in a large number of successive small fractions of accurately known volume (.5 cubic centimeters per fraction). A quantitative analysis of each fraction was made to determine its amino acid concentration. From these analyses a curve was drawn, showing the concentrations of the various amino acids in the successive fractions (*see diagram on page 39*).

The amino acids, which emerge serially from the bottom of the column, appear on the curve as peaks more or less separated from one another by valleys. Complete separation of all the amino acids in the original mixture is not obtained in a single chromatogram; several emerge together in one peak. Those that overlap can be separated, however, by running additional chromatograms with different solvents. Moreover, the quantity of amino acid present is given accurately by the area under each of the peaks. It has been possible, therefore, to separate and to determine quantitatively each of the 20 or more amino acids found among the cleavage products of a protein. Starch chromatography has proved useful in several laboratories for determining accurately the composition of blood proteins such as hemoglobin and of important hormones of the pituitary gland. It is being employed also in investigations of the metabolism of amino acids using isotopic tracers.

An efficient chromatogram often requires a very slow rate of solvent flow through the column. It takes seven days, for example, to complete an experiment of the type we have been discussing. Obviously it would be too tedious to stand by all this time and collect each fraction by hand. A simple automatic collecting machine has therefore been built. It consists essentially of a circular rack holding the receiving tubes and a photoelectric counter to count the drops emerging from the chromatogram (*see photograph on page 38*). After a set number of drops have emerged, the turntable moves one notch to bring a new tube under the column. The machine is capable of operating 24 hours a day, thus making practical the performance of experiments of long duration.

Recent Refinements

This article would not be complete without calling attention to other recent developments which appear likely to broaden even further the scope and utility of the chromatographic method. Arne Tiselius and S. Claesson in Sweden have described two new chromatographic techniques known as "frontal analysis" and "displacement development." These procedures, based on new principles, give curves consisting of a series of steps, instead of peaks and valleys. The Swedish workers have devised recording instruments for measuring the stepwise changes in concentration of the effluent. The development of these methods has provided the chemist with additional valuable tools to aid him in his never-ending quest for better ways of resolving complex mixtures. They have already been used to fractionate such divers mixtures as gaseous hydrocarbons, amino acids, peptides, fatty acids and sugars.

The recent development of organic ion-exchange resins also promises to have profound effects upon the chromatographic method. These ion exchangers were originally prepared to remove dissolved salts from water ("Ion Exchange," by Harold F. Walton; SCIENTIFIC AMERICAN, November, 1950). It soon became apparent, however, that they are capable of much wider application. During the war, workers at Oak Ridge and associated university laboratories employed columns packed with ion-exchange resins to separate many of the rare-earth elements formed as fission products in nuclear reactors. Columns of ion-exchange resins are now being used in many laboratories to separate organic compounds. Indeed, current investigations by S. M. Partridge in England and by the authors at the Rockefeller Institute suggest that ion-exchange resins may prove much superior to starch or cellulose as adsorbents for the separation of amino acids and peptides.

It has been said by many, notably the eminent 19th-century physiologist Claude Bernard, that progress in science frequently depends upon the development of good methods. Chromatography furnishes a vivid example of the truth of this statement. It is doubtful that even the fertile imagination of Michael Tswett could have foreseen the great advances in scientific knowledge that have already come, and the greater ones that will surely come in the future, from the application of his chromatograms.

William H. Stein and Stanford Moore are associate members of the Rockefeller Institute for Medical Research.

THE HORN OF THE UNICORN

The unicorn is legendary, but the horn is not. Although an early naturalist discovered the animal from which it came, modern biologists still find it a puzzling problem

by John Tyler Bonner

THE legend of the unicorn is very old, but the first clear accounts of it date only from early Christian times. It appears in the various texts of an ancient book on natural history sometimes called the *Bestiary* and sometimes the *Physiologus* (*i.e.*, the naturalist). The unicorn, says the legend, is a fierce, proud beast that resembles a goat but possesses one straight horn rising from the center of its brow. It is difficult to hunt the unicorn; in fact, there is only one way in which it can be subdued. The hunters take a virgin to the forest where the unicorn dwells and leave her there. The unicorn is powerfully attracted and lays its head in her lap. Only then can the hunters capture the unicorn.

It is not entirely clear what animal was the basis for this legend. Odell Shepard, who wrote an authoritative book called *The Lore of the Unicorn,* says that a number of real animals probably suggested it: the rhinoceros, the oryx (a graceful African antelope with two straight horns that in profile appear like one) and others. But if history is vague about the unicorn, it is specific about its horn. The church of Saint-Denis in Paris, the treasures of San Marco in Venice and many a royal treasury throughout Europe without question contained unicorn horns. They varied in length from three to eight feet; they were as thick as a man's wrist at the base and tapered to a point at the end. Horns of good size weighed about 15 pounds. Along their length were grooves running in a low-pitched gyre, giving them the appearance of gigantic screws. These alone were considered true unicorn horns, or alicorns.

Shepard tells us that there was a period during the 15th and 16th centuries when a unicorn horn was worth 10 times its weight in gold. In the collection of Lorenzo the Magnificent, which like the other Medici collections was enormously rich, an alicorn was considered the second most valuable object, the first being the famous Farnese cup. Another renowned alicorn was the British Horn of Windsor, which was valued at 100,000 pounds, and was reserved as a jewel by Queen Elizabeth.

The fabulous value of alicorn can be ascribed partly to its rarity, but even more important were its symbolic and magical attributes. The horn was a symbol of courage, and its prophylactic properties were miraculous: it could render any poison harmless. For this reason goblets were made from sections of unicorn horn, a safety measure that only kings could afford. It was a common procedure to dip the alicorn into a well or spring to purify the water. The horn was a powerful medicine: either its powder or water that had touched it could cure many diseases. At the end of the 16th century Ambroise Paré, a court physician in the period of Catherine de' Medici, was among the first to show that these properties were not supported by experiment. He fed pigeons arsenic and alicorn and found that the effects of the arsenic were unchanged. It was at about this time that the market for unicorn horn began to drop, but for other reasons.

In 1638 the Danish naturalist Ole Wurm was asked by the merchants of Copenhagen to investigate the true nature of what they were selling as unicorn horns. There had been disquieting rumors to the effect that these horns were not really those of unicorns. It was a matter of considerable importance because Scandinavians had become the principal suppliers of alicorns. Wurm's verdict was that their commodity was not from a unicorn nor even a horn. It was the tusk of a small arctic whale called the narwhal (*Monodon monoceros*). Wurm proved his point by exhibiting the cranium of a narwhal with one huge tooth at its side.

THE cold water of such skeptics as Paré and Wurm dampened the attractive legend of the unicorn and its horn. There remained a peculiar whale with an incongruous tooth sticking out above its upper lip. Even the hunting of this real unicorn was prosaic compared to the legend.

H. C. Raven of the American Museum of Natural History has described the hunting of the narwhal in Greenland. The narwhal is a mammal, and when it comes up for air the Eskimos gauge where they will next sight it. They harpoon the animal from kayaks; the line attached to the harpoon goes to a sealskin float and a drag. When the narwhal is harpooned, it plunges below the surface. It comes up when it tires, and the hunter dispatches it with a lance. The legendary unicorn could only be tricked by a virgin, but a lone Eskimo hunter can master the true unicorn or narwhal.

As a rule only the male narwhal possesses a tusk. In a large male 15 to 18 feet long the great tooth may occasionally reach a length of nine feet. Only two of the narwhal's teeth come to maturity at all; the long one is the left. In females both teeth are short, although there are a number of cases of both females and males that have two protruding tusks. In Hamburg reposes one of the oldest museum specimens of a narwhal: a pregnant female with two tusks, both approximately seven feet long. The animal was brought there in 1684.

The narwhal and its tusk raise some questions. What is the function of the tusk? The most likely possibility is that like deer antlers it is connected with sexual selection. Once it was believed that the narwhal used its tusk to break holes in the ice when it came up for air. However, a Swedish naturalist named M. P. Porsild actually watched narwhals trapped beneath the ice in a bay; they broke the ice with their foreheads and appeared careful not to harm the tusk. Porsild also saw narwhals resting by leaning their tusks against the ice; when disturbed they gingerly withdrew the tusk into the water. Frequently narwhals are captured with broken tusks;

Porsild has seen four cases in which the central cavity of a broken tusk was filled with the thin tip of the tusk of another narwhal. The Eskimos say that old narwhals with broken tusks feel uncomfortable and fill their cavities by ramming young narwhals and snapping off their tusks. If this is true, the narwhal is the lowest mammal to practice dentistry.

The distinctive feature of the unicorn horn was its screwlike gyre. In the period when unicorn horns were so rare and valuable there were unscrupulous merchants who steamed ivory, wood and other materials so that they could twist them and make counterfeit alicorns. The gyre of the narwhal tusk likewise interests the modern biologist. The problem of how the twist is imparted to the narwhal tusk is puzzling. We understand how the shells of the snail and the nautilus and even the horn of the ram grow in spirals, but the gyre of the narwhal tusk is an entirely different matter.

THE most plausible explanation has been offered by a great English biologist, D'Arcy Wentworth Thompson of St. Andrews University, who died three years ago after being a professor for 64 years. If his explanation is correct, the method of nature does not differ too greatly from that of the merchants with their steaming and twisting. The narwhal tusk grows continuously from a fleshy pulp in the jaw; somehow the pulp manages to impart the gyre. Thompson points to a curious anomaly: when a narwhal has two tusks, the twist of each is in the same direction. Thus they are unlike the other paired spiral structures of the biological kingdom, which always twist in opposite directions. Thompson's explanation leans on the fact that the dolphin is known to give a slight twist with every push of its tail. If this is true of the narwhal, every thrust of its tail would exert a twisting force on the base of its great tusk, a force that would affect the fleshy pulp. Thompson suggests that during the lifetime of a narwhal its rotary swimming motion is sufficient to impart four or five full twists to its tusk. He cites as evidence the fact that the cranium of the dolphin is asymmetrical, showing a screwlike twist to the left; this he believes to be a manifestation of the same phenomenon.

Thompson's explanation has a quality that will make it last a long time, for how are we ever to test it? It is somehow appropriate that, like the unicorn, his hypothesis is bold, intrepid and hard to capture.

John Tyler Bonner is assistant professor of biology at Princeton University.

THE HUNT OF THE UNICORN, a late 15th-century French or Flemish tapestry that is now in The Cloisters of New York's Metropolitan Museum of Art, shows a unicorn the size of a goat. Its horn has a twisted design.

Fertilization in Mammals

The union of the mammalian sperm and egg is a delicate process, yet it can be manipulated by experimental techniques. In some animals the egg alone can be artificially stimulated to grow into an offspring

by Gregory Pincus

THE FERTILIZATION of an egg by a sperm is on the face of it a simple phenomenon. But any investigator who attempts to reproduce the event artificially in the laboratory soon discovers that the conditions necessary for a successful fertilization, particularly in a mammal, are far from simple. In the case of mammalian fertilization, which is the subject of this article, there are at least six fundamental requirements for success: 1) the mating must be so timed that the father's sperm will meet the mother's eggs soon after the eggs are shed from the ovary at the mother's periodic ovulation; 2) the eggs must take their proper place in the Fallopian tubes; 3) adequate numbers of sperm must pass from the vagina, where they are deposited, to the Fallopian tubes in the upper part of the reproductive tract; 4) the eggs and the sperm must remain in a fertilizable state until the actual union takes place; 5) the sperm must get through several barriers to penetrate into the egg, and 6) all this must take place at a specific temperature—between about 37 and 40 degrees Centigrade.

Before considering the experiments to be discussed here, let us examine the sequence of events in the normal fertilization of the mammalian egg. At mating the male deposits a huge number of sperm—far more than are necessary for fertilization. It has been shown, for example, that a semen sample from a rabbit, which on the average contains 100 million sperm, can be diluted 100 to 200 times and there will still be enough sperm to reach and fertilize 10 eggs in a female rabbit by artificial insemination. In the case of cattle, with about 4 billion sperm in a single ejaculate, a 300-fold dilution is sometimes adequate for successful fertilization. The minimum number of sperm that must be deposited in a mammal's vagina to achieve fertilization of one egg ranges from 50,000 to 20 million, depending on the species of animal. Of the sperm deposited, comparatively few actually reach the site of fertilization in the Fallopian tubes—no more than about 2,000 in the rabbit and only 100 at most in the rat. The others meet death or entrapment in the female's reproductive tract.

It takes the successful sperm somewhere between 15 minutes (in the guinea pig) and 6 hours (in the ferret) to travel from the vagina to the Fallopian tubes. After arriving there, the survivors face further hazards. Generally they arrive before the ovary has liberated any eggs for them to fertilize, and the sperm cannot wait around indefinitely; their lifetime in the female reproductive tract is limited to a matter of hours. (A notable exception is the bat, whose sperm, deposited in the fall, can actually winter over in the female tract until eggs are ovulated in the spring.) On the other hand, the sperm are also unfortunate if they arrive very long after the egg does. Mammalian eggs are capable of fertilization for only a few hours after they have been discharged from the ovary—from 6 hours in the rabbit to a maximum of 30 hours in the ferret. After that they begin to deteriorate. There is another hazard that sperm may encounter even before they meet the egg. This is the female hormone progesterone, normally secreted by the corpus luteum in the ovary after the egg has been released. Progesterone can prevent fertilization, as experimental injections of the hormone in a female animal at or shortly before the time of mating have demonstrated.

LET US suppose that all these difficulties have been mastered and an egg and some sperm finally achieve a meeting while both parties are in a condition fit for fertilization. Even now the sperm still have a large hurdle to overcome—the armor of the egg itself. It is surrounded by a sticky mass of follicle cells, held together by a thick viscous cement composed chiefly of a sugarlike substance called hyaluronic acid. Fortunately the spermatozoa possess an enzyme, hyaluronidase, which breaks down the hyaluronic acid and permits them to pass through between the cells; when large numbers of sperm are present, the follicle cell covering may be completely dissolved. But the sperm that succeed in getting through this obstacle encounter a second barrier: a thick, gelatinous membrane called the zona pellucida which encloses the egg proper. Ultimately a single sperm may work its way through this membrane and gain entry into the egg. When it does so, the door is shut to all the others; they are either trapped in the zona or left swimming in a space between the zona and the egg body, or the vitellus.

As soon as the fertilizing spermatozoon enters it, the egg shrinks slightly; its nucleus divides in two. One of its two sets of chromosomes passes into a newly formed polar body that is expelled from the egg; the other set remains in the egg, forming the female pronucleus. The head of the fertilizing sperm proceeds to form the male pronucleus, and in the course of a few hours these two pronuclei migrate to the center of the egg and come to lie side by side. Now, within 8 to 20 hours after the fertilization, comes the first cleavage of the fertilized egg into two cells. These in turn go through a series of further divisions that creates a ball of small cells. Each cleavage normally is preceded by a division of the chromosomes so that every cell has both a maternal and paternal set of chromosomes. This subdivision of the egg continues in the Fallopian tubes for two and a half to three days. Then the egg enters the uterus and proceeds to expand somewhat in size. A central cavity, called the blastocyst, is formed within the egg. In the uterus the egg enters upon a growth stage, involving expansion of the blastocyst, which lasts for three to four days in most species. The amount of expansion varies with the species: at fertilization and during cleavage all mammalian eggs are about the same size (from .08 to .15 millimeters in diameter), but the size of the eventual blastocyst differs considerably in different species.

The implantation of the egg in the wall of the uterus is a rather precisely timed and regulated process, and so is its subsequent growth. Unless a corpus luteum is present in the ovary to secrete progesterone, the blastocyst will not grow. The progesterone secreted by the corpus luteum acts upon the uterus to furnish a growth stimulus for the egg. It also conditions the uterine tissue to make implantation of the egg possible.

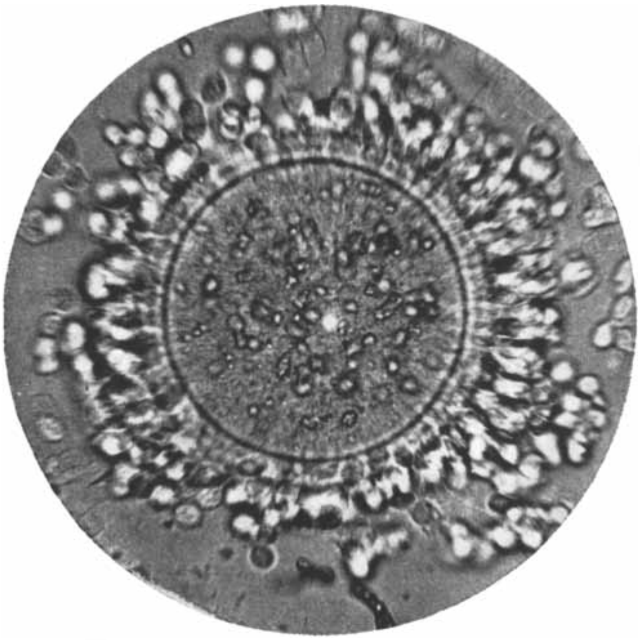
This same hormone progesterone also exercises some control over the fertilization of eggs in the first instance, as we have already noted. If, after an egg or group of eggs has been fertilized, a fresh ovulation occurs, even a heavy insemination with sperm will fail to fertilize the later eggs, so long as corpus luteum tissue in the ovary is actively secreting progesterone. In this way the hormone insures that the uterus will not have to carry fetuses of different ages.

THIS, then, is the picture of what takes place when a mammalian egg is fertilized and begins its development. Obviously there are great practical difficulties in the way of investigating the process experimentally in mammals. For this reason most of our fundamental knowledge of the nature of fertilization and development in animals has had to come from studies of non-mammalian animals ("Fertilization of the Egg," by Alberto Monroy; SCIENTIFIC AMERICAN, December, 1950). Frogs and sea urchins have been favorite subjects, because they shed thousands of eggs and billions of sperm, fertilization takes place in the water and an experimenter can observe in laboratory dishes what goes on in streams, ponds and the sea in nature. Recently, however, some of the obstacles that have stood in the way of effective experimental studies of fertilization in mammals have been removed or reduced by the development of certain new techniques.

One of the difficulties is that mammals ordinarily yield only a few eggs at one ovulation. The mammals commonly available for laboratory experiments produce from 3 to 16 eggs at most, and some of the most interesting species—*e.g.*, man, the cow, the horse—generally ovulate only one egg in each breeding cycle. This of course is a considerable handicap in any study that requires accurate quantitative data. A number of years ago the medical scientists Philip E. Smith and Earl T. Engle, then at Stanford University, made a most fortunate discovery: they found that if pituitary gland tissue was implanted in immature female mice, the mice would ovulate 3 to 10 times the normal number of eggs. The agent that is capable of producing this superovulation, it was later learned, is the pituitary's gonad-stimulating hormone. By injecting this hormone we have caused a rabbit to ovulate more than 100 eggs at one time, instead of the usual 6 to 10, and a cow to produce up to 150 instead of the customary single egg. Furthermore, a single insemination is capable of fertilizing practically all of these superovulated eggs. The photograph at the bottom of the next page shows 22 superovulated eggs that were taken from the Fallopian tubes of a female rabbit 24 hours after a mating. Every single egg has been fertilized and has proceeded to cleave. By stimulating superovulation and removing the eggs at a chosen time, an experimenter can obtain good numbers of unfertilized eggs in any desired stage.

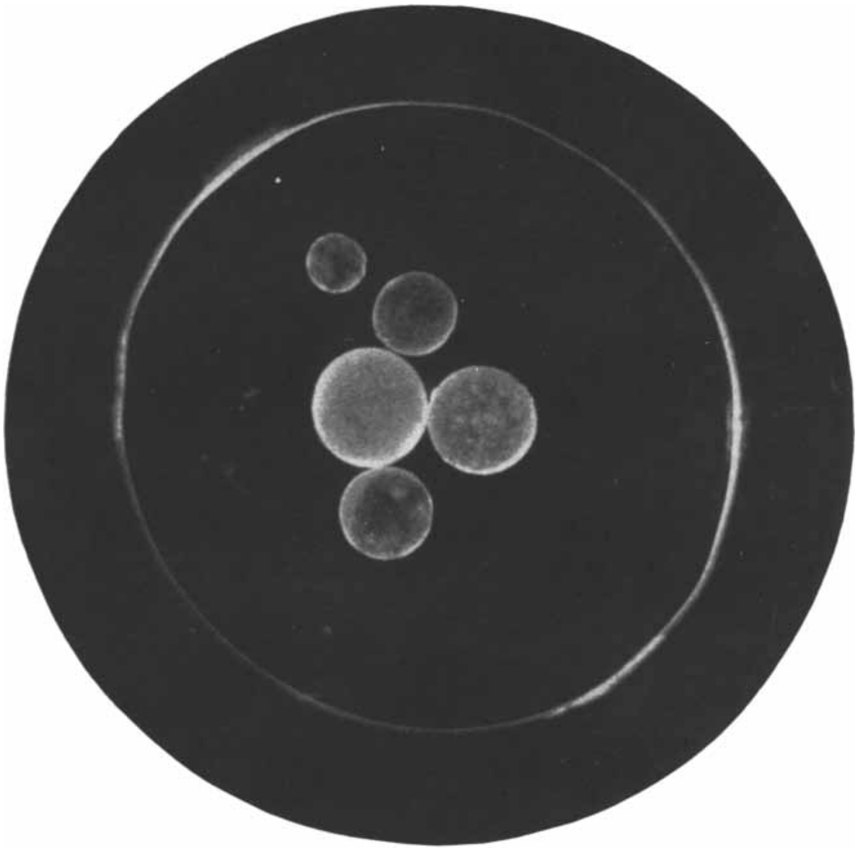
A SECOND important advance that has helped in the experimental study of mammalian eggs is the development of methods for keeping eggs alive outside the female reproductive tract. Rabbit eggs have been grown to the late blastocyst stages in a culture medium of blood serum. M. C. Chang at our laboratory has recently shown that fertilized rabbit eggs can be stored for several days at refrigerator temperatures, just as sperm are stored for use in artificial insemination.

The third useful technique is the transplanting of eggs from one animal to another. Sixty years ago the brilliant English physiologist Walter Heape transferred fertilized eggs from one rabbit into the Fallopian tubes of another female rabbit, and the second animal produced offspring from these eggs. Twenty years ago the writer took up the technique and used it not only to transplant eggs from rabbit to rabbit but also to plant eggs from an experimental culture into a host female. The transplanting of eggs has now been successfully accomplished in rats, mice, sheep and goats, and it is being tried in cattle. The eggs in a few cubic centimeters of blood serum may be taken up in a pipette and deposited in either the Fallopian tubes or the uterus. The best results are obtained when the developmental stage of the egg corresponds with that of the tubes or uterus. One of the advantages of the egg transplantation technique is

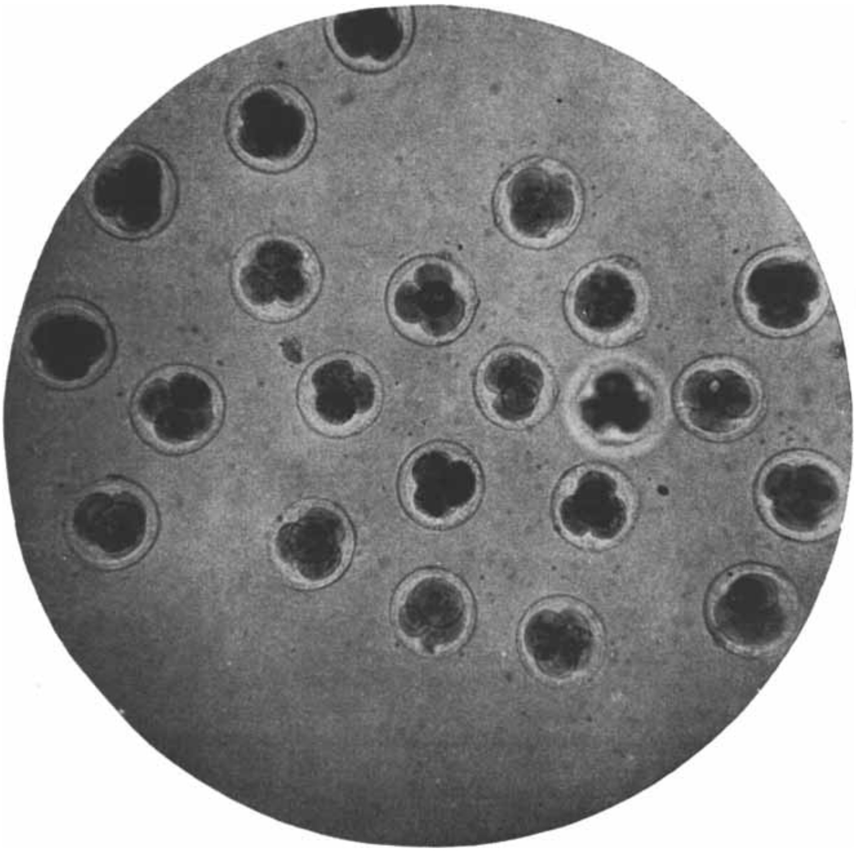


UNFERTILIZED EGG was taken from the Fallopian tube of a rabbit. It is surrounded with follicle cells. The ring between the cells and the egg is the zona pellucida.

FERTILIZED EGG was taken from the Fallopian tube of a rabbit six hours after ovulation. The two translucent objects at the bottom are the polar bodies.



RABBIT BLASTOCYSTS were placed in a watch glass six days after fertilization. The blastocyst is a stage in the development of the fertilized egg.



SUPEROVULATED RABBIT EGGS were taken from the Fallopian tubes 22 hours after mating. Each of the eggs has cleaved into several small cells.

that genetic "markers" may be used to identify specific eggs. For example, when eggs obtained from a white rabbit are transferred to a colored rabbit, the white young born obviously come from the donor mother.

The development of these techniques has made a wide variety of problems accessible to investigation. One of the first was the possibility of fertilizing mammalian eggs outside the body. About 20 years ago the writer and E. T. Enzmann made an attempt that appeared to be completely successful. We added a few drops of sperm to freshly ovulated rabbit eggs in a watch glass. In about half an hour we saw the follicle cell masses surrounding the eggs break up. We removed the eggs, washed them and transferred them to female rabbits in a pseudopregnant condition (*i.e.*, females that have ovulated without their own eggs being fertilized). These rabbits bore young which clearly came from the true parents, since the offspring had the specific genetic markers of the donor female and the male furnishing the semen.

Yet in recent years many attempts have been made to fertilize mammalian eggs *in vitro*, and with one possible exception (a human egg) all apparently have been quite unsuccessful. In Paris R. Moricard, seeking an explanation, has found some evidence suggesting that too much oxygen may impede fertilization. Ordinarily there is relatively little oxygen in the Fallopian tubes. Moricard removed Fallopian tubes containing freshly ovulated eggs from rabbits, injected sperm in the tubes and then sealed them off to prevent access of air. He found that sperm then penetrated into some of the eggs. Since in unsuccessful experiments under the usual laboratory conditions sperm apparently do not even enter the zona pellucida, it may be deduced that oxygen in the air may change the physical state of the zona so that it becomes an impenetrable wall to attacking sperm. It should be noted, however, that in Moricard's experiments sperm penetrated into only 22 per cent of the eggs, whereas normally close to 100 per cent of the eggs in the Fallopian tubes are fertilized. This suggests that some unknown factor in the tubes also is necessary for the effective fertilization of mammalian eggs. Perhaps in our original experiments sufficient amounts of this essential substance were present more or less accidentally. Eventually the Mystery of the Missing Factor will be solved, but its existence illustrates again the special conditions demanded even for the apparently simple process of sperm penetration.

CHANG has recently unearthed other factors that apparently oppose the union of the sperm and the egg. The seminal fluid evidently contains a substance toxic to eggs, for eggs placed in the sperm-free liquid from a semen sample are killed within an hour. In normal mating this toxic factor must be removed, probably by the tissues of the uterus and Fallopian tubes, before the tide of fertilizing sperm reaches the eggs. Chang has also discovered that blood serum possesses a substance that kills sperm. This poison, too, acts quite rapidly. Fortunately the walls of the oviducts filter the blood serum and normally prevent the passage of the spermicidal factor into the Fallopian-tube cavity. But any hemorrhage into the cavity is a real hazard to the sperm present.

In view of what we have learned about how finely balanced the mechanism of fertilization is, it may seem foolhardy indeed to try to "fertilize" the egg by completely artificial means. Yet parthenogenesis (*i.e.*, the initiation of embryo development without the intervention of sperm) is much more common in nature than most people realize. It is the normal method of production of the male bee, of some worms and of many other animals, to say nothing of plants. The eggs of certain aquatic animals, such as the sea urchin, can easily be made to produce normal young by stimulation with a chemical, heat or some other artificial agent. A species of parthenogenesis sometimes occurs even in mammals. Investigators have often observed a spontaneous cleavage of eggs within the ovarian follicles or the tubes of certain animals, and in some instances even fairly advanced development of an embryo. Such embryos, however, are destined for death before birth, and it is a fact that no proved case of a true parthenogenetic birth among mammals has ever been found in nature.

In 1927 Dr. Champy of France discovered, in a culture of unfertilized rabbit eggs cultivated *in vitro* at body temperature, that some of the eggs underwent cleavage very similar to that of fertilized ova. The writer, following up these observations, found that true cell division and chromosome reproduction took place in many of these eggs. He noted that eggs taken from the Fallopian tubes immediately after ovulation mirrored normal development rather faithfully, whereas ova taken one to three days later tended to fragment and degenerate. He proceeded to expose rabbit eggs to the treatments used to induce artificial parthenogenesis in non-mammalian animals. These included high temperature, low temperature, hypertonic solutions, hypotonic solutions, certain chemicals and so on. Most of these treatments when properly administered initiated a certain degree of development of the egg, such as the typical movement of the egg nucleus from the periphery to the center of the egg, chromosome division and cleavage. But none of the treatments led to the prompt and uniform cleavage and development seen in non-mammalian eggs. Even with the best treatments devised, only a minor proportion of the rabbit eggs proceeded to cleave at a normal rate. And among those that apparently did cleave normally, many soon stopped, due to degenerative processes that set in. From the large number originally subjected to activating treatment only an occasional egg reached the blastocyst stage.

Two new experiments were then resorted to: 1) treated unfertilized eggs were transplanted to pseudo-pregnant female rabbits, and 2) artificially ovulated eggs were cooled shortly after ovulation within the rabbit's own Fallopian tubes. The latter was accomplished by an operation which exposed the Fallopian tubes and enclosed their mass of superovulated eggs in a special cooling apparatus devised by H. Shapiro. Both of these experiments yielded some true parthenogenetic offspring, all females. In a large number of trials, a few of the rabbits that received transplanted treated eggs bore normal rabbits. From the cooling experiments there came a single embryo that developed to term. But all together only about one egg in 2,500 subjected to activating treatment emerged as a live offspring—a most discouraging proportion when contrasted with the 90 to 100 per cent success achieved with similar treatments of sea-urchin eggs.

THE experiments on egg-cooling have recently been extended by C. Thibault in France. He has obtained percentages of advanced development roughly similar to ours. In our experiments we noted that the eggs whose development was most nearly normal contained the normal diploid (doubled) number of chromosomes, and we traced this situation to the fact that in these eggs the formation and expulsion of a second polar body was suppressed. Instead, the polar-body nucleus acted within the egg as a substitute for the male pronucleus. Thibault, besides confirming the occurrence of this phenomenon in the rabbit, has also observed it in the sheep. But in the rat, curiously, the result is different: rat eggs given precisely the same cooling treatment promptly extrude the second polar body. The resulting eggs, containing only a single (haploid) set of chromosomes, fail to undergo normal development. Evidently the formation of a double set of chromosomes is essential to produce even an approximation to normal parthenogenetic development.

It is clear that we are barely on the threshold of experimentation in artificial activation and mammalian parthenogenesis. The mature, unfertilized mammalian egg is a short-lived, delicately balanced organism, and we are far from knowing the elements involved in this balanced system. It may be that in certain mammalian species the contributions of the spermatozoon are so essential that duplication of the process of fertilization in the absence of sperm is impossible. This appears not to be true of the rabbit and is probably not true of the sheep. Only further experimentation can decide the issue.

What is the use of investigating mammalian parthenogenesis? One obvious answer of course is that whatever contributes to our knowledge of the biology of reproduction is worth while. But there are also engaging implications. A parthenogenetic offspring contains only maternal genes. Furthermore, it is well on the way to complete genetic homogeneity, and the successive self-reproduction of its female descendants should lead in a few generations to a degree of genetic uniformity which in normal sexual reproduction would be attainable only after many generations of inbreeding. A successful method of parthenogenesis would therefore be very useful for breeding desirable qualities in animals, since such characteristics as high milk yield in dairy cattle, superior wool in sheep and high meat quality in beef and swine are controlled by the genes. By selecting high-quality females and reproducing the desired genes by successive parthenogenesis of the right eggs, it would be possible to get superior animals comparatively quickly. Moreover, since this method yields mainly females, it could be used to multiply the number of milk cows.

EVENTUALLY, by a combination of some of the techniques that have been described, a new *modus operandi* in animal breeding may be attained. It may become feasible to (1) obtain large numbers of eggs from superior animals by making them superovulate, (2) activate these eggs by parthenogenetic means, and then (3) transfer the eggs to ordinary females that would serve merely to develop and bear the young. But clearly it will take long years of experiment to arrive at this goal. To me it is surprising that a few men working in widely separated parts of the world with meager resources have come far enough at least to develop the beginnings of the way. A man in Japan, a group in England, a veterinarian in Texas take up where others have left off. The mammalian egg is taken from its dark and secret hiding place, and against the multiple and cunning safeguards put upon it by centuries of evolution are pitted the patience and sagacity of the truth seeker. I imagine that the latter will one day emerge a victor on behalf of his fellows.

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Color Blindness

Because the visual defect is relatively commonplace, its mythology has a surprising vitality. The psychologist has worked diligently to separate its facts from its fictions

by Alphonse Chapanis

ON the night of July 5, 1875, the steamship *Isaac Bell* put out to sea from Norfolk, Va., on a routine voyage. The night was clear, the sea calm, visibility excellent. The officer of the deck idly watched the lights of an approaching tug off starboard. As it came close he suddenly realized that the tug was heading into the steamship's course. It was too late to avoid a collision. The two vessels crashed, and 10 lives were lost.

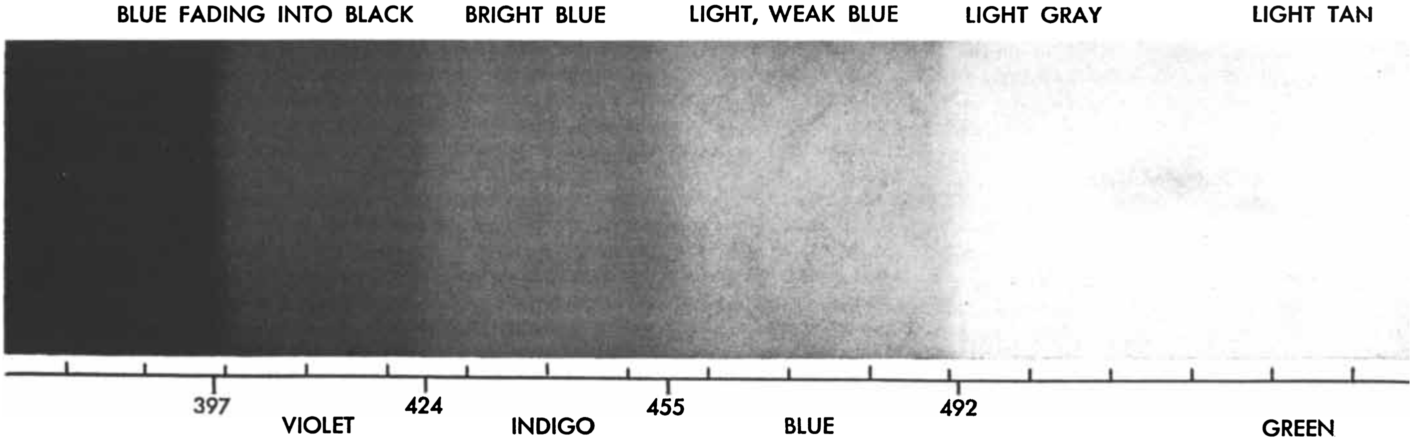
In the investigation that followed, the master and officers of the steamer swore under oath that at the time they signaled the tug its captain could have seen only the steamship's green starboard light. But the captain of the tug insisted that he had seen a red light and had acted accordingly. The accident remained a mystery for four years, until one day the tug captain reported for an examination by the surgeon of the marine hospital at Norfolk. The surgeon, checking the captain's vision, discovered that he was so color-blind he could scarcely distinguish red from green at a distance of three feet!

History records other well-documented instances of the capricious and often unsuspected role that color blindness has played in human affairs. In 1769 one of the leading astronomers of the 18th century, the Jesuit priest Maximilian Hell, made some important observations of the transit of Venus from the northern tip of Norway, the most favorable spot on the globe for seeing it. He recorded his observations in a journal, which was later deposited in the Vienna Observatory. Sixty-four years later the director of the Vienna Observatory, Joseph Johann von Littrow, announced a scandal that upset the astronomical world. Examining Father Hell's journal closely, Littrow found what he thought was clear evidence that many entries had been altered. The original notations, he contended, had been scraped out in many places and replaced by new writing in ink of an entirely different color. Littrow concluded that Hell had faked some of his data.

In 1883, half a century later, the famous U. S. astronomer Simon Newcomb happened to have some time on his hands during a visit to Vienna to inspect a new telescope, and he took a look at Hell's journal. Newcomb soon made an astonishing discovery: The differences in ink color which Littrow had described were not actually color differences but variations in intensity of the same color. Newcomb then examined the paper under a magnifying glass and proved conclusively that no erasures had ever been made. It was obvious that Hell, conscious of the importance of his data, had traced over much of his original writing, often imperfectly, to make it darker and so less likely to fade with time.

Newcomb now had a strong suspicion as to the cause of the whole affair. He inquired whether Littrow was known to have been color-blind. He was, indeed; it had been a matter of common knowledge at the Observatory that Littrow was unable to distinguish between the red color of Aldebaran and that of the whitest star. Thus Newcomb demonstrated that for half a century astronomers had repudiated an important piece of work because of the innocent but mistaken testimony of a color-blind man about the colors of inks in a manuscript.

ABOUT one person in 25 is color-blind, and his defect is likely to influence his everyday living in many small and large ways. I know a young lady who



NORMAL AND ABNORMAL color vision are illustrated by this one-color representation of a full-color spectrum. The colors indicated below the spectrum are those seen by a normal person. The numbers below the spectrum describe the limits of each color in millimicrons of wavelength. The colors indicated above the can wear only one particular shade of lipstick, because if she used any other shade she would not be able to see lipstick smears on her clothes. A color-blind house painter once ruefully told me that he had had to repaint half a house because the color he had used on one side of the house did not match the other. Then there is the chemist who has to rely on his laboratory assistant to identify colors in flame tests of metallic substances; the electronic technician who cannot match strands of wire by their color codes; the farmer's son who has trouble picking cherries "because the blamed things match the leaves in color." And no one knows how many accidents color blindness causes.

Yet the average person still seems to think that color blindness is not a serious defect. Many people go through life without the slightest awareness that they are color-blind, or if they do know, paying it very little heed. Indeed, if you consult your physician about it, the chances are that he will be unable to give you much information. Nonetheless, there are thousands of scientific articles on the subject, and it is the purpose of the present article to touch on some of the highlights of our knowledge about the condition.

Color blindness is probably as old as man. In fact, it used to be thought that among primitive peoples color blindness must have been the prevailing condition. Linguists studying the ancient classics were impressed by the scarcity of names for colors in these writings. For example, the Vedas, the Hindu sacred scriptures, are filled with descriptions of the sky but never once mention that its color is blue. The Greeks' Homer seldom referred to color. Primitive tribes even lack many words to differentiate colors; they prefer to identify a knife as rusty rather than brown, meat as well done or underdone rather than brown or red, a berry as ripe or unripe rather than red or green. The Fiji Islanders commonly use the same term for blue and green and call the dark shades of all colors black. Evidence such as this led early philologists to conclude that the early civilizations must have been made up of men who were almost uniformly color-blind.

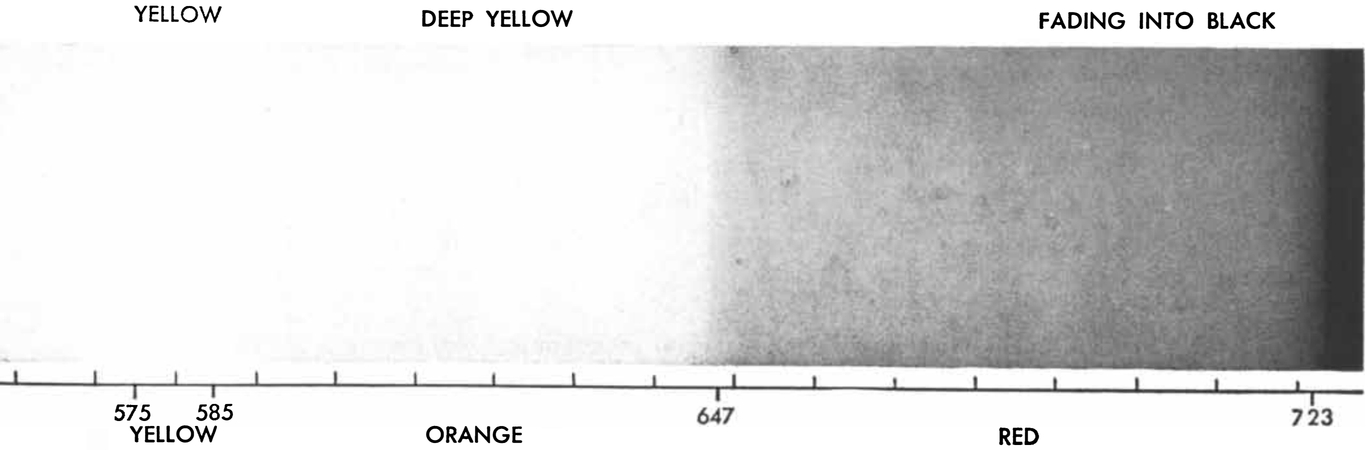
But anthropologists' researches toward the end of the 19th century showed that the philologists were wrong. The Kaffir herdsmen of Africa, for example, were found to possess 30 different names for the colors and markings of cattle. Tests showed that most members of primitive tribes could see and distinguish all the colors from red to violet, although they might not have names for them. A recent study of more than 600 male Fijian natives disclosed that only five were color-blind. This incidence of less than one per cent is far smaller than that among civilized European peoples, where color blindness among males runs seven to eight per cent.

Evidently the reason why primitive man did not have many color names is that he did not need them. He was not called on to make many color discriminations in his everyday life. But to modern man color is vastly more important. The difference between red and green in a small distant light may mean life or death to an airplane pilot and his passengers or to a motorist. A modern physician can often find helpful diagnostic clues in the color of a patient's skin. And in everyday life a man picks out his car in the parking lot by its color and finds it necessary to select a necktie to match his suit. The advertising copy writers have further complicated life for us by adding to the language of color such terms as Russian sable, rosy future, pink lightning, raven red, dynamite, fatal apple, canary yellow, cocoa, toast brown, tender beige, tanglint, copperglo, coffee and camel.

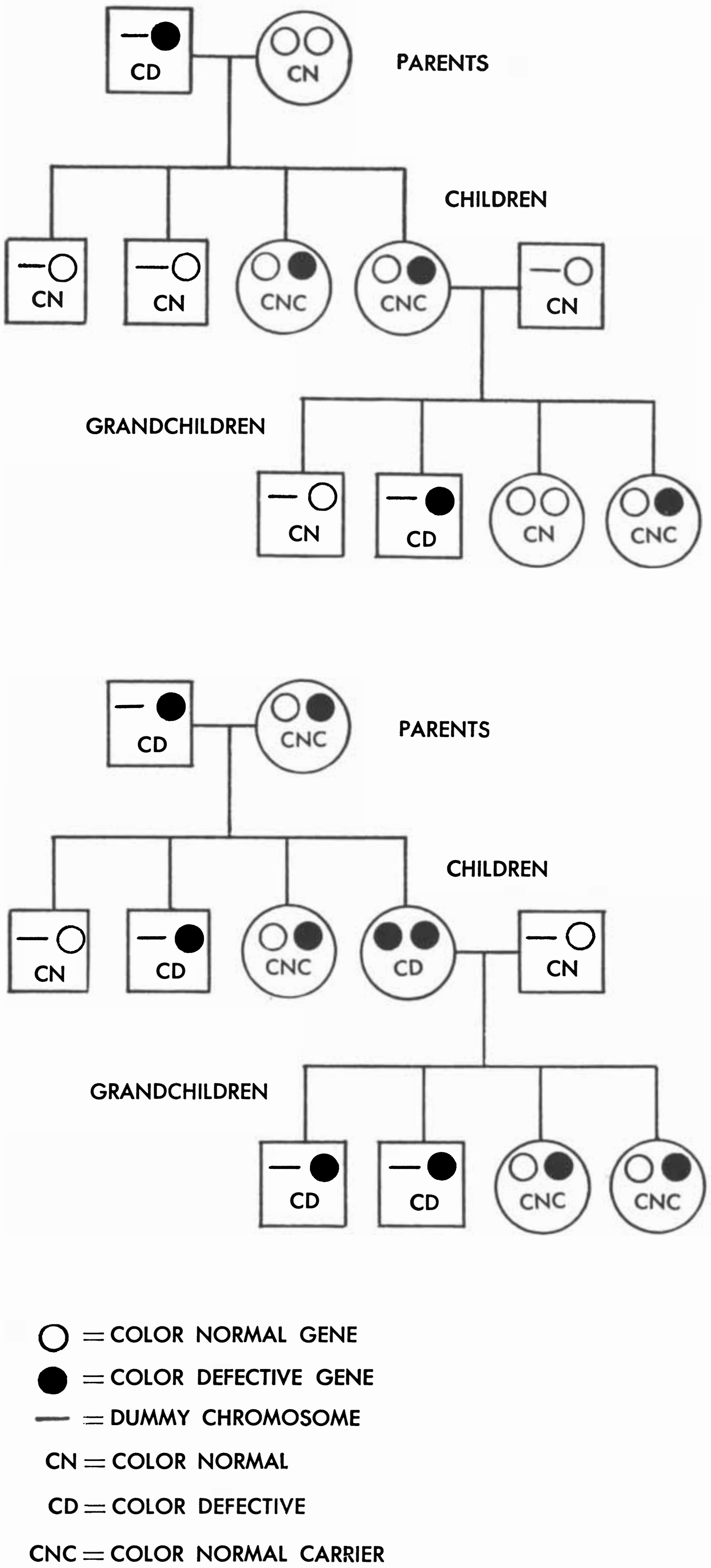
WHAT is color blindness? It is certainly not the inability to identify a color by a particular name, for that is a question of language. Nor is it actually blindness. Most color-blind people are not really blind to color. They can usually see colors, but they confuse certain critical ones. It was John Dalton, the author of the atomic theory in chemistry, who clearly recognized this fact and presented one of the earliest and best scientific accounts of the defect. Dalton himself was so color-blind that when Oxford University conferred on him the scarlet gown of the Doctorate of Civil Laws, the scientist wore the gown everywhere for several days, not realizing that he presented a conspicuous appearance, and astonishing his friends, who knew he was a Quaker and was supposed to wear the somber garb of that sect. In 1794, at the age of 28, Dalton gave a report before the Manchester Literary and Philosophical Society on his sensations to color. This classic description of color blindness caused the defect to be known for more than a century afterward as Daltonism. He said: "All crimsons appeared to me to consist chiefly of dark blue; but many of them seemed to have a tinge of dark brown. I have seen specimens of crimson, claret and mud which were very nearly alike. . . . The colour of a florid complexion appears to me that of a dull, opake, blackish blue, upon a white ground. . . . Blood appears to me . . . not unlike that colour called bottle green. . . . There is not much difference in colour between a stick of red sealing wax and grass."

Reduced to its essentials, color blindness is a defect that makes it impossible to distinguish between two or more colors which most people can differentiate readily. It is not, as is commonly supposed, a single type of deficiency. There are several different varieties of color blindness, and for each kind the defect may occur in varying degrees.

Total color blindness, called achromatism, is extremely rare; only about 100 cases of it have been found in the whole history of visual science. To the achromat, who usually also has other visual



spectrum are those seen by a person suffering from protanopia, sometimes called red-blindness. In protanopia there is a neutral point in the area labeled "light gray." To the left of this point the protanope sees only blues; to the right, only yellows. The protanope also does not see as far into the red as the normal person.



INHERITANCE of color blindness is sex-linked. Men (*squares*) possess only one color normal or color defective gene; women (*circles*), two. The color defective gene is recessive, which means that women are color-blind only if they possess two of them. The chart at the top of the page shows that a color-blind man passes his defect through his daughters to half of his grandsons. The lower chart shows one of the two rare combinations that will result in a color-blind woman. The lower chart also shows that if a color-blind woman marries a color normal man, all of their sons are color-blind.

defects, the world looks like a black-and-white photograph. He can distinguish between white, black and gray of various intensities but he does not see colors as such.

By far the most common kind of color blindness is two-color vision, known as dichromatism. For people with this defect color is essentially reduced to two types of hues: yellows and blues. Most dichromats confuse reds, greens and yellows of certain shades with one another and are unable to distinguish clearly between bluish greens, blues and violets. But they never confuse the first group of colors with the second; yellows and blues are always clearly distinguishable. In addition, there is a particular shade of blue-green that dichromats confuse with gray. Among the red-yellow-green confusers visual scientists distinguish two principal varieties: those who see all colors in their normal brightness relations, though they may confuse one color with another, and those who have abnormal brightness sensitivity to certain colors. To the latter deep red, for example, appears so dark that it may be confused with black.

There is a class of color-blind individuals whose impairment is so slight that only the most sensitive tests will reveal it. They are "color-weak" rather than color-blind. They have little trouble with bright or vivid colors but reveal their defect in attempting to distinguish between the very pale or light browns, tans, greens and pinks.

Dichromatism of various types used to be called simply red-green blindness, red-blindness, green-blindness, blue-blindness, red-green weakness and so on. But these terms have now been replaced by more specific Greek-derived names such as deuteranopia and protanopia. For this there are two reasons. First, terms such as red-blindness and green-blindness are based on a particular theory of color vision, and it is not yet certain that this theory is correct. Second, the term green-blindness, for example, implies that the individual concerned is blind to green. This is a distortion of the facts. When a "green-blind" person looks at a patch of green, he sees a color. Indeed, he will even be able to name it correctly about half the time. The color that he sees is not the same as a normal person sees, but it is a color.

WHAT exactly do color-blind people see? This question is more difficult to answer than one might suppose. We cannot trust the color names used by color-blind individuals; indeed, they may sometimes be quite bizarre. I once heard a color-blind person describe a shade of orange as "grass-green red"! When a color-blind man describes a lemon as yellow, for all we know he may actually be seeing a color which we would call red. Or when he identifies grass as being green, it may actually have the same appearance to him as yellow does to us. In short, although two persons may use the same color names to describe their respective experiences, we cannot be certain that each man would recognize the other's sensations.

Hence visual scientists have had to depend largely on shrewd inferences to deduce what kinds of sensations color-blind people have. Fortunately it has been possible to verify these deductions by one type of direct evidence. A few people have been found with one color-blind eye and one normal eye. Controlled experiments in which these individuals have been asked to look at colors separately with the color-blind eye and with the normal eye have provided us with very valuable information.

From such studies it seems clear that the typical dichromat sees red, yellow and green as simply different saturations, or degrees of purity, of what a normal person sees as yellow. Green appears to him as a relatively desaturated light brown or tan, hardly different from light gray. Yellow is a somewhat more definite tan but still light. Red is a strong, dark yellow, much as a lemon would appear to a normal person in dim light. A slightly greenish blue appears as a very pale desaturated blue, and blue as we see it looks very much the same to the color-blind. These findings are the basis for the statement that dichromats have two-color vision—yellow and blue. Under most conditions they can distinguish between green and red as shades of yellow, but in certain shades and brightnesses red and green may seem identical.

Why is it that most people who have color-vision defects do not know it? During the war it was a common experience in Air Force and Navy recruiting centers to have color-blind applicants emphatically deny the fact. "What do you mean, Doc? I can see colors! I've never had trouble with colors." To the color-normal person it seems incomprehensible that a man can go through life failing to see the richness and variety of color as others do and not be aware of the fact.

The answer to this puzzle is complex and cannot be resolved with a single explanation. In the first place, as we have already noted, most color-blind people do see some colors. Furthermore, nobody can appreciate what he has never sensed. A man born without taste buds will never understand the saltiness of the ocean or the sweetness of an apple. What is the tone of a 50,000-cycle vibration, above the range of human hearing? Or what is the color of infrared light? We cannot give the answers to these questions because they are outside the realm of our experience. Moreover, since we have never experienced them, we never miss the fact that we *cannot* experience them. Color-vision defects, then, do not reveal themselves in a positive manner.

Another part of the explanation lies in the fact that the color-deviant person has learned to use correct color names for many common objects. He knows that grass is green, lemons are yellow, ripe apples are red, and so on, because he has learned these names from infancy. From experience he becomes habituated to follow the names used by everyone else and readily accepts correction. If you correct a color-blind person who calls a light green "pink," he will almost invariably reply, "Oh, yes, it's green. I see it now." All our color names will satisfy him, because he is unable to make sensitive and positive distinctions.

USUALLY it takes special conditions or a specific test to find out that a person is color-blind. Take him out on a dark night away from all other means of identification and ask him to pick out red, yellow and green lights at a distance or through a slight haze. This test may not work if you ask him to identify red and green traffic lights, for he has cues to help him there. In most cities the red light is consistently above or below the green, and the green light is usually a little brighter than the red one. Many cities also have shape or form cues as well as the color differences to distinguish the signals.

Most modern color-vision tests use a more scientific method than merely asking the examinee to name a color correctly. One test, for example, consists of a card with brilliant purplish red dots which form a numeral against a background of deeply saturated blue-green dots. A normal person can see the number immediately because its color contrasts so vividly with the background. But individuals with certain types of color blindness cannot read the number, because to them the dots are all apparently of the same color.

The U. S. Navy has a color-naming test which also avoids ambiguity. The examinee sits down before a lantern which can show a green, red or white light. Each color is identified for him. He is also told that these three are the only lights he will see. Following these instructions he is shown a series of lights in a scrambled order. If he now calls a red light green, or *vice versa,* he has committed himself. Lantern tests are useful not so much to find out whether a man is color-blind, but rather to convince him that he does or does not see things the way most people do. Most examinees will accept the results obtained on a simple lantern test, whereas they will not believe those on a chart test.

This is a good place to lay to rest the popular myth, developed during the late war, that a color-blind person can detect camouflage more easily than one with normal vision. It is hard to trace the origin of this particular fancy, but at one time it was widely publicized. One story I have heard concerns a crew of eight men in a bomber. While they were flying across the southern tip of England, one of the crew members is supposed to have pointed out to his astonished friends the location of camouflaged gun positions, huts, hangars and the like that were invisible to them. News of this man's accomplishment filtered up to higher quarters, and in the course of events he was examined by an ophthalmologist to discover the secret of his remarkable perceptive capacities. The only unusual thing the physician could determine about the man was that he was color-blind. Some time later, after the story hit the headlines, the man confessed that he had known the camouflaged positions because he had helped camouflage them originally. When asked why he had not revealed the fact to the physician who examined him, he stated that at the time he did not realize that his visual examination had anything to do with the airplane trip. I do not vouch for the veracity of this story.

It is theoretically possible that color-blind people might on some occasions see through camouflage better than normal people, but it would certainly not be true in most situations. The Army Air Forces actually conducted extensive experiments during the war to test the possibility. At Eglin Field in Florida a large number of color-blind and color-normal men were flown over a series of camouflaged positions and each man was asked to point out what he could spot. Although some of the color-blind men had better scores than some of those with normal vision, on the average the normal group did better than the color-blind group.

CAN color blindness be cured? The answer, unfortunately, is that at the present time there is no known cure. Most kinds of color blindness are inherited; the defect has been identified as a sex-linked recessive characteristic. That is, it is carried on the sex chromosomes, of which each man and each woman has a pair. This kind of genetic linkage results in some rather involved pedigrees. A color-blind man who marries a normal woman with no defective genes will have normal children. But all his daughters will be carriers of his defective genes and will transmit them to their sons, half of whom will be color-blind. Thus the defect travels from father to grandsons through the father's daughters. If a woman who is a carrier marries a color-blind man, all the children—boys and girls alike—stand a 50-50 chance of being color-blind. The union of a color-blind woman and a normal man will result only in color-blind sons, but the daughters, though all outwardly normal, will be carriers of the defective genes. Since recessive characteristics that travel on the sex chromosomes have a better chance of appearing among men than among women, color blindness is mainly a male defect: about one man in 15 is color-blind, but less than one woman in 100 is so afflicted.

Color blindness is occasionally produced by damage to the eye, the optic nerves, or the visual centers of the brain. The yellow vision of jaundice is well known. The defect also can arise from overloading of the body with certain toxic substances, such as digitalis, santonin and nicotine. But removal of these substances often restores normal vision.

The hereditary nature of most color blindness does not automatically preclude the possibility of our ever finding a cure. Modern medicine has found ways to control some hereditary diseases—diabetes, for example. During the past 75 years an amazing array of remedies has been tried against color blindness: repeated exposure to bright colors, subcutaneous injection of iodine, electrical stimulation of the eyeball, warming of one eye, dosage with extremely large quantities of vitamins, injection of cobra venom, the continuous wearing of tinted glasses, and many others. There is no scientific evidence whatsoever that any of these remedies has produced a permanent cure.

During World War II color-blind men who sought to enlist in the Air Forces, Navy or Marines, which require normal color vision, were willing to try almost anything to circumvent this barrier. One optometrist sold color-vision "training" plates. Courses of training were sold for $100 to $200. "Remedies" were publicized over the radio, and advertisements guaranteeing sure cures were published in newspapers. Most of these claims were made by optometrists. (It is important to remember the distinction between an optometrist and an ophthalmologist. An optometrist is licensed to prescribe eyeglasses but is not medically trained; an ophthalmologist or oculist is a medical specialist.) Most of the people who attempted to cure color blindness were sincere but uninformed with respect to the physiological and psychological aspects of color vision. Not one of the techniques they offered does cure, improve or otherwise affect color blindness.

Some patients thought that they could see better after these training exercises. As we have already noted, however, the color-blind man is no judge of his own condition. The claims of improvement rested on the fact that many who took the training were able to pass tests of color vision which they had previously failed. But it is well known that anyone who practices long enough on any particular test can improve his ability to take that test. That was precisely what was happening in the case of the color-blind men. But if, after training, they were confronted with an entirely different test of color vision, they turned out to be as color-blind as ever.

Herein lay a real danger to the services. Most visual experts who were in the services during the war saw at least a few color-blind men who had been able to get by the initial visual examinations but whose judgment in critical situations where color discrimination was needed could not be trusted. So dangerous has the situation become that a spokesman for a naval medical research laboratory has recently prepared a report repudiating all such alleged cures. This report has been accepted by the American Medical Association's Section on Ophthalmology, the American Ophthalmological Society, the American Committee on Optics and Visual Physiology and the Association of Schools and Colleges of Optometry.

If you think you are color-blind, or if you have even the slightest suspicion that you may be color-blind, the thing to do is to have yourself tested by a reliable ophthalmologist. If the results of the test show that you are color-blind to even the slightest extent, accept the fact as best you can and remember that your judgments on matters of color may sometimes be incorrect.

ON the positive side of the ledger a great deal can be done to help the color-blind person in his everyday living. It would be extremely helpful, for example, if traffic lights were standardized so that the red always appeared above the green, or *vice versa,* everywhere in the country. Indeed, it would be possible to design traffic lights that most color-blind people would never confuse, simply by making them yellow and blue. The city of Baltimore has traffic lights which are better than most in this respect. The red light contains a considerable amount of orange and the green light is actually a bluish green. Although not bluish enough, this color is usually distinguishable from the red by the color-blind. Most of the traffic lights in Baltimore also have a vertical streak running through the green light and a horizontal streak through the red light. To most color-normal people the streaks are not noticeable, but color-blind people have found them an additional helpful cue.

Despite such aids, there will always be occupations in which color-blind workers will find themselves handicapped. Until scientists can unravel completely the complexities of color blindness and find a cure for it—if one exists—the answer will probably lie in the proper selection of personnel. Early recognition of color-vision defects in schools and proper vocational counseling would do much to eliminate serious disappointment in later life. We hope that eventually color-vision tests will be administered routinely as a part of every child's regular physical examinations.

Alphonse Chapanis is assistant professor of psychology at The Johns Hopkins University.

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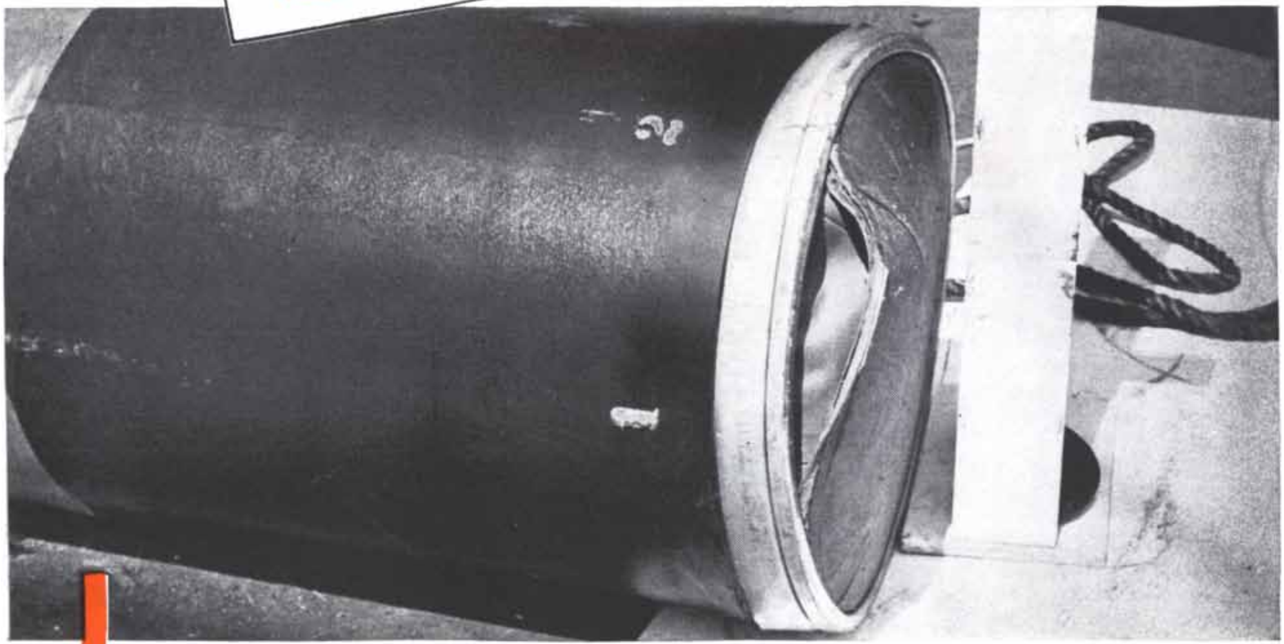

A close-up of an FPEB drum-package dropped twice from a height of two feet on its bottom chime, at an angle of approximately 45 degrees. Although the fibre bottom pulled out of the metal chime, the envelope —made of VISQUEEN—did not leak.

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WARM CLOTHES

What fabrics or combinations of fabrics best insulate the body against the loss of heat? An account of an unusual study that produced some objective and practical answers to this question

by M. E. Barker

IN North Africa during the last war we saw the Arabs put on heavy wool overgarments in hot desert storms when the thermometer passed 125 degrees Fahrenheit. They did this to keep from blistering in the dry air, the humidity of which sometimes dropped to less than 10 per cent. On the other hand, in Alaska soldiers on still, sunny days occasionally walked about in their shirt sleeves with the thermometer below zero.

Plainly what a human being needs to wear to keep comfortable depends upon a number of factors besides the temperature of the air. The body is a heat machine, and the function of clothing is to provide it with the proper kind and amount of insulation against a given outside environment. There are so many variables, however, that the requirements are not easy to determine. An engineer can calculate the heat loss from a steam pipe under a known set of conditions with a considerable degree of accuracy. But in the case of the human machine we must take into account not only such factors as the relative temperatures of the skin surface and the surroundings, the area exposed and the rates of heat loss by contact, by convection and by radiation, but also the heat produced by the body's internal mechanism, the amount of water evaporated from the skin, the energy used in heating the air breathed, and so on. Furthermore, different parts of the body are at different temperatures which may change rapidly, and this complicates matters.

We are accustomed to think of the human body temperature as about 98 degrees F. That is the temperature inside the body, but on the surface the skin of the back may be 90 degrees, of the legs 85 degrees and of the feet 50 degrees or even lower without too much disturbance. The body's automatic controls act to cut off circulation to surfaces exposed to cold; in this way they prevent the body as a whole from losing too much heat. In cool weather the skin temperature drops to an average of 90 degrees or less.

The human body is a machine of from one-tenth to one-fifth horsepower. At complete rest the average man generates about 280 British thermal units of heat per hour, which is the heat that would raise 280 pounds of water one degree F. At hard work his heat output may be at the rate of about 500 B.T.U. per hour for short periods. Under average conditions he generates somewhere between 300 and 400 B.T.U. per hour. We shall take 400 as the standard figure. Now about a quarter of the heat produced is expended in evaporating water into the breath and warming the air drawn into the lungs. That leaves about 300 B.T.U. per hour which must be dissipated from the body surface to keep the body at a stable temperature. If we lose heat too slowly, we get heat prostration; if we lose it too fast, we chill and develop all kinds of complications. Since the average man has approximately 20 square feet of body surface, about 15 B.T.U. must be lost per hour through every square foot of body surface.

Nature has several excellent automatic control mechanisms, such as sweating and change of body-surface temperatures, to regulate this heat loss, but we must help her by the judicious selection of proper clothing. Clothing serves exactly the same purpose as a snowbird achieves on a cold morning when it fluffs its feathers to get a little more air into them as an extra overcoat. Our clothes put a barrier of many layers of small cells filled with air around the body as insulation, and the insulation value of a fabric depends upon the amount of *still* air trapped in the cloth.

MANY excellent technical studies have been made, some of them still classified as military information, in this general field. The published studies agree on certain conclusions that are particularly pertinent here. The rate of heat loss from a warm surface to the air is proportional to the difference in temperature. Air currents blowing over the surface increase the heat loss in proportion to their velocity. The insulating effect of a fabric covering depends on the thickness, kind and condition of the fabric. Certain types of porous fabrics actually accelerate the loss of heat from a surface, because the holes, or channels, in the cloth act like finned tubes to increase the surface and the air turbulence. Cloth has much less insulation value when it is stretched or pressed than when it is not under such tension or pressure. Moreover, moisture in the cloth also increases the heat loss. Hence a thin porous fabric that is damp or tightly stretched over the body surface may have less than zero value for insulation. A porous, or cellular, type of fabric covering, such as a sweater, is a good insulator only when it is protected against air currents by an outside layer of closely woven fabric or paper.

The study to be reported in this article was designed to isolate and measure the effects of such factors with a view to improving the design and selection of clothes for outdoor wear. To eliminate psychological factors and obtain objective measurements, the tests were carried out on standard mechanical objects instead of on the human body. The "bodies" used were rectangular one-gallon varnish cans filled with warm water at a temperature of 100 to 110 degrees F. They were clothed with various fabrics and combinations of fabrics, fitted around the can snugly and uniformly like a sock. The cans were then exposed to air of varying velocity, temperature and humidity, and the rates of heat loss were measured.

All the samples of cloth, purchased new from commercial sources, were washed twice in warm water and soap, air-dried, ironed, dried further in an oven at 200 degrees F. for 30 minutes and then allowed to come to air moisture equilibrium. This procedure was intended to reduce the cloth to the condition of garments after some wearing. The can itself weighed about 8.8 pounds when full and had a surface area of a little under two square feet, so its surface per unit weight was about twice that of a man. This made the experimental "body" more responsive to the varying conditions than a man would be. The can was placed so that the wind from the blower, after passing through the air-conditioner, blew directly against one edge of the can and whipped around all its surfaces, simulating the case of a man exposed to the wind.

Some 300 different tests were conducted on these cans. They were tested without clothing and in many different kinds of garments, wet and dry. They were subjected to hot and cold weather conditions, were exposed to still air and to winds ranging up to 2,000 feet per minute. To ensure accuracy each test was run three times on three different days.

A sample of cloth was first tested dry in still air and in a stream of air moving at 1,200 feet per minute—about 13 miles per hour, a moderate outdoor breeze. The same cloth sample was then tested after being wetted so it had a water content equal to the dry weight of the fabric, which is the amount of moisture found in many undergarments after an hour's wear during exercise. Though we are not generally aware of it, our clothes always contain some moisture. For instance, a human subject was given a freshly dried cotton undershirt to put on and was asked to walk one mile at a moderate rate in fine weather; the outdoor temperature was 68, the humidity 60 per cent and a 5-mile-per-hour breeze was blowing. At the end of that walk the undershirt had gained 17 per cent moisture by weight; yet the subject was sure that he had not sweated.

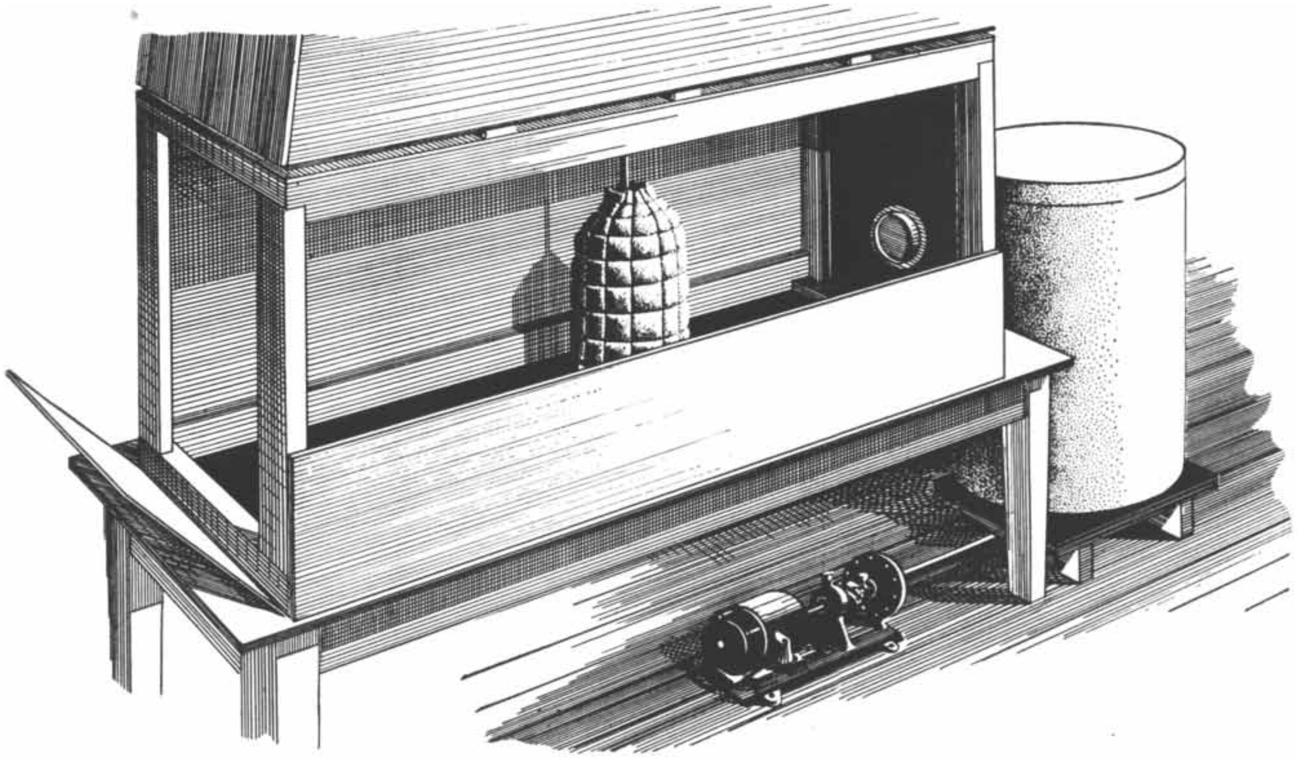
It is believed that the apparatus and the methods used in the can experiments give results that parallel field wearing tests with a good degree of accuracy and that conclusions drawn from this study are reliable, especially since they check with practical experience.

BEFORE examining these results it will be helpful to consider briefly a few pertinent facts concerning the mechanism of heat loss from the human body. Actual temperature measurements taken on a man wearing an undershirt, shirt and closely buttoned jacket on a day of moderate temperature, with the air at 70 degrees F., showed that the temperature at the outside surface of the coat was 74 degrees; the air between the coat and the shirt was 80 degrees; between the shirt and undershirt, 83 degrees; between the undershirt and the skin, 85 degrees, and at the skin surface, 94 degrees. The temperature gradient between the skin and the undershirt of course is the primary factor in comfort.

But the moisture conditions also are extremely important. Suppose, for example, that the 85-degree air next to the body has a water saturation, or humidity, of 80 per cent. As this air with its water vapor diffuses outward through the clothes, it cools and its relative saturation rises, since the moisture-holding capacity of air drops with temperature. If the incoming air with which it mixes is dry, the water content may stay below the saturation point. But when the outside air has a high humidity, say 80 per cent, the air passing through the clothes becomes supersaturated with moisture, which then condenses in the fabric. The dampened cloth, with moisture filling some of the tiny air cells that would otherwise provide insulation, conducts heat away more rapidly and therefore increases the heat loss from the body. It may multiply the heat loss as much as three times, as compared with the loss through dry clothes. (Hence there is a real physical basis for the cliché that "It isn't the temperature; it's the humidity.") Damp clothes also have another cooling effect: they take heat to evaporate their moisture. The evaporation of sweat absorbed by the clothes during exercise therefore increases the rate of bodily heat loss and reduces the temperature of the inner layer of cloth.

Two other factors that affect the rate of heat loss require special mention. One, already noted, is the movement of air between the body and the clothes, which accelerates cooling. The other is the emissivity, or rate of heat radiation, of the cloth: black clothes have a higher emissivity than white.

THESE observations help to explain the results of our experiments. The tests showed, for example, that an uncovered can loses heat six times as fast when air moves past it at 1,200 feet per minute as it does in still air. A dry covering on the can greatly reduces this loss: on the average the loss from a can covered with dry cloth is only twice as great in a 1,200-feet-per-minute wind as in still air. As for the effect of moisture, in still air a can covered with a single layer of wet cloth on the average loses heat 1.7 times as rapidly as one clothed in a layer of dry cloth, and in air moving at



ARTIFICIAL BODY was placed in a tunnel through which air could be circulated at various speeds, temperatures and humidities. The body, a can filled with water from 100 to 110 degrees F., was fitted with fabrics.

TYPE OF COVER	STRUCTURE OF FABRIC	WEIGHT OF COVER (OUNCES PER SQUARE YARD)
CAN WITHOUT COVER	METALLIC SURFACE	
		SINGLE LAYER OF FABRIC
BYRD CLOTH	DENSE HARD WOVEN COTTON WITH SMOOTH OUTER SURFACE	5.2
BARKER CLOTH	DENSE HARD WOVEN COTTON WITH WOOL GRIDS ON ONE SIDE	10
WOOL BLANKET	WOOL FILLER ON COTTON FRAME WITH SMOOTH EVEN TEXTURE	17.3
COVENT CLOTH	SOFT FELT-LIKE CLOTH WITH 80 PER CENT WOOL AND 20 PER CENT COTTON	9.8
COTTON FLANNELETTE	SOFT POROUS CLOTH WITH CLOSE NAP ON ONE SIDE	3.7
COTTON UNDERSHIRTING	RIBBED POROUS COTTON CLOTH WITH ELASTIC WEAVE	5.4
RAYON SHIRTING	HARD RIBBED WEAVE WITH SMOOTH FINISH	5.8
KRAFT PAPER	TOUGH BAG PAPER	2
QUILTED CLOTH	COTTON AND CHICKEN FEATHER BATT BETWEEN POPLIN AND FLANNELETTE	23
		TWO LAYERS OF FABRIC
BYRD OVER FLANNELETTE		8.9
BYRD OVER COVENT		15
BYRD OVER BARKER		15.2
BYRD OVER BLANKET	SEE DESCRIPTIONS OF SINGLE-LAYER FABRICS	22.5
BARKER OVER BARKER		20
KRAFT OVER COVENT		11.8
COVENT OVER KRAFT		11.8
BYRD OVER BYRD		10.4
		THREE LAYERS OF FABRIC
BYRD OVER BLANKET AND FLANNELETTE		26.2
BYRD OVER COVENT AND FLANNELETTE		18.2
BYRD OVER BLANKET AND COVENT	SEE DESCRIPTIONS OF SINGLE-LAYER FABRICS	32.3
BYRD OVER COVENT AND BARKER		25
BYRD OVER BLANKET AND BARKER		32.5

INSULATING VALUE **of various fabrics and combinations of fabrics was tabulated after experiments with the artificial body. The insulating values given in the two columns at the far right are averages for still air and air**

1,200 feet per minute the heat loss through wet cloth may be eight times as great—*i.e.*, greater than the loss from an uncovered "body." This means, of course, that the principal aims in designing clothes for protection against cold must be (1) to keep air currents away from the body and (2) to keep the inner layer of clothing as dry as possible.

The insulation values of several types of fabrics and combinations of them, as measured by our tests, are tabulated in the chart above. The values are given in percentages: *e.g.*, a thermal insulating value (TIV) of 60 means that the fabric prevents 60 per cent of the heat loss that would occur from a bare surface under the given conditions. A negative TIV value means that the heat loss from the can is actually greater through the fabric than when the surface has no cover at all. In order to record comparative ratings of the fabrics for all wind conditions, the TIV is calculated as an average of the fabrics' behavior in still and moving air.

The tests demonstrate, as expected, that an open-weave or ridged fabric, such as the common undershirt, has the smallest insulation value. A dense cotton cloth gives somewhat more protection, and wool still more, the extent of protection depending also on the weave, thick-

DOUBLE BLACK POPLIN		9
DOUBLE WHITE POPLIN	SMOOTH HARD COTTON CLOTH	9
POPLIN WHITE OUTSIDE AND BLACK INSIDE		9
POPLIN BLACK OUTSIDE AND WHITE INSIDE		9

COLOR EFFECT **was also tabulated after experiments with the artificial body. The vertical columns in the table correspond to those in the table at the top of these two pages. Obviously black fabrics have a smaller in-**

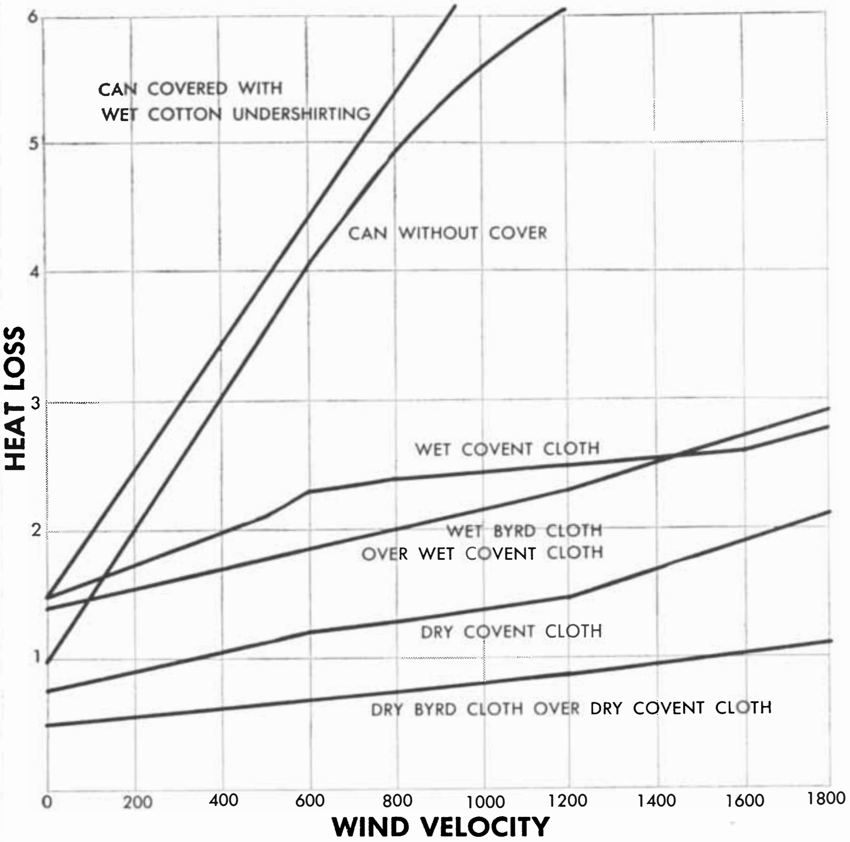
AVERAGE RATE OF HEAT LOSS (T U PER HOUR PER SQ FT PER DEGREE F DIFFERENCE IN TEMPERATURE)				AVERAGE THERMAL INSULATING VALUE	
DRY		WET			
STILL AIR	AIR AT 1,200 FEET PER MINUTE	STILL AIR	AIR AT 1,200 FEET PER MINUTE	DRY	WET
.97	6	.97	6		
.68	1.72	1.37	3.25	60	19
.52	.96	.89	1.96	79	59
.55	.91	.97	2.2	79	55
.74	1.42	1.38	4.4	69	17
.74	1.97	1.36	7.72	61	−30
.9	2.04	1.36	7.8	58	−32
.81	1.83	1.6	4.4	62	14
.67	1.8	1.6	2.68	74	38
.25	.5			89	
.53	1.08	1.39	3.03	77	37
.54	1	1.45	2.58	79	43
.43	.73	.97	1.63	83	63
.49	.68	.86	1.5	83	66
.54	.78	.9	2.2	81	56
.69	1.22			73	
1.09	1.37			65	
.68	1.1	1.15	2.84	74	42
.44	.56	1.3	2.78	86	42
.45	.87	1.35	2.85	81	40
.48	.67	1.02	2	83	55
.42	.61	.9	1.97	85	58
.33	.54	.92	1.71	87	62

at 1,200 feet per minute. The values are given in per cent, *i.e.*, a fabric with a value of 60 holds in 60 per cent of the heat radiating from a bare surface.

ness and certain other factors. But all single-layer fabrics decline greatly in insulation value when they are damp; in still air almost all of them are worse than no covering at all. The situation is greatly improved, however, when the fabrics are used in combination in two or more layers. The combinations are not particularly helpful in still air, but in moving air two layers are about 40 per cent more effective, on the average, than one alone. Much depends, however, on how these layers are placed. A combination of two layers has 25 per cent more insulation value when the more closely woven fabric (*i.e.*, a windbreaker) is on the outside than when the layers are reversed. Also, if one of the two layers is wet and the other dry, the heat loss is twice as great when the wet layer is next to the body surface as when the dry layer covers the surface. In fact, a single thin dry

.88	1.6	2.1	3.23	65	24
.68	1.35	1.78	2.72	71	39
.68	1.35	1.76	2.62	71	43
.74	1.5	1.9	3.08	68	28

sulating value than white. The author recommends that indoor workers wear black clothes in summer to allow the heat of their bodies to radiate away.



WIND EFFECT was also plotted. The units of heat loss and wind velocity are the same as those that appear in the tables on the preceding two pages.

layer of cloth next to the warm surface is highly effective even when all the outer layers are wet.

The high insulation value shown by paper in these tests bears out what hobos well know: that two or three layers of newspaper make a warmer cover than a heavy overcoat. Anyone who has traveled in cold countries is aware that the most efficient covering of all is fur, or clothing made of duck down quilted between two layers of cloth. Furs are expensive and so is duck down, but a mixture of cotton fibers and chicken feathers (without the central stem), quilted into layers a quarter- to a half-inch thick under pressure, offers the greatest insulation for the weight and money.

THE general conclusion from this study is that the most comfortable clothes in cold weather are dry, thick clothes. Anyone who must stay in the open at low temperatures should take precautions to keep his clothes, especially his underclothes, dry. He should have a densely woven outer garment, snuggly fitted at the wrists, neck and ankles, to keep out the wind. A good compromise between warmth, lightness and economy is obtained by using a closely woven Orlon fabric of moderate weight for underclothes, a very closely woven wool cloth for shirt and trousers, a thick quilted coat of mixed cotton and feathers and an outer windbreaker in the form of a parka made of two layers of Byrd cloth treated to make it water-repellent. Careful attention must also be paid to the feet, generally the most neglected part of the body in winter. Heat transfer is high through leather and the compressed fibers of thin socks. Foot comfort can be improved by wearing thick socks and air-filled innersoles.

The study suggests that research should be directed toward development of the following improvements in winter clothing: underclothing of fibers that do not readily absorb water, outdoor garments of cloth that will hold considerable quantities of air in extremely small bubbles, quilted clothes made with a batt of chicken feathers and cotton, and shoe innersoles of porous, noncompacting materials. A great deal of work needs to be done on the problem of chemical treatment of fibers to make them waterproof before they are woven into cloth. Garments need to be designed so they will permit free ventilation during exercise but will eliminate such ventilation when the wearer comes to rest, thereby helping nature to remove just the right amount of heat from the body at all times.

M. E. Barker is head of the department of chemical engineering at the University of Arkansas.

A CHEMIST SEES A CAR LIKE THIS. Here are samples of the hundreds of chemical compounds in one of our cars. The piles of powder and crystals are metal compounds—the bars metal alloys. The liquids in the bottles, and the gases in the tanks (rear) will be used to process parts of the chassis, body, rubber fittings, plastic and upholstery. Chrysler chemists specify the exact chemical composition for more than 175 kinds of steel, 200 kinds of rubber compositions—each best for its job and each adding to car comfort, life and value.

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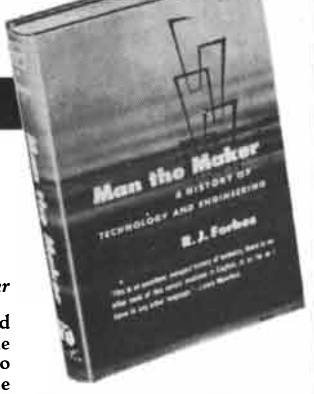

by Charles A. Cofer

THE HUMAN GROUP, by George C. Homans. Harcourt, Brace and Company ($6.00).

HOW may the behavior of groups be described and how may changes in it be predicted? These questions are fundamental to the methodology and theory of the social sciences, and satisfactory answers to them are essential to systematic progress in the understanding of social behavior. As yet, however, there is little agreement concerning which of the many dimensions of social groups are best suited to their description; as a consequence, few studies of groups can be compared with one another. In *The Human Group* George C. Homans, professor of sociology at Harvard University, has stated his answers to these questions, and has tested the variables he has chosen against the behavior of several groups. He takes pains to point out that the ideas he uses are not original with him, but he believes that his particular combination of old ideas will be fruitful and will perform the function of theory, which, as Willard Gibbs once put it, is "to give the form in which the results of experiment may be expressed."

The small human group, which Dr. Homans defines as a group of which every member can communicate directly with every other, has been relatively neglected as an object of sociological study. Sociologists have most often been concerned with larger aggregates of people, such as the community, the society, the region and the like. Yet the small group is a ubiquitous form of human association; its study is therefore of interest to everyone, excepting possibly hermits. Through the study of small groups Dr. Homans hopes to construct a theory of their nature and function and then, perhaps, to generalize the theory to larger and more complex human aggregations.

It seems to me that the basic notions in Dr. Homans' theory are, when shorn of their special terminology, simple, reasonable and inoffensive. Briefly they amount to this. Many groups come together because of situational demands: their members have desires, feelings and motives which lead them to join the group. The situation often prescribes

BOOKS

An ambitious attempt to bring the behavior of all human groups within the scope of a single sociological theory

what the members are to do, how much they are to do and with what other group members they are to communicate in the course of group activity. The members of a small construction gang, for instance, come together because they need money; the requirements of the job and the skills of the workmen prescribe what they will do, how much work they will do in a day, who will work with and be supervised by whom, and so on. Such factors, however, are not sufficient for the description of the group. Other variables will enter in: the group members will develop likes and dislikes for one another; they will engage in activities not required by the job, like gambling; there will be interactions among group members not provided for in the job descriptions, such as horseplay; a code of conduct will develop dealing with matters as diverse as what is a proper day's output and what is permissible profanity. There is obviously nothing new in this description, but Dr. Homans is pleased with the familiarity of the elements he has invented. He points out that "the fact that an apple would fall was the dreariest fact in the world until Newton showed that an apple and a planet obeyed the same laws of motion."

In Dr. Homans' theory, then, there are two systems of variables necessary for the description of a group's behavior. One system antedates the formation of the group and consists in the motives of the group members and the activities, interactions and codes of conduct prescribed by the situation. The other system develops within the group and consists in feelings, actions, interactions and standards of conduct arising from social life itself. The two systems of variables will of course interact with one another in a sort of feed-back process; indeed, they are difficult to untangle. These ideas are used in the analysis of five groups and in the discussion of leadership, authority and social control. The analysis is persuasive and the variables seem in general to fit the evidence in which the author is interested. I was somewhat shaken by my discovery that two of the groups analyzed are not groups at all by Dr. Homans' definition of a group, but I will describe his analysis of one of them because through its portrayal the entire scope of his theory can be revealed.

Hilltown was once a prosperous New England community. Its families led an active social life and were interested in local affairs; thus the town had effective means of social control. Its leaders were definite, and the punishment meted out to those who deviated from its moral and ethical codes of conduct was stern and prompt. The town's prosperity was a tribute to the cooperative efforts of its inhabitants, who, faced with an unfavorable environment, pooled their resources in joint ventures such as threshing bees and house raisings, thus accomplishing together tasks which individuals alone could not perform. During the course of these activities, shared out of necessity, the townspeople interacted and formed friendships, which led to other social activities such as parties and church "socials." This active community life led to the exchange of opinion and belief and, as a result, to agreement on many issues: religious, political and moral. In other words, it led to clear-cut norms of conduct. The leaders of the community were those who conformed most closely to all of these norms; it is a general principle, says Dr. Homans, that the leaders in a group are those persons who conform most closely to whatever norms the group recognizes and approves. Social control could be effective in early Hilltown because the norms were clear, recognized and accepted, and the leaders and the group itself would in various ways, *e.g.*, by social ostracism, punish those who deviated too far from accepted standards of conduct. As time went on, however, physical and technological changes affected Hilltown. Its land wore out; commodities and services which once had been a product of community effort now became available in impersonal ways. At the same time the national standard of living went up, and Hilltowners, desirous of improving their financial status, found that they could no longer get along on the basis of the old activities shared within the community. As a result the joint activities and the resultant interactions declined in frequency; social life decreased. Many residents went elsewhere in the search for a better share of the national prosperity. Because of all these changes, but primarily because of the decreased social contact, people became less certain about their values and beliefs; it is through social interaction that group members develop their norms and gain the support necessary for their continuation. Hence the norms became loose and ill-defined. When this happened, acts which formerly would have met with prompt censure went unpunished, for when the norms are unclear it is difficult to judge an act right or wrong. Sexual delinquency increased, and a town official who absconded with public funds went virtually unpunished. Social control was no longer effective. Hilltown could no longer be called a community; it had become a mere aggregation of individuals inhabiting a geographic area.

The tale of Hilltown illustrates what I take to be the crucial feature of Dr. Homans' thesis: that interactions among group members breed more interactions; that out of interactions grow norms and leadership which provide for social control. The interactions may arise, as in Hilltown, because of external environmental demands, but they may also arise from within the group itself.

As long as I am under the persuasive influence of the regular cadences of Dr. Homans' prose, I believe that *The Human Group* constitutes a contribution to sociological theory. As he writes, everything falls into place, and the variables—the activities, the interactions, the feelings, the norms—seem to account for the group phenomena that he brings to the reader's attention. With the variables he formulates a number of general principles of group behavior, principles which are stated in essentially quantitative form and which appear to be testable in other groups and by other investigators and by experimental means. Nevertheless, the very generality of the theory, its applicability to such widely different groups—to groups which are not groups, for example—makes it suspect. I believe that the variables are too loosely defined, and although Dr. Homans has no difficulty in stretching them to fit groups of varying size, complexity and history, other students may not be able to do so. Adding to this the fact that there are aspects of the group with which the theory does not pretend to deal, such as the role of personality differences among the group members, I believe that the answers in this book to the questions with which this review began must be judged inadequate.

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PSYCHOANALYSIS AND ANTHROPOLOGY: CULTURE, PERSONALITY AND THE UNCONSCIOUS, by Géza Róheim. International Universities Press, Inc. ($10.00). In recent years cultural anthropologists have come more and more to investigate "primitive" cultures in the light of certain psychoanalytic assumptions concerning man's nature. In turn, however, their findings, fed back into psychoanalysis, have helped to produce major revisions in psychoanalytic theory, especially with regard to its assumptions concerning the universal and basic characteristics of the unconscious. As a result a revised and largely desexualized psychoanalysis has developed which emphasizes the childhood experiences of people in their cultures as the determining factor in personality development rather than universal, instinctual drives. Dr. Róheim's book was written to change all this. In it are presented analyses of a number of cultures—their folklore, myth, ritual and the like—the data from which are shown by Dr. Róheim, to his own evident satisfaction and in contradiction of the interpretations of other analytically oriented anthropologists, to support his belief that the unconscious is essentially the same, whatever the cultural variation. Why do other students miss the facts so obvious to him? "This impression of complete diversity of various human groups is largely created by the Oedipus Complex, that is to say, the Oedipus Complex of the anthropologist or psychiatrist or psychologist. He does not know what to do with his own Oedipus Complex—he therefore *scomatizes* clear evidence for the Oedipus Complex, even when his training ought to enable him to see it." There are many real difficulties and uncertainties in obtaining and interpreting cultural data, and one can hardly accord a warm scientific welcome to a viewpoint that allows its advocate to ignore them while vanquishing the opposition in terms such as these.

THE BRITISH OVERSEAS; EXPLOITS OF A NATION OF SHOPKEEPERS, by Charles E. Carrington. Cambridge University Press ($9.00). Carrington's massive narrative deals with the British pioneers and emigrants who beginning in the 16th century made permanent settlements in empty lands all over the world, built the greatest empire of modern times and spread their culture, their social customs and their political ideals to Africa, Asia, the Pacific and America. This is a formidable historical undertaking which despite shortcomings (such as the failure adequately to discuss the broad consequences of these historic migrations) and omissions (the history of Ireland, for example, has been treated only lightly) has been successfully and readably fulfilled. Illustrated with portraits, maps and graphs.

WORLD GEOGRAPHY OF PETROLEUM, edited by Wallace E. Pratt and Dorothy Good. Princeton University Press ($7.50). This handsome, lavishly illustrated volume contains a comprehensive survey of certain major aspects of the world's oil. Various experts contribute chapters on petroleum geology, the organization of the petroleum industry, the different regions in which petroleum occurs, the extent of petroleum resources and the problems of utilizing them. A first-class piece of scholarship and bookmaking.

THE PLANET MARS, by Gérard de Vaucouleurs. The Macmillan Company ($2.00). A French astronomer's lucid summary of what we know about the most intriguing of our planetary neighbors: its chemical constitution, its clouds, the seasonal variations of its climate, its "canals," not to mention its possible life. This little book is more fascinating than most science-fiction.

DE RE METALLICA, translated by Herbert Clark Hoover and Lou Henry Hoover. Dover Publications, Inc. ($10.00). Long out of print and obtainable only at $75 to $100 a copy, this translation by the former President and his wife of a classic on metallurgy and mining has been made available in an exceptionally handsome reprint. The book retains all the material of the 1912 edition, including appendices, footnotes, indices, facsimile pages and the 289 16th-century woodcuts.

THE STANDARD DICTIONARY OF FOLKLORE, MYTHOLOGY AND LEGEND, edited by Maria Leach; Jerome Fried, associate editor. Funk & Wagnalls Co. ($15.00). From Aa (in Assyrian and Babylonian religion the consort of Shamash) through Zya (the Buriat term for the figure of a person drawn on cloth or paper for purposes of working magic against him) a comprehensive survey by 32 authorities of the superstitions, faiths, fancies, fears, hopes, aspirations, games, proverbs, songs, dances, legends, riddles, folk art, primitive music, ballads and symbols that mark the cultures of the world in their unending variety and underlying unity. Whatever criticism individual scholars may legitimately voice regarding interpretation, emphasis and of course omissions in their specialized fields, this must clearly be regarded as a distinguished achievement of scholarship as well as an engrossing work for the general reader.

CHINA AND THE SOVIET UNION, by Aitchen K. Wu. The John Day Company, Inc. ($6.00). Mr. Wu, a former professor of international relations at Yencheng and West China Union universities who has a background of 25 years in the Chinese diplomatic service, presents a study of Sino-Russian relations from 1618 through the spring of 1950. "No reasonable Chinese can fail to realize," writes Dr. W. W. Yen, former Chinese Ambassador to the U. S., in his introduction, "that with a common frontier of many thousands of miles and with diplomatic and commercial relations dating back to an earlier period than those between us and other nations of the Occident, the Chinese and Soviet peoples should and could not be anything but the best of friends, and this idea runs like a thread throughout the length of the book."

THE NEW YOU AND HEREDITY, by Amram Scheinfeld. J. B. Lippincott Company ($5.00). Scheinfeld has revised and substantially enlarged this excellent popular account of the problems of human inheritance which first appeared in 1939. Three quarters of the work has been rewritten to incorporate the advances of the past decade; special consideration has been given to topics of contemporary interest such as the Lysenko controversy, the genetic effects of nuclear radiations, the Kinsey findings. There are numerous new illustrations and a useful list of suggested readings. The new edition deserves to inherit the reputation of the old.

Also Noteworthy

THE SEA SHORE, by Charles M. Yonge. William Collins Sons & Co., Ltd., Toronto ($5.00). The Regius Professor of Zoology at Glasgow University describes the natural history of the seashore, notably the British, in a beautifully illustrated and well-written book.

SCIENCE AND RATIONALISM IN THE GOVERNMENT OF LOUIS XIV, 1661-1683, by James E. King. The Johns Hopkins Press ($3.75). A learned monograph dealing with the influence of science and rationalism in determining the policies and reforms of Louis XIV and Colbert.

THE PHYSICAL BASIS OF MIND: A SYMPOSIUM, edited by Peter Laslett. Basil Blackwell & Mott, Ltd., Oxford ($1.00). A series of British Broadcasting Company programs by leading scientists and philosophers on what goes on in the body when men and animals think. Nothing remotely comparable either in scientific excellence or interest emerges from any known radio station in this country.

CONTRIBUTION TO MATHEMATICAL STATISTICS, by R. A. Fisher. John Wiley & Sons, Inc. ($7.50). A collection of 43 original papers, the majority of which have appeared only in journals and are therefore not readily available, by the most noted and creative of contemporary statisticians. A valuable compilation for specialists.

ILLUSTRATED ENGLISH SOCIAL HISTORY, by G. M. Trevelyan. Longmans, Green & Co., Inc. ($3.75). The second volume of this most attractive edition of Trevelyan's noted work covers the age of Shakespeare and the Stuart period.

THE AMATEUR ASTRONOMER

Conducted by Albert G. Ingalls

THE large portable telescope shown in the drawings on these two pages is a long-focus instrument of the type best suited to planetary observation, yet it is small enough to be carried disassembled in the trunk and rear seat of a car. Weighing 215 pounds, it is a careful compromise between full stability and extreme lightness. Some of its features might well be worth including in any telescope.

The builders of this instrument, R. A. Stolle of the Stolle Engineering and Manufacturing Company, Los Angeles, Calif., and his son Mark Allen Stolle, became telescope makers by accident. One evening they started out for a science lecture, but through a mixup of addresses found themselves instead at a meeting of the Los Angeles Astronomical Society. "From then on," Stolle senior writes, "we made telescopes.

"After we had built a 4-inch refractor, and an 8-inch reflector with gas-pipe mounting, we had an opportunity to see George Schmid's 10-inch *f*/7 portable telescope on a mounting that he had designed. It was operated from an Edison battery in his car with a little d.c. electric motor. Seeing that there could be something better than our mountings, we began work on a mounting like Schmid's for a 10-inch long-focus mirror we procured from Thomas R. Cave.

"Everyone was skeptical about whether such a long telescope could be at once portable and sufficiently steady. So we modified some of the Schmid features to handle our longer tube, hoping that the design would prove satisfactory and still be portable—and I don't mean like a piano.

"We find we can disassemble this instrument and pack it in our car very nicely, with the stepladder that we use for observing attached to ski racks on top. Without our knowledge we were timed; it took us only seven minutes to remove the parts from the car, carry them a short distance, assemble them and have the telescope in operation.

"The pedestal is as steady as if the pipe were set in concrete, and the mounting, while not perfectly steady, is so nearly so that if you slap the tube it will settle after about three oscillations, or as fast as you can count three. It has surprised a good many skeptics who believed that only concrete and massive weight could hold a telescope of this size and length steady.

"The drive movement is a 7-watt synchronous motor. It operates on 110-volt, 60-cycle current when we are at home. When house current is not available we use our car battery, or any small 6-volt battery, with a 6-volt vibrator inverter which changes 6 volts d.c. to 110 volts a.c. This vibrator is similar to those used for radios on cars. We can hold a star in the center of the field for several hours with a half-inch eyepiece giving 225 diameters magnification. We can do even better than this if we vary our frequency with an inverter.

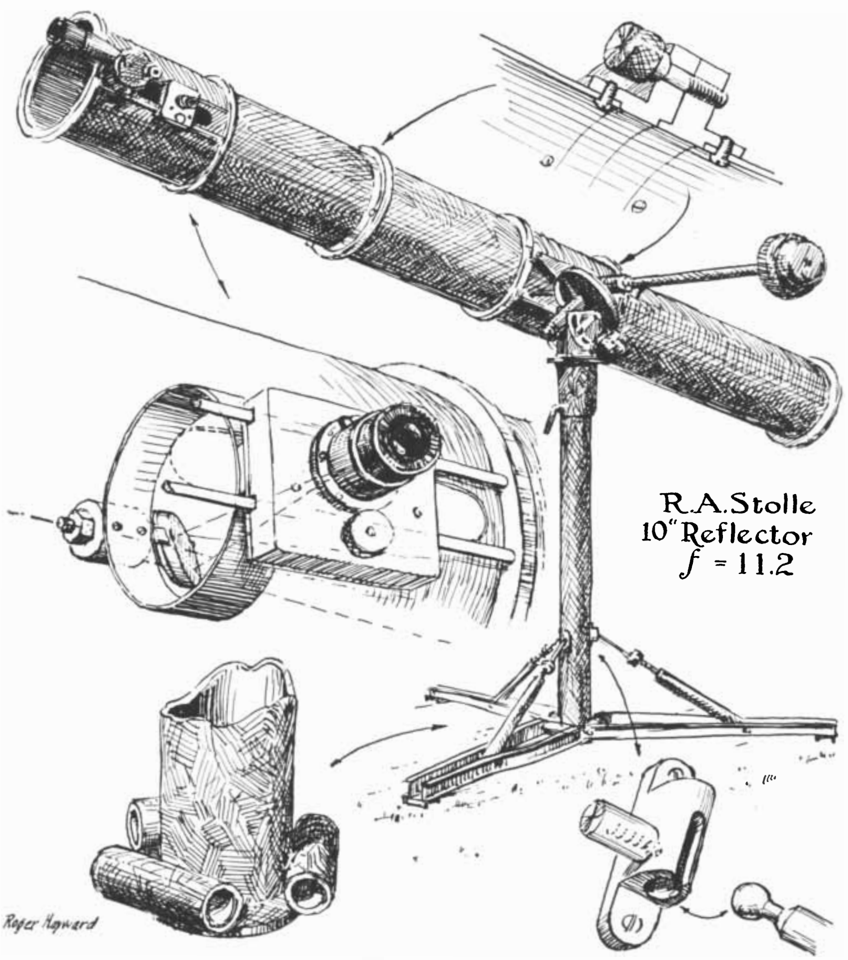
"The long tripod legs are individually adjustable, making it possible to set up the telescope on uneven ground. The upper tips of their diagonal braces latch into sockets on the side of the pedestal and are held there by spring-loaded balls while the screw in the brace is run out.

"Please give much of the credit for this telescope to my son Mark, who with supervision did most of the actual work, and to Schmid, whose design was largely used."

The pedestal of the Stolle telescope is made of 3 5/16-inch outside diameter, 3/16-inch wall steel tube. The mounting is carried on a short tube that drops over the pedestal, and carries a level glass for plumbing it. The polar-axis adjustment is a sector, permitting accurate use of the telescope in different latitudes.

The polar axis is a short length of 1-inch Shelby tubing with an adjusting nut. Sliding over this is a length of 1⅜-inch outside-diameter Shelby tubing with a knurled brake-tension adjusting nut. The braking surface is on the side of the bronze worm wheel, which is lubricated with vaseline. This supplies the desirable slip-ring feature described by Russell Porter in *Amateur Telescope Making*, fourth edition, pages 145-146, and saves much unnecessary labor in setting the telescope on stars from the atlas or ephemeris.

On the 1-inch declination-axis shaft is a lock for the extension that carries the two counterweights. (The second coun-



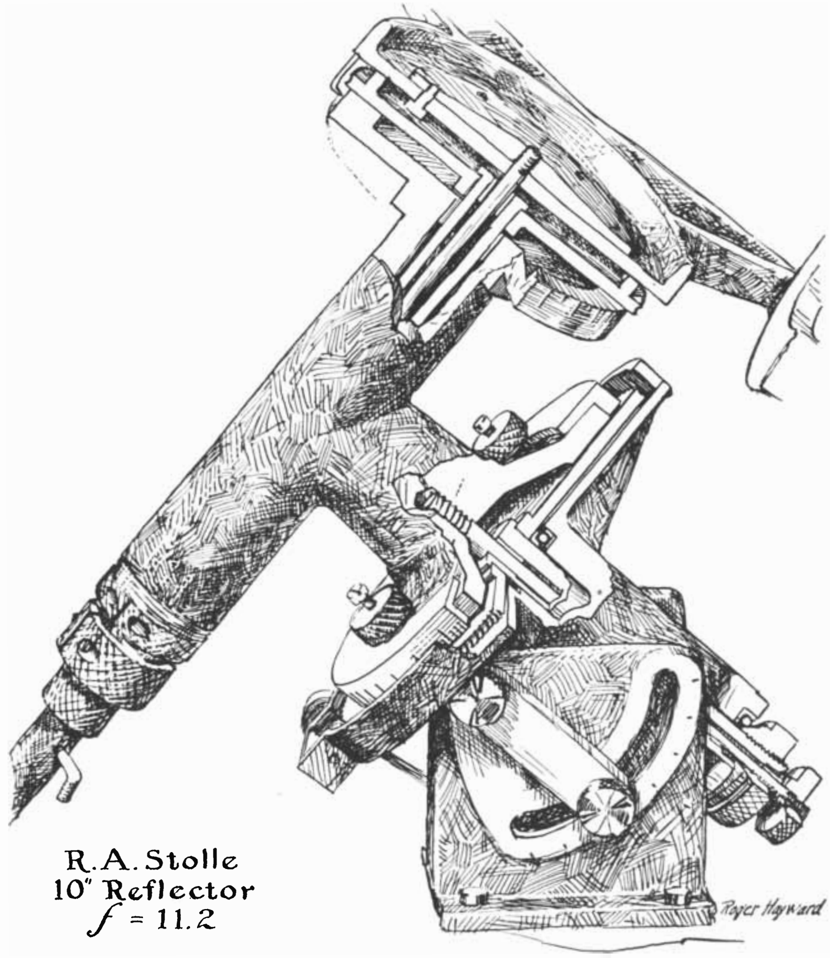
A seven-piece telescope for transportation in a car terweight is used sometimes for balancing a camera and at other times to balance a 4-inch refracting guide telescope that rides pick-a-back on the larger telescope when it is used as a camera.) Also on the declination-axis shaft are a knurled adjusting nut for smooth rotation in declination, a larger knurled nut for brake-tension adjustment, and a fiber washer next to it; this end is arranged much like the lower end of the polar-axis shaft. At the head of the declination-axis shaft is a 144-tooth 22-pitch bronze gear, and against its side another lubricated braking surface.

Believing with Stolle that the braking surfaces damp the vibrations and thereby give the telescope its steadiness, illustrator Hayward, himself an amateur telescope maker, suggests experimenting with lanolin for lubrication. Lanolin, he points out, is quite viscous, yet it has a starting friction of nearly zero; it might damp the vibrations critically and increase the stability still further.

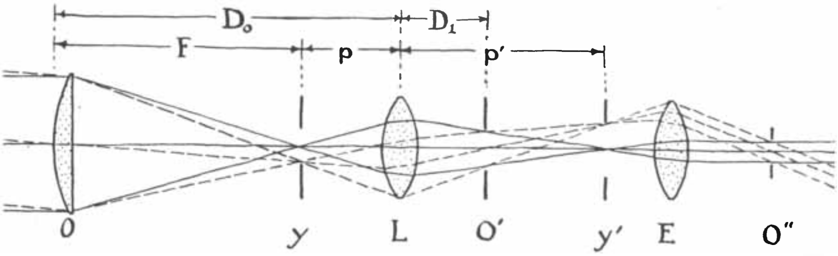
The tube saddle consists of two members having a deep, stiff section. The tube rotates in the saddle rings, obviating the neck-wringing otherwise suffered by the observer. Knurled screws on each of three tube-section joints permit quick assembly of the tube.

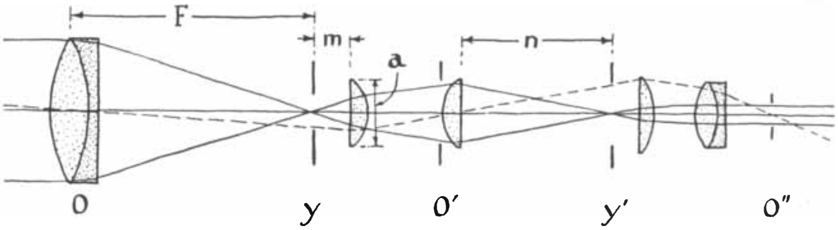
The eyepiece-diagonal unit slides as a whole on ball bearings against two rods; focusing is accomplished by turning a knurled screw below the eyepiece. This screw turns a rubber friction roller that bears against one of the rods. The adapter tube slips quickly into position, as determined by a spring-loaded ball on the inner wall of the boss or ring that receives it. This boss can receive an eyepiece of full 2-inch diameter to accommodate the wide images given by the long-focus mirror. A camera may be attached in place of the eyepiece for photography either at the prime focus or through the eyepiece. The diagonal support arm is a 5-inch ring for spreading the diffraction around the field, and is made of hard rubber to avoid the temperature effects of metal. The entire telescope has a black crackle finish.

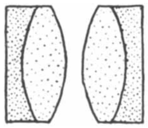
REQUESTS for full instructions to build riflemen's target and spotting 'scopes have reached this department occasionally for many years. Nearly all of these come from riflemen who are not telescope makers. There is a chapter on target 'scopes in *Amateur Telescope Making—Advanced,* but no pretense is made that it is suited to optical novices. It has therefore been necessary to advise such inquirers to approach their goal by a roundabout route: first make a reflect-



Details of the mounting for the Stolle telescope







$$(1)\quad p' = \frac{F'^2}{p - F'} + F' \quad \text{where } F' = \frac{1}{\frac{1}{p} + \frac{1}{p'}}$$

$$(2)\quad \text{e.f.l.} = \frac{FF'}{F - F' - (F - p)}$$

$$(3)\quad M = \frac{Fp'}{F''p} \quad \text{where } F'' = \text{focal length of } E$$

$$(4)\quad \frac{1}{D_1} = \frac{1}{F'} - \frac{1}{D_o}$$

$$(5)\quad a = \frac{m\left(\frac{O+y}{2}\right)}{F} + \frac{y}{2} \quad \text{where } O = \text{aperture at } O \text{ and } y = \text{aperture at } y$$

Principles of the erecting or terrestrial telescope

ing telescope as an apprenticeship; then make a small refractor (which might be a spotting 'scope); then tackle the desired target 'scope. This advice has seldom appealed to riflemen.

In a new book entitled *Sporting Rifles and Scope Sights*, written by Truman Henson and published by David McKay Co., New York, 93 pages are devoted to instructions for building three hunting 'scope sights, one target 'scope sight and two spotting 'scopes. The rest of the book deals with the conversion of discontinued military arms into sporting rifles. The instructions are full, detailed and specific. Full-dimensioned drawings are included for each 'scope. The author, a lawyer whose hobby is riflemanship, has himself made every 'scope he describes, excepting their optical parts, which he obtained from war-surplus lens dealers. He has included enough basic optics to assist the non-optical builder adequately.

THE basic principles of the lens-erecting system for terrestrial telescopes are described in the following notes by Allyn J. Thompson, 1628 Mayflower Ave., New York, N. Y., author of the book *Making Your Own Telescope*. Anyone who plans and constructs one of these systems with its aid is invited to describe the experience and the result.

The manner in which the terrestrial telescope functions is shown in the upper drawing on this page. Rays from a distant axial object point are brought to an axial focus in the plane y of the objective O. Rays (dashed lines) from a marginal point of the field are brought to a focus on the opposite side of the axis in the same plane y. This gives us an inverted image of the distant object. Now suppose we regard the erecting lens L as a projecting lens. By placing it at some distance p that is greater than its focal length from the image y, an image of the latter will be projected to y'. The image is turned around or inverted in the course of projection, so that the new image is erect. The distance p' to the projected focal plane y' is found from equation 1 where F' is the focal length of L. The relative size of the images y' and y depends on the ratio p'/p. In the diagram, p' is twice the distance p; the image y has therefore been doubled in the projection, and in effect the focal length of the objective has been amplified two times. The equivalent focal length of the telescope is given in equation 2. The new image y' is viewed with the aid of the eyepiece E, and the total magnification M of the telescope is given by equation 3 where F'' is the focal length of E.

A field stop of suitable aperture should be placed in the plane y' to delimit the field to one of even illumination, and to cut off the poorly imaged external parts.

A reticle can be used either in the same plane or at y. By mounting the erector lens L in a separate focusing tube so that the distances p and p' can be varied, a similar variation in magnification is effected. This action of course will affect the position of y', and complicates the matter of reticle installation. Also, the use of the telescope for different object distances affects the position of both y and y'. In these circumstances, the best thing to do is to mount the reticle in a unit within which the eyepiece can focus.

Just as the image y is projected by the lens L, an image of the objective O is projected to O'. The distance LO' is found from formula 4, where D_0 is the sum of the distances F and p. The relative sizes of O' and O are proportional to their distances from L. O' is the exit pupil of the system OL, and is the entrance pupil of E. As any light passing beyond the boundaries of O' may serve only to fog up the image y', a stop (called an erector stop) should be placed in the plane O'. An image of O' is projected by the eyepiece to O''; this is the exit pupil of the telescope, and it is in this plane that the lens of the eye should be placed when viewing the image. The distance EO'' is known as the eye relief or eye distance, and from formula 4 it is apparent that this distance is greater than if the erecting lens were absent, a condition that is also found in the astronomical telescope. The diameter of O'' is equal to that of O divided by the total magnification of the telescope, provided of course that there is no curtailment of O' by the erector stop.

The erector eyepiece of the upper drawing is the type that was devised by the German mathematician Christoph Scheiner in 1637. In practice it is rendered nearly useless by overpowering aberrations. An immense improvement was effected in 1645 by the Bohemian astronomer Antonius Maria Schyrleus de Rheita, who substituted for L two equal plano-convex lenses separated by their focal lengths, with the convex surfaces facing each other, and for E a Huygenian eyepiece. This arrangement corrects for chromatic difference of magnification, and at $f/8$ or higher ratios its performance compares well with that of modern designs. Rheita's erector is shown in the second drawing, although a Kellner eyepiece is used in that illustration instead of a Huygens.

In using a two-lens erecting system, the amplification or relative sizes of apertures at y and y' depend on the proximity of the erectors to y. If this distance is chosen so that m and n are equal, the image sizes are equal, and the magnification is unity. By moving the system closer to y, the projection distance and the image size are increased. Actually the projection distance is not represented by n, nor the object distance by m; these measurements are referred to what is known as the principal planes of the system. There is no need, however, to delve further into the study of optics. The distances m and n, which are all that are necessary for construction, can be obtained by using an illuminated artificial image at y, and experimentally positioning the erectors until a sharply focused image of the desired enlargement is picked up on a ground-glass screen.

With the lens separation given for Rheita's erector, the pupil at O' is formed within the second erector lens, so the best place for the erector stop is immediately in front of that lens, as shown. To avoid vignetting in the external parts of the field at y', the erector lenses must be of suitably wide diameter. The clear aperture of the first lens should be as shown in equation 5. The clear aperture of the second lens need be no more than that at O'.

The shorter the focal length of the separate erector elements, the less will be the over-all length of the telescope. Modern terrestrial telescopes employ achromatic eyepieces, seldom of more than three inches focal length. Most achromatic eyepieces usually function well for this purpose, as do projecting systems. A single doublet lens will often be found to perform satisfactorily. An arrangement frequently employed is that shown in the third drawing—two identical achromats placed almost in contact. Hardly anything will be found to excel the performance of a Hastings triplet. This is a magnifier designed by Charles S. Hastings, and manufactured in the U. S. by the Bausch and Lomb Optical Company. It is known as a triple aplanat, and is obtainable at shops dealing in optical goods. The requisite aperture can be determined from formula 5.

In lieu of an optical bench, experimental setups can be made by standing the various lenses edgewise in lumps of artists' modeling clay mounted on a stick. Care must be taken to maintain a fairly good axial alignment of the elements. In making tests for image quality, magnification, and best lens spacing, the stick should rest securely on some solid object. This allows for painstaking inspection of the image.

A Hastings triplet makes an excellent substitute for a Barlow lens in effecting image enlargement in the astronomical telescope. A lens of 1-inch focal length can be used with reflectors down to about $f/7$. It gives a slightly curved field, which at low amplifications may be conspicuous in some eyepieces taking in a wide linear field. This is easily mitigated, however, either by stepping up the amplification or by using a higher-power eyepiece. With the use of two such lenses placed nearly in contact, field curvature vanishes, and the spherical aberration is so reduced that the pair can safely be used down to about $f/4.5$. (It is assumed in either case, of course, that the mirrors are perfectly corrected.)

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