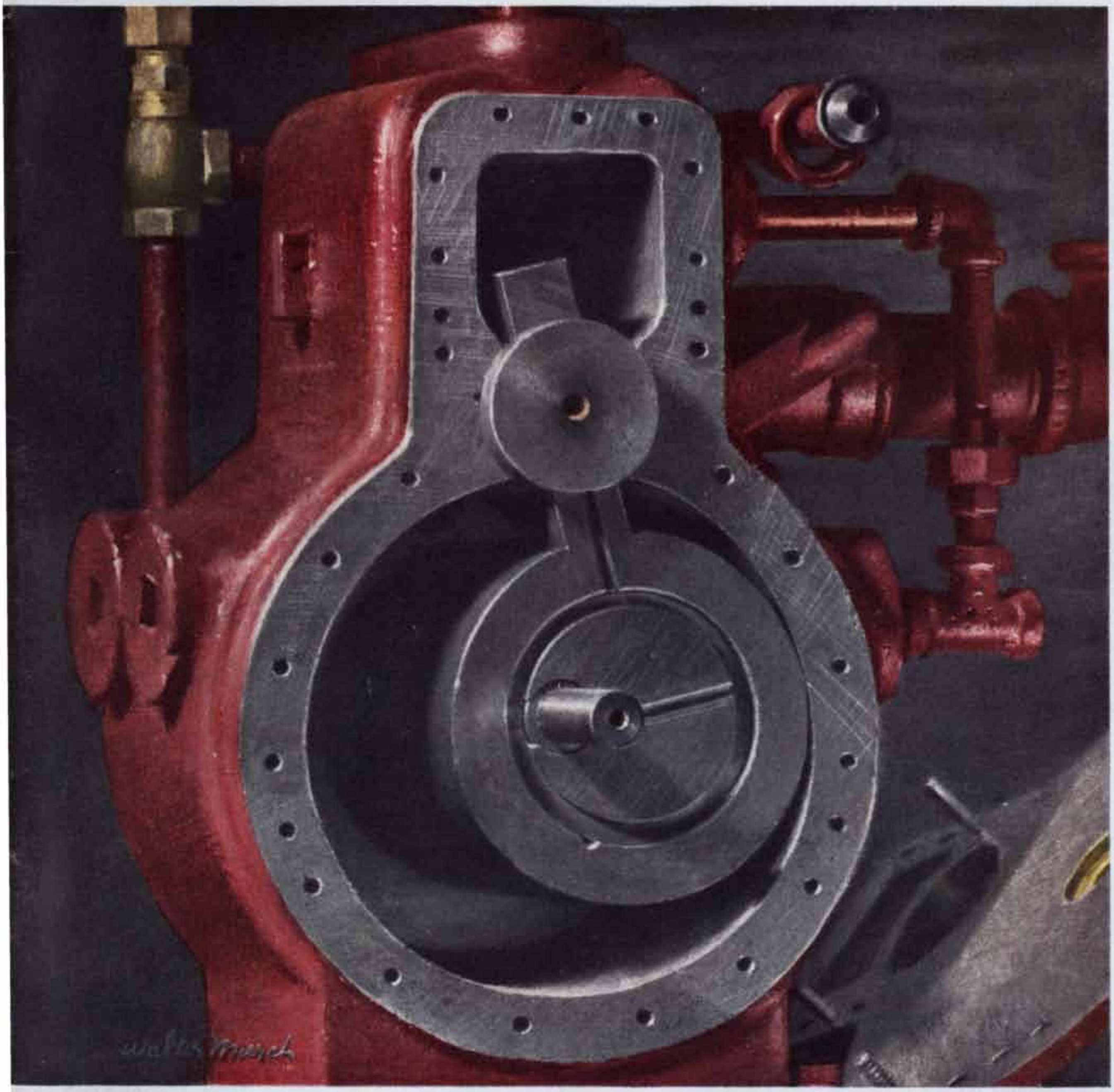
SCIENTIFIC AMERICAN



HIGH VACUUM

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May 1950

Photo by Dixon

"Where did yesterday's wrinkles go?"

HAVE YOU HEARD about the new cotton dresses that resist wrinkles, stay fresh and crisp longer? Even in hot, humid weather, wrinkles disappear overnight, like magic!

The textile industry is giving many of its cotton fabrics this new quality with SUPERSET* Finish, a durable wrinkle-resistant finish recently developed by American Cyanamid's Textile Resin Department. SUPERSET Treated fabrics are soil resistant, too. They stay clean longer, are easier to wash and iron, need no starching—save time and work. This finish lasts as long as the garments themselves.

SUPERSET Treated cottons are available now in women's and children's dresses and sportswear, boys' wear, men's sports shirts and other garments. Here is another way in which Cyanamid chemistry is working to aid the great textile industry in increasing the value and serviceability of its products.

*Reg. U. S. Pat. Off.

AMERICAN *Cyanamid* COMPANY

30 ROCKEFELLER PLAZA, NEW YORK 20, N. Y.

Materials for the Textile Industry—one of the many industries served by Cyanamid

New-type glass for RCA television picture tubes filters unwanted light, to give sharper, clearer images.

Wayward light is disciplined—for better television!

Now television pictures gain still greater contrast and definition—through research originally initiated by scientists at RCA Laboratories.

Their discovery: That wandering light waves inside a picture tube—and even more important, *inside the glass itself*—may cause halation and blur an image's edges. But, by introducing light-absorbing materials into the glass, the wayward flashes are disciplined, and absorbed, so that only the light waves which actually make pictures can reach your eyes!

Glass companies, following this research, developed a new type of faceplate glass for RCA . . . Filterglass. Minute amounts of chemicals are added while the glass is being made, and give it, when the picture tube is inactive, a neutral gray tone. In action, images are sharper, clearer—with more brilliant contrast between light and dark areas. Reflected room light is also reduced.

* * *

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

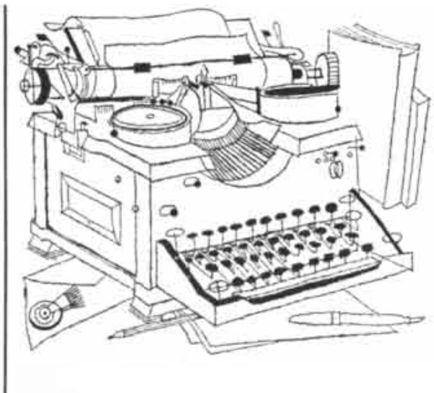
Filterglass faceplates give you more brilliant pictures on today's RCA Victor television receivers.

RCA

RADIO CORPORATION of AMERICA

World Leader in Radio — First in Television

LETTERS



Sirs:

The high compression article by Alex Taub in your February issue is very interesting. A problem as big as "more miles per gallon," however, really merits a broader discussion than Taub has given it. In terms of mechanical octane numbers there are a number of other things worth consideration such as turbulence, supercharging, dual fuel systems, etc. There are many highly qualified persons who think the red-hot exhaust valve is not the chief explanation of the improved performance of the sleeve-valve, rotating head and single-valve engines. In any event, it will be interesting to see how the automotive engineers will react to the proposal that drastically new engines be designed.

A still broader perspective of the "more miles per gallon" problem is to be found in the fact that, in spite of two decades and billions of dollars of greatly increased mechanical and chemical octane numbers, miles per gallon has remained practically constant. One would conclude there has been no gain and that both mechanical and chemical octane numbers are will-o'-the-wisps. Not so. The vehicles weigh 25-50 per cent more, move 25-50 per cent faster, and have 25-50 per cent higher top speeds. Thus we have gained "ton-miles per gallon" at higher speeds.

I am convinced that be they mechanical or chemical octane numbers, or both, instead of "more miles per gallon" the net result of the forthcoming lap in the octane-number race will be "faster ton-miles per gallon." The automotive industry will continue to furnish heavier and faster cars with bigger tires, automatic chokes, air-conditioning, kitchenettes, trailers, fluid drives, automatic transmissions, etc., etc., etc., because these are what the public wants.

R. C. ALDEN

Phillips Petroleum Company
Bartlesville, Okla.

Sirs:

In your February issue I read the article "A Chess-Playing Machine," by Claude E. Shannon, and I make the following comment:

A game of chess is like a painting; the chess master draws a faint outline of the strategy which he is to follow—a strategy based on the weakness of the opponent's position—and then he carefully fills in the gaps on this faint outline until the clear image of victory presents itself. In the process of filling in the gaps he finds that he must add a little here and a little there, and so modifies the colors, but—mind this—whatever modifications he makes of the colors, he does not modify the original outline, as it is the guiding pattern of what he is to do.

We will take for granted that such a computer could be built that will overcome all technical difficulties encountered, and furthermore that this computer will find the best move in a given position. Then, confronted with a move by a human player, the computer will answer it with the best move in that given position. But we do not know what the best move in a given position is until we have compared it with our basic strategical aim, and this not only takes calculation but imagination.

CHARLES A. DU PONT

Miami, Fla.

ERRATUM

The article "Hot Atom Chemistry" in the March issue of this magazine contained the statement: "The [iodine] atom's energy is calculated to be some 200 million electron volts." The latter part of this statement should read "200 electron volts."

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50 AND 100 YEARS AGO

MAY 1900. "So completely have the material achievements of science overshadowed what may be called its theoretical development that we are inclined to underestimate the work which has been done in pure science for the mere love of it. It is because the work of the pure scientist is so self-sacrificing and unselfish that he commands our special regard. Not to mention that most conspicuous example of disinterested scientific research, Faraday, what adequate pecuniary reward has Tyndall derived from the arduous research that culminated in his brilliant theory that heat is a mode of motion? What commensurate reward have Darwin and Spencer received for their investigations in the theories of natural selection and evolution, or Roentgen for the discovery of the rays that should rightly bear his name? These are facts, the significance of which we are apt to forget in an age so purely utilitarian as our own."

"It was natural that the successful results obtained with Marconi wireless telegraphy should have suggested its use for the steering from a distance of floating and submerged vessels. Now the steering of vessels by wireless telegraphy has been accomplished in a test, recently carried out in the south of England for the British government. Mr. Varicas, the inventor of the system, and Commander Colwell, who was carrying out the test for the government, stood by the transmitting apparatus. Commander Colwell uttered an order, Mr. Varicas turned the controlling wheel of the transmitter, and the little boat immediately altered her course to the desired direction. Then followed further orders from the Commander, and the launch quickly performed all the necessary evolutions as though a quartermaster were aboard."

"There has been submitted to Congress a bill which proposes to merge the Office of Standard Weights and Measures in a new bureau, to be known as the National Standardization Bureau, whose function shall consist in the custody of the national standards when such data are of great importance to scientific and manufacturing interests and are not to be obtained with sufficient accuracy elsewhere. The introduction of accurate scientific methods into our various industries calls for a multitude of standards of far greater accuracy than was formerly required. It is sincerely to be hoped that Congress will look favorably upon this bill and not only enlarge the functions of the present Office of Standard Weights and Measures, but provide it with an adequate laboratory, equipment, and working force."

"Prof. Percival Lowell and Prof. Todd have left New York with astronomical material to observe the eclipse of the sun in Algeria. Owing to the fineness of the climate of Algeria, it is a particularly good locality to observe the eclipse."

"The seventy elements which are daily used in the laboratory are surely but the variant forms of a single matter. We have but one force; and why should there be seventy matters? That wonderful periodical law, with its puzzling numbers, seems to contain within it the means of discovering the primeval matter for which chemists have long been seeking. The old alchemist with his theory of the transmutation of elements again lives; but he is now a chemical physicist, who endeavors not to convert a base metal into gold, but to prove the existence of one form of matter. The mysteries of chemical energy are also still to be unfathomed. The forces which we have learned to observe and to measure are phenomena of a secondary nature. The chemical energy whose transformations give rise to these forces is still a puzzle to chemists. Instruments of measurement can reveal only the sum total of this energy, but not the nature of the intramolecular changes which occur."

MAY 1850. "Mr. Roebling's publication on the practicability of an Atlantic Magnetic Telegraph has been read with a good deal of attention, and the Senate Committee, to whom a memorial on the subject has been referred, will avail themselves of the suggestions made. There have been so many wonderful things accomplished in our day that it is scarcely safe to laugh at anything."

"It has been ascertained that the true source of scorbutic disease, as it shows itself in our ships and prisons, is the want of potash in the blood; that salted meat contains little more than half the potash in fresh meats; and that, while an ounce of rice contains only five grains of potash, an ounce of potato contains 1,875 grains, which accounts for the increase of the disease since the scarcity of the potato."

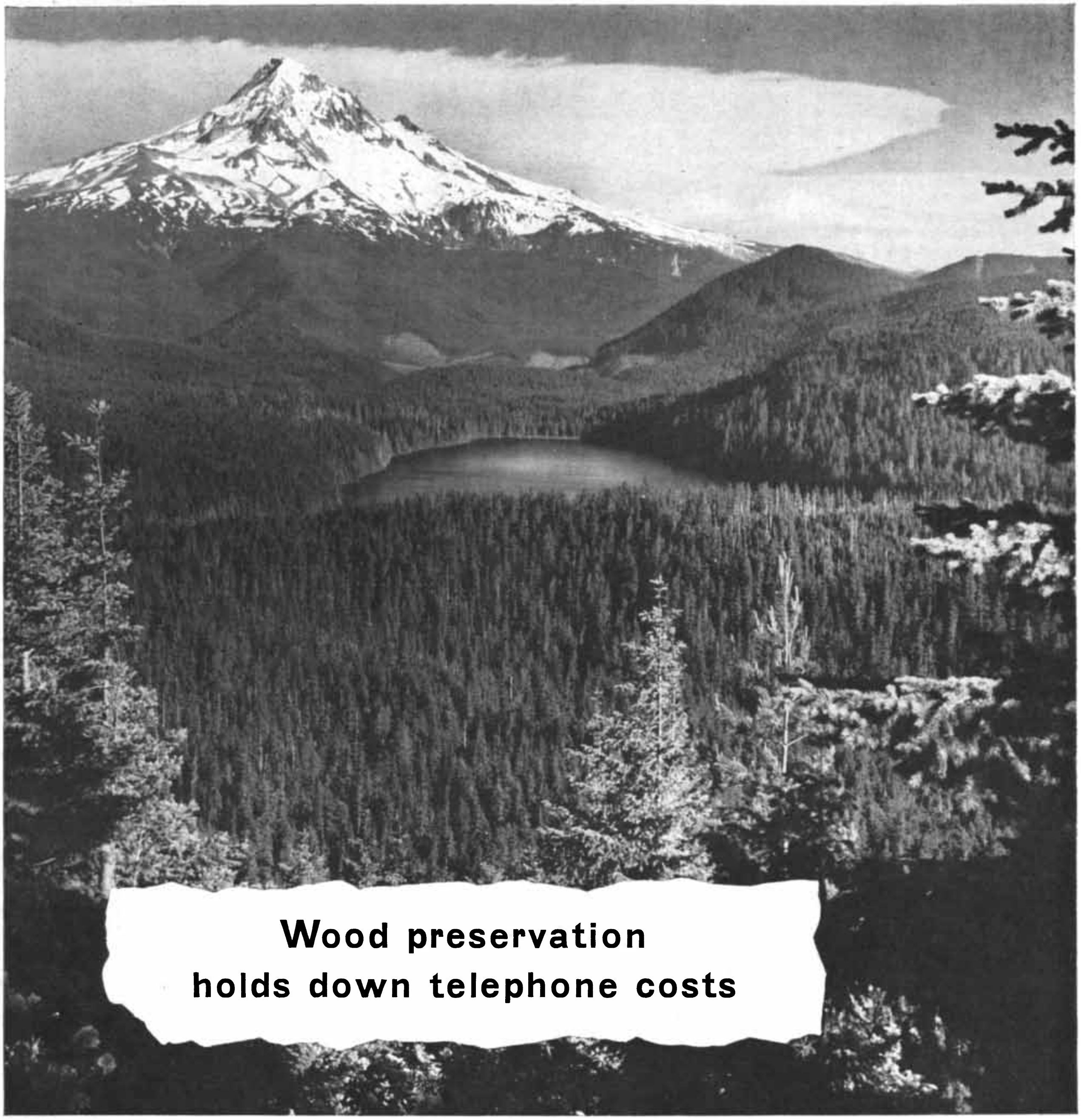
"During the late fine weather in England, Lord Rosse has been able to make use of his splendid telescope to great advantage, and has added three new nebulae to his former important discoveries."

"Professor Rodgers has commenced his course of geological lectures at the Smithsonian Institution. Last evening he adduced many interesting proofs that the interior of the earth consists of lava in a state of fusion. He said at the depth of two miles below the surface water will boil, and that it is calculated that at a depth of twelve miles all is liquid fire. In confirmation of this theory, he observed that from numerous experiments the heat increases in proportion to the depth."

"Roche, the French aeronaut, recently made an ascent at Bordeaux, when his balloon hit a chimney, upset the car, and threw him into the street, where he was picked up with one broken arm and two broken legs."

"Chloroform has been employed in Edinburgh in from 80,000 to 100,000 cases, without a single accident or bad effect of any kind traceable to its use. It saves many lives which otherwise would sink under the nervous shock which is experienced from a severe operation undergone in a state of consciousness. At the same time, chloroform has received the sanction and recommendation of the most authoritative bodies in France and the United States. Nevertheless, the public of London is almost wholly denied the vast benefits of this agent, purely through the prejudices of profession."

"By the Annual Report of the New York City Inspector, we learn that the number of deaths in the city last year was 23,773, of these 5,071 were by cholera, and 2,086 by consumption. These diseases claimed the greatest number of victims. The mortality of our city appears to be yearly on the increase. More than two-thirds of those who died by cholera were foreigners, Ireland furnishing 2,219 victims. How is the evil to be remedied? That is the question."



Poles are a substantial part of the plant that serves your telephone; making them last longer keeps down repairs and renewals that are part of telephone costs. So Bell Laboratories have long been active in the attack on wood-destroying fungi, the worst enemies of telephone poles.

Better, cleaner creosotes and other preservatives have been developed in co-operation with the wood-preserving industry. Research is now being carried out on greensalt—a new, clean, odorless preservative. Even the products of atomic energy research have been pressed into service—radioactive isotopes are used to measure penetration of fluids into wood.

Treated poles last from three to five times as long as untreated poles. This has saved enough timber during the last quarter century to equal a forest of 25,000,000 trees. More than that, wood preservation has enabled the use of cheaper, quickly growing timber instead of the scarcer varieties.

This and other savings in pole-line costs, such as stronger wires which need fewer poles, are some of the reasons why America's high-quality telephone service can be given at so reasonable a cost. It is one of today's best bargains.

BELL TELEPHONE LABORATORIES

Exploring and Inventing, Devising and Perfecting, for Continued Improvements and Economies in Telephone Service.

THE COVER

The painting on the cover shows the interior of a Kinney rotary vacuum pump. Such a mechanical pump is used in association with a vapor pump to produce the high vacuums required for many processes in modern science and technology (*see page 20*). In the painting the cylinder head of the pump has been removed to reveal its principal working part, a cylinder of steel that rotates eccentrically within a cylindrical chamber. The gas from the system to be evacuated enters the pump through the smaller chamber at the top. As the eccentric rotates it admits gas from the smaller chamber into the larger through a valve arrangement that is not visible in the painting. The eccentric then sweeps the gas out of the cylindrical chamber through the large outlet pipe at the upper right. The operation of the pump depends on a tight, oil-sealed fit between the rotating eccentric and the wall of the cylindrical chamber. The pump is a product of the Kinney Manufacturing Company of Boston. The cover is the fourth painted for SCIENTIFIC AMERICAN by the distinguished artist Walter Murch. An earlier painting, which appeared on the cover of the December, 1949, issue of this magazine, was exhibited in the annual showing by New York's Whitney Museum of American Art of the best American paintings of 1949.

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Cover by Walter Murch

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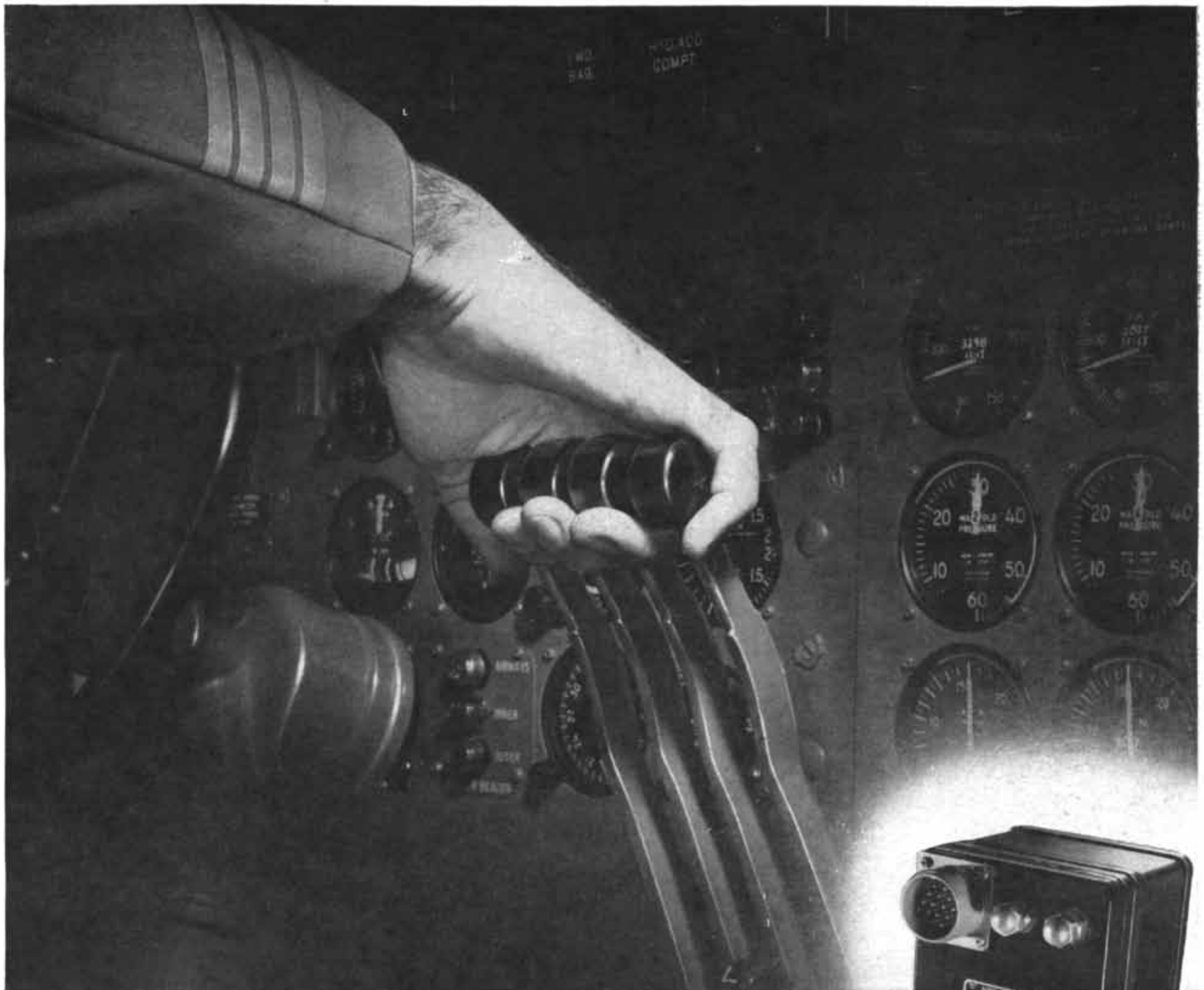

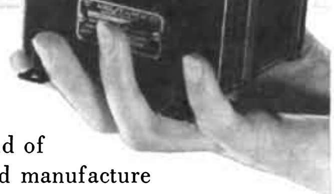

FIRST "FAIL SAFE" ELECTRONIC CONTROL

Pilots on today's giant aircraft adjust engine throttles by means of elaborate remote control electronic systems.

Problem has been to devise an electronic control that would "fail safe" in case trouble developed anywhere in the system. In other words, controls that would stop and hold position at the exact moment of system failure.

Engineers at AiResearch have now perfected such an electronic control. This control has many applications in the regulation of pressure . . . temperature . . . and remote positioning. For the first time, it provides a "fail safe" method of electronic control.

In addition, this new type of AiResearch electronic control is ultra sensitive. It makes possible the application of maximum power—or response to temperature or pressure changes—in almost microscopic degrees.

Such pioneering in the field of electronic development and manufacture is typical of the day-to-day operations of the skilled scientists and engineers at work at AiResearch.

● ***Whatever your field—AiResearch engineers—designers and manufacturers of rotors operating in excess of 100,000 rpm—invite your toughest problems involving high speed wheels. Specialized experience is also available in creating compact turbines and compressors; actuators, with high speed rotors; air, gas and liquid heat exchangers; air pressure, temperature and other automatic controls.***

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Los Angeles 45, California

SCIENTIFIC AMERICAN

Established 1845

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SCIENTIFIC AMERICAN

MAY 1950 VOL. 182, NO. 5

The Hydrogen Bomb: III

The physical, strategic and moral discussion of the last two issues is continued. In this article: the question of whether the weapon enhances our military security

by Robert F. Bacher

THERE have been many conflicting statements about hydrogen bombs and what we should do about them. Some of these statements have become distorted in repetition. Others, while clearly stating physical possibilities, concern events which are so improbable as not to warrant serious consideration at the moment. Some of the statements made by scientists, whether intentionally or otherwise, have been very frightening to our citizens. Back of such statements seems to be the idea, expressed by some, that if the U. S. citizen will just become sufficiently frightened somehow we will not have any war in the future.

There is no question that the hydrogen bomb has terrifying possibilities and I shall try to give some estimate of what such a bomb might be like. It is our very deep obligation, however, as citizens in a democratic country to consider this whole question objectively, dispassionately, and as carefully as we can under the circumstances to decide intelligently just what our country should be doing. It will not improve the judgment of the citizen to scare him to death first. This is a very serious time for the U. S. We cannot afford any irrational or purely emotional action. Our future safety and security depend today on keeping our heads and using wise judgment.

Many people in considering the national policy on the hydrogen bomb have been able to formulate their opinions of this weapon very quickly on moral grounds alone. They say, and with justice, that the hydrogen bomb is a weapon of tremendous mass destruction and that accordingly no civilized country should consider its possible development and use. This is a comfortable position and one very easy to take, but where do we stop? Atomic bombs also are weapons of mass destruction. Are they moral or immoral? Nothing could be more gruesome and immoral than the reports that many of us have heard of some of the hand-to-hand conflicts during the past war. Nothing could be more uncivilized than some of the torture to which war, conflict and slave states have led.

War inevitably leads to many acts which are immoral. The relative immorality of various weapons and acts of war becomes difficult to assess. The hydrogen bomb, being a weapon of tremendous destruction, is more to be condemned on these grounds than lesser weapons if used for needless mass destruction. Indeed, no one can argue that the moral position of the U. S. will be improved by the possession or use of this bomb. Immoral as it is, war consumes a large part of the efforts of the people of the world. Situations arise in which war seems to be the lesser of two evils.

There are of course many other questions about the hydrogen bomb, but let us consider here primarily the practical problem of its effect on our national security. How important is it to our security, and what is the relative value of work on this development as compared with other measures of defense?

BEFORE trying to answer these questions let us look briefly at a little of the technical background of the hydrogen bomb. It has been known for a great many years that if one could somehow find a way of putting light atomic nuclei together to make heavier nuclei, it would be possible to extract energy. The first indication that this process might be important as a source of energy came from the suggestion by Hans A. Bethe that the fusion of the light elements was our fundamental source of energy in the sun and stars. Bethe worked his ideas out in some detail and scientists now believe that this is the origin of solar energy. There is no possibility that the energy release from this type of reaction can be controlled on the earth, as it can be in the case of the fission of a heavy element such as uranium. In the stars the reaction is controlled because of their great size. On the earth these self-sustaining thermonuclear reactions will give either an explosion or nothing at all.

Whether a hydrogen bomb can be made depends upon whether it is possible to create on earth an assembly of materials that will produce a nuclear reaction if heated to a sufficiently high temperature, and then to devise a way to raise these materials to that temperature.

The temperature required is comparable to that reached in the interior of the sun—more than 20 million degrees Centigrade. The only way that we know to reach such a temperature today is in a fission atomic bomb, where the sudden release of energy causes the materials of the bomb to be heated to an extremely high temperature.

The main light element to which I have been referring, of course, is hydrogen. Now ordinary hydrogen will not work. The scientific evidence for this seems to be quite clear. But hydrogen as it is found in nature has another isotope, heavy hydrogen of mass 2, which is a possibility for a fusion-bomb reaction. In recent years heavy hydrogen, as contained in water, has been separated in relatively large quantities.

There is another possibility. For more than 15 years it has been known that a still heavier isotope of hydrogen, called tritium because it has mass 3, is produced in nuclear reactions. This material is radioactive, with a half-life of only 12 years, and ordinarily does not exist in nature. But its nuclear properties are such that it is of basic interest in the release of energy by fusion.

It has been known for many years that tritium could be produced in a nuclear reaction in which neutrons are absorbed. The big nuclear reactors now in operation produce neutrons in large quantity. These neutrons are ordinarily used in the production of plutonium, but they could be used just as well to produce quantities of tritium. Any nuclear physicist can sit down and figure out the theoretical limit of the amount of tritium that can be produced with a given number of neutrons. It would be necesssary, of course, to know a great deal about the actual workings of a nuclear reactor in order to say just how much tritium could be produced in that reactor if one were willing to forego the production of a certain amount of plutonium. It appears that the production of tritium in quantity is at least a fairly expensive if not formidable process. And it is a point worth emphasizing that tritium could be produced only at the cost of using neutrons that might otherwise be employed to make plutonium.

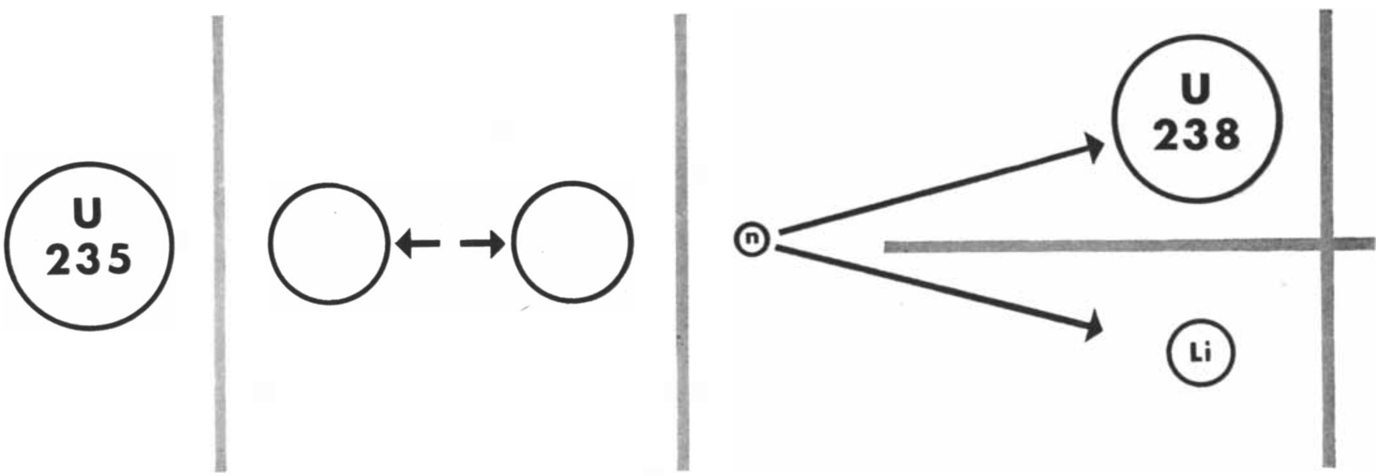
That the heavy isotopes of hydrogen can possibly play a fundamental role in the release of nuclear energy by fusion is well known. Just exactly what relative role they play and how they might play it is not a subject for open discussion today. These questions are secret and we can have no discussion of them. But any nuclear physicist will quickly grasp the requirements as far as the basic science is concerned, even though the actual technology of making a bomb on these principles is more complicated.

THE real problem in developing and constructing a hydrogen bomb is: "How do you get it going?" The heavy hydrogens, deuterium and tritium, are suitable substances if somehow they could be heated hot enough and kept hot. This problem is a little bit like the job of making a fire at 20 degrees below zero in the mountains with green wood covered with ice and with very little kindling. Today scientists tell us that such a fire can probably be kindled with the heavy isotopes of hydrogen. Once you get the fire going, of course, you can pile on the wood and make a very sizable conflagration. Similarly the hydrogen bomb could be built up with more heavy hydrogen. It has been called an open-ended weapon, meaning that more materials can be added and a bigger explosion obtained.

Let us look for a moment at what sort of an explosion is imagined. Here I shall take the figures that have been commonly reported in the press and stick to round numbers. In 1945 President Truman stated that the atomic bomb was equivalent to 20,000 tons of TNT. A hydrogen bomb 1,000 times as powerful as the Hiroshima bomb, which is the number most commonly used in public speculation, would have an explosive effect equivalent to about 20 million tons of TNT. Its radius of comparable blast damage would be about 10 times as great as that at Hiroshima. The radius of severe blast damage at Hiroshima was about one mile, so for a bomb 1,000 times as powerful it would be about 10 miles. Appraisal of the flash-burn effect of the more powerful bomb is somewhat more complicated. If we neglect the absorption of heat radiation by smoke or smog, and do not take into account the shadow effect, we may estimate that the flash-burn effect of the bigger bomb would extend about 100 times as far as that at Hiroshima. The effects of absorption and of the shadows of buildings are important, especially at a distance, but they are most difficult to estimate. In any case, it is clear that the flash-burn effect would be important over a considerably greater area than the blast damage.

There has been a great deal of speculation about the radioactive products of a hydrogen bomb. Since an atomic bomb would be needed to get the conflagration going, some fission products from that bomb would doubtless be present. The hydrogen nuclear conflagration itself would yield neutrons which would produce large quantities of radioactivity if they were absorbed in some material that becomes artificially radioactive. On the other hand, many of these neutrons might be absorbed in material that did not become radioactive. If the neutrons escaped into the air, many of them would be absorbed by nitrogen and produce radioactive carbon. This material is most disagreeable as a radioactive contaminant, since it has a half-life of many thousands of years. If the bomb were exploded under water, very few of the neutrons would escape; most of them would activate sodium and other elements in the sea water, or convert the ordinary hydrogen in the water into heavy hydrogen.

The radioactivity effects of a hydrogen bomb are difficult to estimate, since they depend very much on where the bomb is exploded and what material surrounds it. If the bomb is surrounded with a material selected to yield a maximum of artificial radioactivity, the radiations will be a dangerous hazard over



UNECONOMICAL USE OF NEUTRONS is a production shortcoming of the hydrogen bomb. In the first stage of this schematic representation of the problem is a nucleus of uranium 235, the primary fuel of all nuclear reactors. In the second stage U-235 fissions, producing the surplus neutron of the third stage. This neutron may now be used for capture by a nucleus of U-238, which shortly decays into plutonium 239. The fission of Pu-239 yields 200 million electron volts. The same neutron, however, might be used to bombard the nucleus the bombed region. One of the real scare stories about the effects of radioactivity has postulated the complete explosion of 500 tons of deuterium. While this is not impossible, as far as anyone can say, it is stretching probabilities a long way.

This brief analysis of well-known scientific information shows, then, that a hydrogen bomb would require a considerable quantity of heavy hydrogen, perhaps both deuterium and tritium, as well as an atomic bomb to set it off by raising the temperature sufficiently so that a nuclear conflagration can exist. Technically the problem is to figure out how a sizable fraction of the energy of the heavy hydrogen can be released before the material is cooled too much by emitted radiation or dispersed by the explosion. In the stars the radiation is retained because the stellar material is relatively opaque and there is an enormous temperature difference between the center and the outside of the star. In a hydrogen bomb there is no such protective layer. Thus the central problem is to get a large fraction of the energy released while the temperature is still high enough.

Whether this can be done will of course not be certain until it has been done. There are many opinions as to how difficult it may be. Since the President has directed the Atomic Energy Commission to continue with the development, we can assume that it is regarded as both possible and feasible.

SO MUCH for the technical problems that must be solved in order to develop a hydrogen bomb. Assuming that the problems can be solved, let us try to determine whether or not hydrogen bombs will add materially to our national security by considering their effectiveness as military weapons and comparing them with atomic bombs already in existence.

If we assume that the hydrogen bomb is a thousand times as powerful as the Hiroshima bomb, we can easily see that a hydrogen bomb is capable of destroying any major city, with the exception perhaps of some of the outlying districts. How does this compare with what could be done with atomic bombs? We have been comparing the hydrogen bomb with the fission bomb used at Hiroshima, but it has been stated that since the war there have been significant improvements in fission bombs. These improvements have resulted in more powerful bombs and in a more efficient use of the valuable fissionable material.

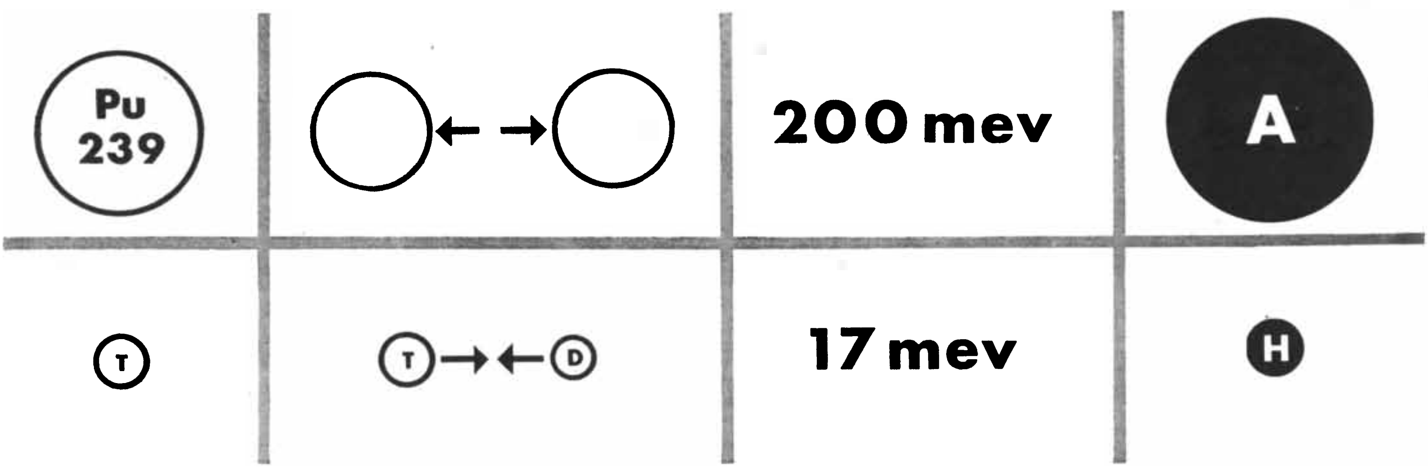
Most large metropolitan areas include many sections that are covered by water or otherwise unsettled. Thus a hydrogen bomb would blast many square miles whose destruction would contribute in no way to the effectiveness of the bomb. Atomic bombs, on the other hand, could presumably be dropped so as to avoid overbombing uninhabited areas. Furthermore, it was found in the last war that a saturation raid which greatly hampered fire-fighting forces caused damage far beyond the areas of immediate blast effects. Considering all these factors, it seems likely that there is no metropolitan area which could not be thoroughly destroyed with 25 atomic bombs at most, and perhaps as few as 10. It also appears that two atomic bombs would completely paralyze a city, even a large one.

Except for the psychological effects and for the most unpleasant and somewhat unpredictable effects of the radioactivity produced, it appears that a hydrogen bomb 1,000 times more powerful than an ordinary fission bomb would probably not be much more effective than 10 fission bombs. For smaller industrial targets it would not be much more effective than a single fission bomb.

In view of this, one begins to wonder just how useful a military weapon the hydrogen bomb would be. Would it really revolutionize warfare, as some say? Certainly it is a terrible weapon, and large numbers of these bombs could cause untold destruction; even a relatively small number could deal a major blow to any highly industrialized and centralized country. But what about the fission bomb and the damage that a sizable stockpile of these weapons could inflict? Suppose, just to take a round number, that the U. S. possessed 1,000 fission bombs of the improved variety. If they could be delivered to military objectives at all, they would go a long way at the rate of 10 for a major metropolitan area and perhaps an even smaller number for major cities. With 1,000 bombs, there would be a great many for relatively minor military objectives, and I imagine that the military commanders would have a hard time figuring out what to do with the last hundred.

It appears that if any nation has as many as 1,000 atomic bombs, the world is already in the position where any nation could be blasted thoroughly and completely, insofar as bombing alone can be effective. If this is the case, just what additional military use is a hydrogen bomb? It looks very much as if everyone is simply fascinated by the idea of "the bigger the better." There are some examples in the history of the world that should lead us to question this view. We should not forget the dinosaur nor the dodo. Indeed, we should not forget the battleship, now almost extinct.

Actually it might turn out that in a shooting war it would not be possible to deliver hydrogen bombs, atomic bombs or any other kind of big bomb to the targets. Hence if atomic bombs or any



of lithium. This capture yields tritium (T), the hydrogen isotope of mass 3. The fusion of tritium and deuterium (D), assumed here to be essential in a hydrogen bomb, releases 17 million electron volts. On this basis the expenditure of a neutron in the manufacture of tritium produces much less energy than in the manufacture of plutonium. The relative energy release of A- and H-bombs per neutron is symbolized at the far right. This diagram was prepared by the editors on the basis of statements by the author and other unclassified material.

big bombs are to be a major part of our military preparation, from the military standpoint the solution of the delivery problem is vastly more important than exactly what kind of bombs would be carried if they could be delivered.

IF HYDROGEN bombs would not add very much to the military effectiveness of the U. S., would they add much to the U S.S.R.'s military potential? Here, of course, one gets involved in even more uncertain speculation. It is extremely difficult to judge whether the Russians would have an appreciable chance of delivering the hydrogen bomb by air against the radar defense which we are now constructing. Even if a reasonably effective system of air defenses is built, however, there is another method of delivery which would perhaps be quite effective for the Russians. Many of the big cities of the U. S. are on the seacoast. Into any one of these harbors, or at least reasonably close to it, a hydrogen bomb might easily be brought in the hold of a tramp steamer or in a relatively small unmanned craft. While this might not be the most effective place to detonate a hydrogen bomb, it would be a simple method of delivery for a surprise attack. On the other hand, practically no Soviet cities could be reached in this way. This means that the hydrogen bomb would be a more effective weapon for the Russians than for the U. S.

Some people have argued that if we develop the hydrogen bomb and can really keep its details secret, the Russians will never be able to develop it. There is absolutely no reason to believe this. Recent experience has shown that the Russians have an atomic energy enterprise adequately developed to make a sizable atomic explosion. In addition they probably have fairly detailed information about our work on atomic weapons and about at least some of the early thoughts on the possibility of a hydrogen bomb, obtained from the blundering indiscretions of some months ago, espionage activity and the widely known basic scientific principles. Given adequate time they can surely make a hydrogen bomb if it is possible at all.

The President's decision to go ahead with the development of the hydrogen bomb created a tremendous stir in the nation. From the standpoint of its military effectiveness, there seems to be little reason to attach such great significance to the hydrogen bomb. While it is a terrible weapon, its military importance seems to have been grossly overrated in the mind of the layman.

What is probably much more serious about the hush-hush subject of the hydrogen bomb is that here is a weapon about which the average citizen is so ill-informed that he thinks it can save the country from attack. Pumped full of hysteria by Red scares, aggravated by political mud-slinging, the average citizen is easily convinced that he can find some security and relief from all of this in the hydrogen bomb. The most tragic part is that the hydrogen bomb will not save us and is not even a very good addition to our military potential.

Here we have the outcome of what can happen in a democracy when decisions of far-reaching national significance are made without public scrutiny of pertinent information. While most of the pertinent information is not at all secret, some of the information the citizen should have in order to judge whether our national policy is sound is being kept secret. One of the most important facts the citizen should have to make a reasonable judgment is the approximate number of atomic bombs in our stockpile. It would be quite surprising if the Russians could not figure this out from the information they have obtained. Senator Brien McMahon, chairman of the Joint Committee on Atomic Energy, raised the question of making the number of atomic weapons available generally. He was vigorously criticized. As of last spring, not even the members of the Joint Committee knew how many atomic bombs the U. S. had.

ANOTHER item of information that would help the citizen appreciate the relative cost of hydrogen bombs and atomic bombs is the amount of fissionable material needed to get the hydrogen reaction started and the plutonium equivalent of the tritium to be used in a hydrogen bomb. Since neutrons are required to produce either plutonium or tritium, the neutron cost of a hydrogen bomb may be larger than first appears. The diversion of neutrons from the manufacture of plutonium to make tritium would mean a very real sacrifice of potential atomic bombs in order to obtain the ingredients for hydrogen bombs. As for the money cost of the hydrogen bomb, there have been such wide discrepancies in the estimates that the citizen can reach no sensible conclusion about it at all.

It is most important in our democracy that our government be frank and open with the citizens. In a democracy it is possible to have good government only when the citizens are well informed. It is difficult enough for them to become well informed when the information is easily available. When that information is not available, it is impossible. While it may well be that some of the information the citizen needs to make an intelligent judgment of national policy must be kept secret for military reasons, the present use of secrecy far exceeds this minimum. These are the methods of an authoritarian government and should be vigorously opposed in our democracy.

The hydrogen bomb and its potential usefulness to the U. S. as a military weapon is a subject on which citizens should be much more fully informed. It is a weapon whose effectiveness has been grossly exaggerated, and one in which we can place relatively little reliance for the future. Quantities of hydrogen bombs will not contribute very much to the security of the U. S. Unfortunately the citizen today believes that they will.

What, then, might be done to improve our military security in an important way? There are probably many answers to this question, but let me just make one suggestion that I am sure is clear to anyone who has thought seriously about the problem.

If the Russians should decide to move into Western Europe, we would immediately be faced with the prospect of fighting a war. Presumably we could use atomic bombs. It would not be long, however, before we would need a large army, and supplies not only for that army but also for our allies in Europe. We would have to send these supplies to Europe. But just how would we get them there? During the last war the Germans came dangerously close to shutting off our supplies to England on at least two occasions. This was before the development of the Schnorkel type of submarine, which we are told the Russians now have in quantity. It is well known that this Schnorkel submarine, while not absolutely impervious to detection by radar, is most difficult to run down. No method of detection has been developed that can locate it at any great distance under water. It appears that a determined enemy with adequate bases and Schnorkel submarines could go a long way toward preventing us from delivering men and supplies to Europe. We could presumably deliver a certain amount of material by air, but when it comes to delivering millions of tons, our experience with the Berlin air lift should show us that this is not a feasible solution.

Here is a problem whose solution would contribute greatly to our military strength and therefore to our security. Its solution might even deter the Russians from overrunning Western Europe if they planned to do so. Hence it seems much more important to devote our attention to this problem than to the more spectacular hydrogen-bomb development.

THERE exist a great many other problems that are probably almost as important. For example, there is the matter of the development of long-range guided missiles. This development is clearly important to military strength. During the last war both the Germans and the Russians were very successful in the tactical use of airplanes with ground troops. New technical work might greatly increase the effectiveness of airplanes in tactical use.

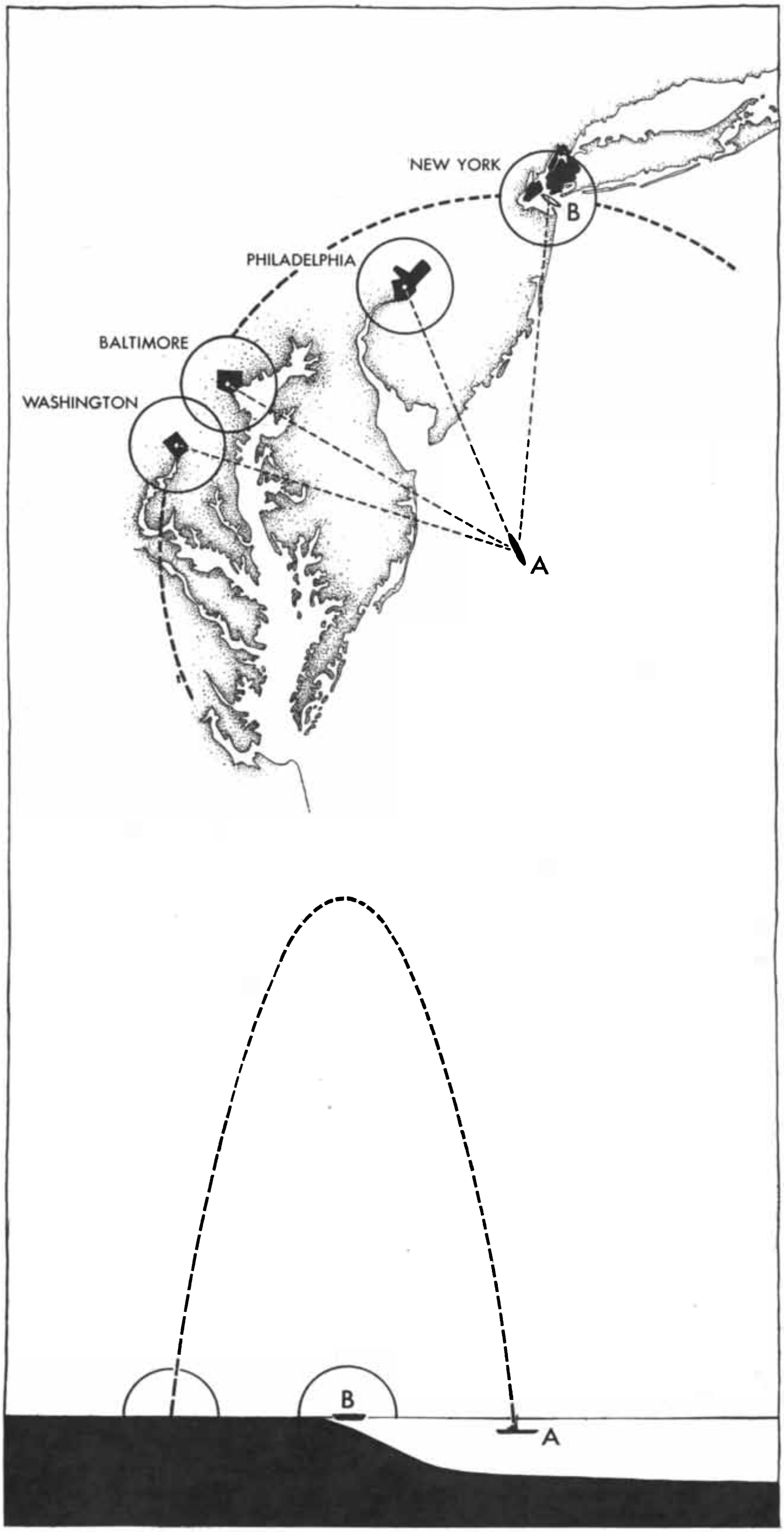
In the field of atomic energy itself we need to make a choice between weapons and other developments of nuclear power which may have long-range peacetime significance as well as military applications. These long-range peacetime assets may add to our industrial strength and thereby make a greater contribution to our security than the more immediate development of weapons.

At the present time it is most difficult to ascertain how our government decides what policies to follow regarding national security. High government officials find themselves beset with advice to pursue this or that development or construct this or that weapon without being very sure how one weapon compares with another. Where the development of a weapon may compete with a long-range industrial development the problem is still more difficult. Although the U. S. is a rich country, we cannot afford to follow every recommendation that anyone believes will increase our national security.

The best way to make sure that a reasonable policy is followed is to have those policies and the information on which they are based open for public scrutiny. The citizen must choose, insofar as that is possible. Today if he tries to come to some conclusion about what should be done to increase national security, he runs up against a high wall of secrecy. He can of course take the easy solution and say that these questions should be left to the upper echelons of the military establishments to decide. But these decisions are so important today that to leave them to the military men is for the citizen essentially to abrogate his basic responsibility. If in time of peace decisions on which the future of our country depends are left to any small group not representative of the people, we have gone a long way toward authoritarian government.

The U. S. has grown strong under a Constitution that wisely has laid great emphasis upon the importance of free and open discussion. Under the influence of a large number of people who have fallen for the fallacy that there is security in secrecy, and of many, including, I regret to say, eminent scientists, who prophesy doom just around the corner, we are dangerously close to abandoning those principles of free speech and open discussion that have made our country great. The democratic system depends on intelligent decisions by the electorate. Our heritage can only be carried on if the citizen has the information with which to make an intelligent decision.

Robert F. Bacher, from 1946 to 1949 a member of the Atomic Energy Commission, is professor of physics at the California Institute of Technology.



U.S. DISADVANTAGE in a war involving hydrogen bombs is illustrated in this map and section drawing. Cities on or near the coast would be vulnerable to a submarine (A) firing a hydrogen bomb in a rocket or to a hydrogen bomb-carrying robot ship (B). Range of rocket is assumed to be 150 miles.

MALE FERTILITY

Perhaps two thirds of the cases of human infertility are chargeable to men rather than women. Some recent studies have revealed a few interesting reasons why

by Edmond J. Farris

NO PROBLEM concerns mankind more deeply than the problem of human fertility. It interests physicians and philosophers, demographers and politicians, psychiatrists and anthropologists, biologists and businessmen, policemen and sociologists. Demographers meet this root-problem when they study world food conditions, psychiatrists when they attempt to deal with psychological difficulties of childless couples, adoption agencies when they grapple with the imbalance of supply and demand for children. Millions of laymen are personally and profoundly concerned with one or another of the problem's phases.

There are of course two basic aspects of the fertility problem: conception and contraception. The elements of the latter are clearly understood, and the problem can be solved easily by any informed couple; whatever difficulties arise in connection with the application of contraception are usually concerned with groups rather than with individuals. The elements of conception, on the other hand, are only partly understood, even by the well informed, and are often misapplied to such an extent that infertility results.

It is highly probable that in some cases infertility in a couple results from emotional factors which are most difficult to define and resolve. But recent experiments show that in more than 80 per cent of those couples who seek aid the problem is physiological in origin, not psychological, at least so far as the male contribution is concerned.

More often than not, infertility in a couple is charged to the wife. This is often a grievous error. In about two thirds of all cases, infertility is actually chargeable to the husband. It is therefore important that both physicians and laymen learn more than is now generally understood about semen and the varying degrees of potential fertility in men.

Studies of this kind have been made in our laboratory at The Wistar Institute with the aid of a new method we have developed for analyzing semen. Where former methods relied upon a fixed cell count, the new one makes it possible to determine accurately the number of *active* spermatozoa in any semen sample. In the experiments to be described, 406 specimens were obtained from 239 individuals. They included both married and unmarried men. Some of the married men were of proved fertility. About 90 per cent of these were studied within three months after their wives had become pregnant.

OUR first concern was to determine the minimum number of active spermatozoa that must be produced by the husband if the wife is to conceive. We grouped 49 fertile men according to whether they had had one child or two or more. In the first group were 38 men with one child each who had come to us because their wives were experiencing difficulty in conceiving a second time. In the second group were 11 men who had at least two children; none had a fertility problem.

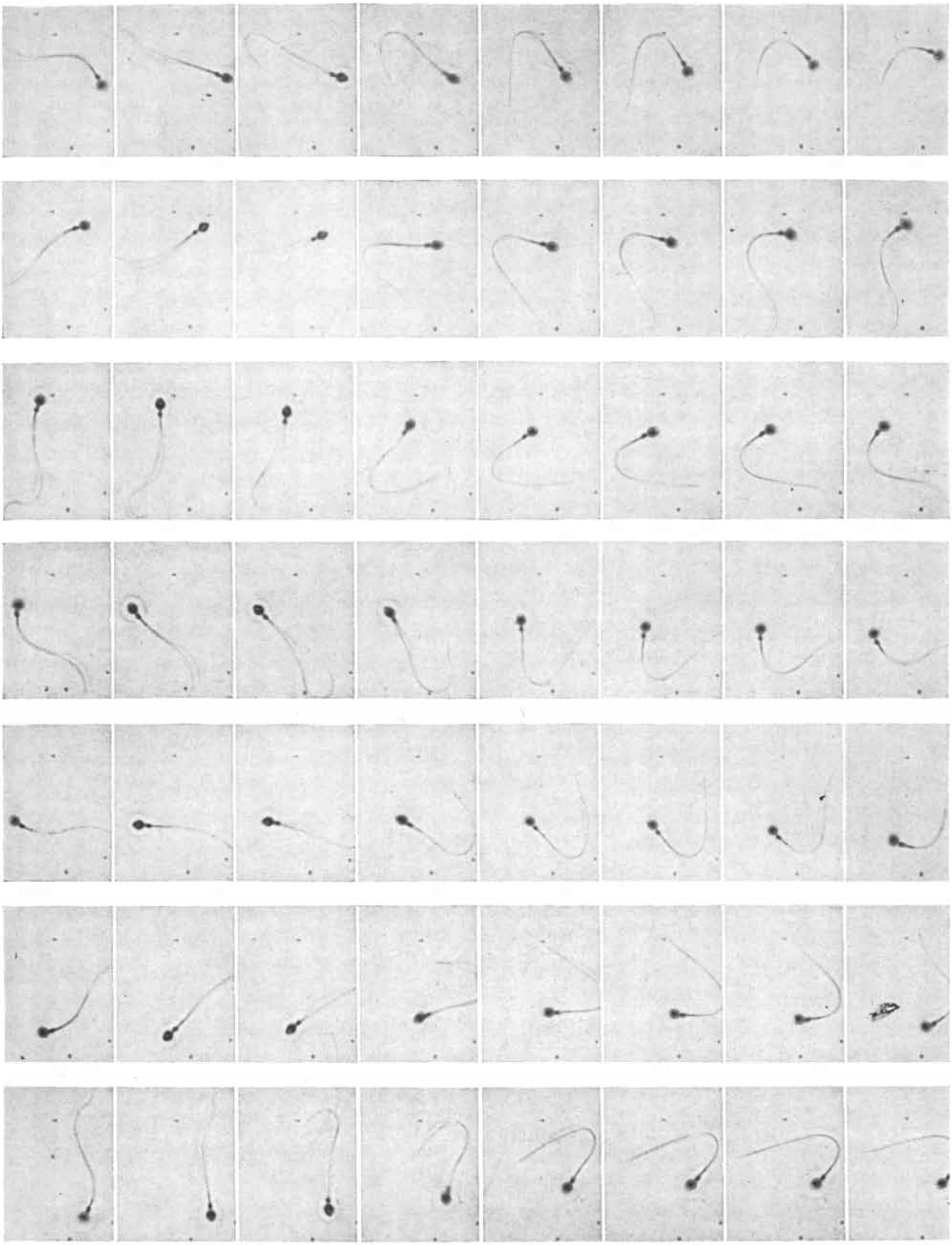
The results of the semen analyses in these cases are shown in the table at the top of page 19. The most significant figures for our present purposes are those which give the number of active spermatozoa in the total ejaculate, *i.e.*, the "absolute motility." They show that the smallest number of active spermatozoa in any specimen from these 49 men was 83 million. All of the men whose counts were near this lowest figure were in the less fertile group. From this we obtained a hint that somewhere in the low 80 millions might be the dividing line between men who could be viewed as subfertile and those who might be said to have "normal" fertility.

We have since confirmed this to our satisfaction by making similar analyses of many married men who have come to us with various problems. We found that about 97 per cent of the men whose counts of absolute motility fell below 80 million either had had no children at all or (in a comparatively few cases) had had children at some time in the past but had since become infertile. In such cases the couple seeking help can succeed in having a child only with great difficulty and with the most careful clinical guidance. On the other hand, we have rarely found ourselves unable to help the wife of a man with a count higher than 80 million to conceive, unless the wife also has a fertility problem.

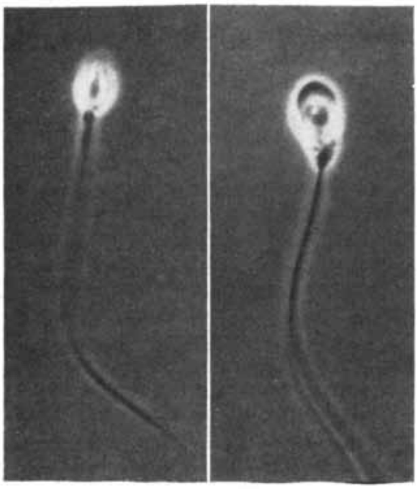
In the tests described above, all the specimens were obtained at least five days after the last previous emission. With the aim of obtaining a measurement of the degree of fertility in a shorter interval, we ran a pilot series of observations on 23 individuals. Two semen specimens were taken from each man: the first after five days of abstinence and the second 24 hours after the first. On the basis of counts of active spermatozoa the men were divided into three groups. In all three groups the count fell on the second day. But the principal fact we noticed was that all of the men in the first group, who had an absolute motility of well over 80 million the second day, had had a count of more than 185 million on the first day. In other words, it appeared that any man with an active spermatozoon count of 185 million or more could engage in coitus two days in succession and still not drop into the subfertile zone. Later investigations showed, in fact, that these men remain in the fertile zone for at least three successive days. But the group who had counts be-

EDITOR'S NOTE

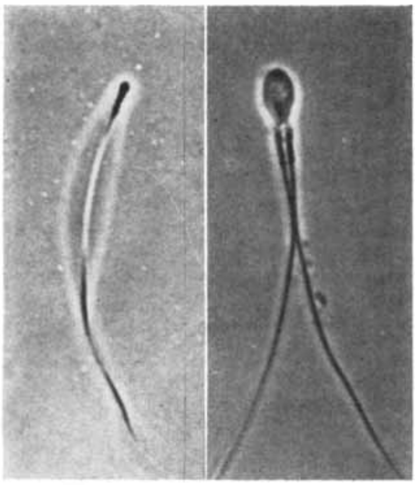
The material contained in this article is treated at greater length in a chapter of a new book by the author. The title of the book is *Human Fertility*. It was published late last month by The Author's Press of White Plains, N. Y. It is copyrighted 1950 by The Author's Press, Inc.



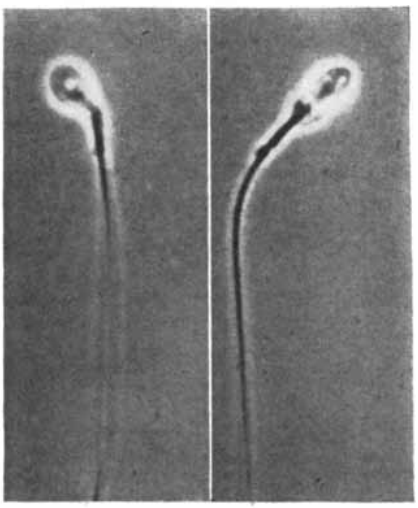
CIRCLING HUMAN SPERMATOZOON is photographed at 24 frames per second. Such a spermatozoon has a negligible chance of traversing the approximately 180 millimeters to the ovum. It is accordingly not qualified as a "progressive" spermatozoon. Other non-progressive spermatozoa merely fail to move very far in any direction. Still other imperfect spermatozoa are not only non-progressive; they appear to be completely inactive.



NORMAL spermatozoon is viewed through phase microscope. At right: abnormal specimen with a giant head.



ABNORMAL spermatozoa are shown at left and right. Specimen at left is "pinhead"; the other is "duplicate."



ABNORMAL spermatozoon at left is "hammerhead"; specimen at right suffers an irregularity of cytoplasm.

tween 80 and 185 million the first day dropped into the subfertile zone on the second day, and the group who were under 80 million the first day fell still lower.

These discoveries have a practical application to couples with fertility problems. A husband whose semen has an absolute motility of over 185 million has a good chance of bringing about conception for at least three consecutive days during the period in which his wife's ovulation takes place. Thus it is usually not necessary for him to know his wife's ovulation time with great accuracy. On the other hand, a husband with an absolute motility of 80 to 185 million is faced with a problem. Since he is subfertile on the second day, he can have sexual intercourse with some hope of success on only one day during the fertile period. In his case it is necessary that an accurate prediction of his wife's ovulation time be made in order that he may make the best use of his limited fertility. Such a prediction can be made by means of a new rat test which has been developed at The Wistar Institute. The test, involving injection of urine containing hormones from the patient into a rat, makes it possible to predict a woman's time of ovulation within 12 hours in the majority of cases.

OUR findings permit us to define three degrees of fertility in the male: 1) high fertility, indicated by a count of above 185 million active spermatozoa on the first day and above 80 million on the next day; 2) relative fertility, with a range of 80 to 185 million on the first day, but less than 80 million on the next day; 3) subfertility, with a count of less than 80 million in the majority of semen examinations.

Another study was designed to find out what other factors were associated significantly with this index of fertility. The subjects in this investigation were 221 childless men who sought our advice because of the inability of their wives to conceive. On the basis of counts of active sperm they were classified in four groups: highly fertile, relatively fertile, subfertile and sterile (no spermatozoa). The results of this study are shown in the table at the bottom of the opposite page. The analysis indicates, more conclusively than the earlier study, that most of the other factors are related to the absolute motility. One factor that shows relatively little correlation with it is the volume of the ejaculate. The variations in volume appear to be within the range of normal physiological variation, and even the sterile men were not far from the norm in this respect. This finding should be an effective answer to the many men who think they are fertile because their semen volume is large.

The most critical factor in this study, as in the others, is the average number of active spermatozoa; the count for the fertile males in the first two groups is three to eight times greater than for those in the subfertile group.

Occasionally the spermatozoa counts of an individual vary sufficiently to cause a temporary shift from one classification into another. Obviously no exact borderlines can be established; it would be ridiculous to say that a man with a count of 80 million active spermatozoa can have a child and one with 79 million has no hope of ever having a child without guidance. But wide variations are most often found in the moderately fertile and subfertile groups. Highly fertile males usually remain consistently in the high-count category if they practice moderate abstinence.

The fertility of a man cannot be judged on the basis of his physical appearance. Semen analyses on men of all physical types have demonstrated that within each type one will find the full range of classifications from highly fertile to sterile. The heavyweight boxer is not necessarily more or less fertile than the ascetic. One must look primarily to physiological standards.

WHAT are the standards? In a study of more than 200 husbands whose wives conceived while the couples were being studied, the semen samples gave the following median values: the volume was four cubic centimeters (the largest volume we have ever recorded was 15.5 c.c. in a relatively fertile man); the speed of the spermatozoa was one twentieth of a millimeter per second; 87 per cent of the spermatozoa were of the normal oval type; 44 per cent were active; there were 51 million active spermatozoa per c.c. and 209 million active sperm in the total ejaculate. When the husbands' semen had these median values, their wives conceived without difficulty. The minimum conditions for conception appear to be a volume of two and one half cubic centimeters, a spermatozoa speed of one twentieth of a millimeter in .7 to 1.2 seconds, 80 per cent oval cells, 38 per cent motile cells, and 80 million active spermatozoa in the total ejaculate.

These standards serve only as a guide. One cannot state dogmatically that a male with less than the minimum standards can never father a child, but there is only a negligible chance that he will. Occasional pregnancies have occurred when the count was less than the minimum figures.

Semen samples below the minimum for ordinary conception may sometimes be used successfully for artificial insemination. A series of 24 successful inseminations was performed with semen of varying degrees of fertility; in one case the absolute motility was only 38 million. But these tests are not sufficient to give us a clear indication of the minimum standards. For obvious reasons it is not feasible to experiment in artificial insemination with semen specimens of all degrees of fertility. In donor inseminations we always supply the samples from men we know to be highly fertile, in order to avoid an additional unfavorable factor. In time we may be able to accumulate sufficient data to determine minimum standards by studying all cases of insemination in which the husband's semen is used.

On the basis of the experiments described in this article, and with the aid of the highly accurate ovulation-timing test, it has been possible to develop a complete and integrated program for the alleviation of sterility. Much of the program can be applied by the childless couples themselves, and with great effectiveness. In complicated cases the physician, the clinician and patients working together can bring about conception in a high proportion of those cases that do not involve subfertile husbands.

To check on the effectiveness of the integrated program, we have started a survey of a group of couples treated between 1946 and 1950. They were selected at random from our files for those years, except that we eliminated all cases in which we knew there was a female problem. We have lost contact with some of the couples and do not know whether they have had children; in a few cases treatment is not yet complete, and in some there may be female abnormalities not yet discovered. Each of these factors will tend to improve the figures when we have re-established contact and filled in the gaps. In the meantime it is interesting to observe what the results have been so far, conservatively stated.

In general our studies suggest that about 40 per cent of the males were highly fertile, about 35 to 40 per cent relatively fertile, about 15 per cent subfertile and the rest sterile. In couples involving subfertile husbands, success was attained in only 15 per cent of the cases. Most of these couples will have to resort to heterologous artificial insemination to conceive. But among highly fertile husbands the program has been successful in a minimum of 86 per cent of the cases; and in those cases involving relatively fertile men it has been successful at least 75 per cent of the time. In the two groups together, 81 per cent of the couples have conceived one or more times as a result of the program. On the whole it appears that couples afflicted with temporary sterility now can have reasonable hope that their problems may be solved.

Edmond J. Farris is executive director of The Wistar Institute of Anatomy and Biology.

	ONE CHILD	TWO OR MORE CHILDREN	COMBINED FERTILE GROUP
Number of men	38	11	49
Volume of ejaculate (cc)	4.5 (1.8-9.6)	4.0 (1.2-8.4)	4.3 (1.2-9.6)
Active and inactive sperm in total ejaculate (millions)	496 (232-1062)	661 (276-1284)	555 (232-1284)
Active sperm in total ejaculate (millions)	221 (83-499)	292 (151-462)	246 (83-499)
Percentage of active sperm	45 (15-74)	46 (23-64)	45.5 (15-66)
Speed of sperm (seconds)	1.2 (0.7-2.8)	1.2 (0.5-3.6)	1.2 (0.5-3.6)
Percentage of specimens active after 24 hours	70	80	76
Percentage of oval (normal) forms (stained specimens)	87 (75-96)	91 (82-90)	90 (75-99)

FERTILE MEN were studied at The Wistar Institute to determine the minimum number of active spermatozoa required for conception. The figures in parentheses are the largest and smallest value recorded in each group.

	ACTIVE SPERM CELLS IN MILLIONS			
	More than 80 million		Less than 80 million	
Number of men	57	71	81	12
Volume of ejaculate (cc)	4.7 (1.2-10)	3.9 (1-10)	3.5 (0.5-8)	3.4 (0.35-8)
Active and inactive sperm in total ejaculate (millions)	611 (307-1465)	346 (122-1254)	155 (3-530)	–
Active sperm in total ejaculate (millions)	283 (182-576)	129 (83-185)	37 (0.5-80)	–
Percentage of active sperm	44 (16-65)	40 (11-72)	26 (2-75)	–
Speed of sperm (seconds)	1.6 (0.5-1.8)	1.2 (0.7-2.1)	1.9 (0.9-12.3)	–
Percentage of specimens active after 24 hours	84	70	26	–
Percentage of oval (normal) forms	90 (79-99)	88 (58-97)	70 (10-96)	–

FERTILE AND INFERTILE MEN were similarly studied. Most of the factors appear to be related to the "absolute motility" of the spermatozoa. Volume of sperm has little influence on the number of active spermatozoa.

HIGH VACUUM

The void of the ancient Greek philosophers has become the essential medium of subtle processes in modern science and technology

by Philip and Emily Morrison

OPEN the door of a physics laboratory—any physics laboratory, anywhere in the world today—and you will almost certainly hear one characteristic background noise: the low, steady pulse of the vacuum pump, the heartbeat of the laboratory. Walk into the room, and the most characteristic bit of apparatus you will see is the vacuum tube, which is as essential to a modern physicist as the microscope is to a bacteriologist or the nail to a carpenter.

The vacuum sealed within the tube and the vacuum produced by the pump serve much the same ends. The tube is a ready-made package of commercial vacuum, while the pump is a means of providing vacuum custom-built for the experimenter who cannot find on the market a package to suit his special needs. The vacuum itself is almost literally the lifeblood of modern physics, the essential medium in which its important experimental structures are bathed.

In the fifth century B.C. the Thracian philosopher Democritus of Abdera came to the conclusion that all things were made up of atoms and the void between them, and that the void was fundamentally as real as the atoms themselves. Two hundred years later Strato the Physicist, a successor to Aristotle at the Lyceum of Athens, made an airtight metal sphere fitted with a pipe through which he blew in and sucked out air. By this means he sought to demonstrate experimentally his theory that "small vacuums exist in a scattered state in air, water, and other bodies. . . . The particles of air do not completely fit into one another [but] leave empty spaces between, as does the sand on the beach." Strato used his theory in the explanation of many phenomena, including the propagation of light: "If vacuums did not exist, neither light nor heat nor any other material force would be able to penetrate the substance of water or air or any other body."

Physicists today believe with Democritus that all things are made of atoms and the void and that the two are inseparable. With Strato they believe that the void—empty space—is not featureless but has properties as definite as those of the atoms, that it can transmit light and gravitation, and that in it move the atoms themselves. The void can be studied only through the behavior of the atoms which fill it or bound it, and the atoms can be described only in terms of their structure in space. Both the theories of Democritus and the experiments of Strato continue in the imagination and the experience of physicists, and the ideas suggested by these two ancients are subjects of discussion today.

Their work was largely forgotten, however, and it was not until the Renaissance that the next famous vacuum experiment was performed by Galileo's pupil Evangelista Torricelli. He filled with mercury a long narrow glass tube closed at one end, placed his finger over the open end and inverted the tube in a basin of mercury. The mercury in the tube sank at once, leaving an apparently empty space at the top, later called the Torricellian vacuum. In effect Torricelli had made a barometer. The height of the mercury column (about two and a half feet) measured the sea-level atmospheric pressure, *i.e.*, the weight of the air pressing on the surface of the mercury in the basin. The great French philosopher Blaise Pascal repeated these experiments on top of the Puy-de-Dôme, and found the weight of the air to be less at that altitude than at sea level. He concluded "that the vacuum is not impossible in nature, and that she does not shun it with so great a horror as many imagine."

Independently Otto von Guericke, burgomaster of Magdeburg, invented the air pump. This he used in many demonstrations, the most spectacular of which was performed before the Emperor Ferdinand III and his Reichstag at Regensburg in 1654. Here von Guericke used two large copper hemispheres made airtight by a sealing ring of leather soaked with oil and wax. Once he had pumped the air from his hemispheres, 16 horses could not pull them apart. In England Robert Hooke and Robert Boyle built an improved air pump which Boyle used for an almost whimsical variety of experiments, including an observation of the effect of reduced pressure on a bee.

It was the mechanical properties of the vacuum, the visible demonstration of the weight of the air, that mainly concerned these pioneers. Not until later did experimenters focus their attention on the internal nature of the vacuum, as, with the growing skill of their technique, the idea of the fine structure of matter became clear.

WHAT is vacuum? In the old philosophic sense vacuum is void or nothing or empty space inextricably linked with the existence of atoms. In modern science space and matter are still major categories for our basic understanding of the real world. But we shall speak of vacuum pragmatically, as something the physicist has made a long series of efforts to produce. In the latter sense vacuum is a "fourth state of matter" as different from gas as liquid is from solid, and in much the same way.

The differences among the four states of matter are essentially those of the spacing and the motion of the molecules, and these differences are obvious in such examples as the crystal ice and the liquid water. The molecules contained in an ordinary ice cube will fill a five-gallon can if they are converted into steam at atmospheric pressure; the flying molecules of the vapor are about 10 times as far apart as they were in the solid ice. When a housewife confines the molecules of this amount of water in her pressure cooker and heats them sufficiently, she is making steam at double normal pressure; if she opens the valve a bit too soon, she receives a graphic demonstration of the behavior of a gas as the molecules crowd through the narrow tube into the air. The molecules of a gas—fast and slow, spinning and oscillating, converging and scattering—hurtle through space in a completely random course. Indeed the word gas is simply the Greek word chaos, transliterated into Flemish by the alchemist Jan van Helmont.

Starting with our five-gallon can of

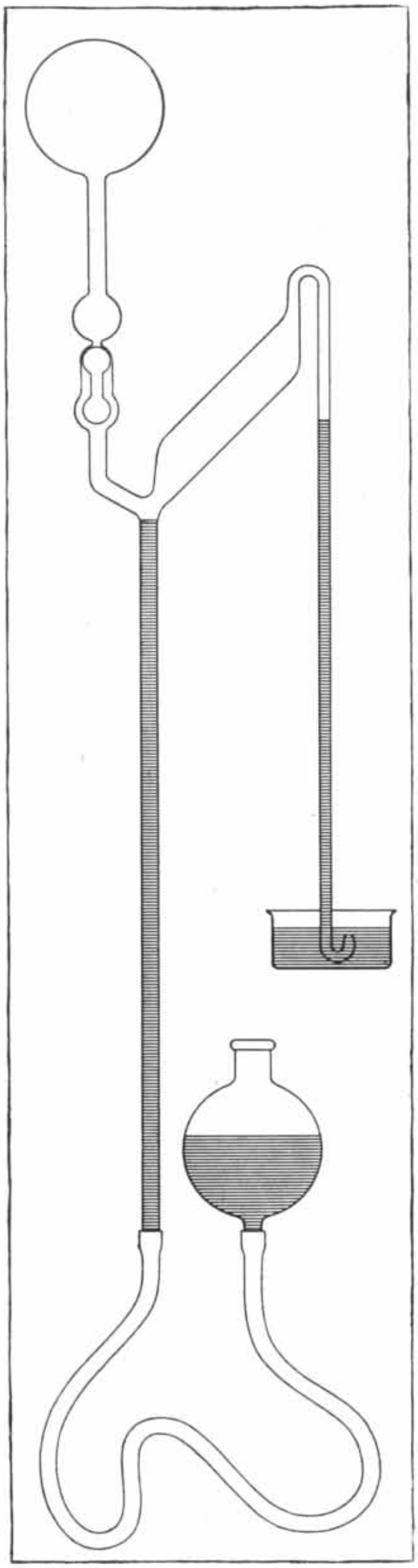
steam at normal pressure, we can obtain a reasonably good vacuum—after strongly re-enforcing the can to withstand atmospheric pressure—by pumping out all but one out of every million of the original molecules. (This would leave only enough water to make a snowflake.) Like the pressure cooker our container must be tight, but now in order to keep molecules of air from rushing in rather than molecules of steam from bursting out. The molecules remaining within the container fly about freely. Since there are few of them in a comparatively large space, they do not collide with one another as often as do those in a gas at normal density. In the normal air of a room an average molecule flies with the speed of a rifle bullet and in a similar straight path, a little curved by the force of gravity. After one molecule collides with another, each goes off in a new direction; on the average in normal air such a molecule can travel only a few millionths of an inch—less than the length of a light wave—before hitting a neighbor. The physicist says that the mean free path of this molecule is very short. In our evacuated container, on the other hand, one of the rare remaining molecules travels two inches on the average before hitting another. In the best vacuums now attainable, where all but one out of every million million molecules are removed, a molecule can travel miles before hitting any others except those in the walls of the container.

It is just this long mean free path of a molecule in a gas at very low pressure that is characteristic of our fourth state of matter. Only in high vacuum is the physicist able to study and control the behavior of a single particle without the interference of its fellows. Only in a vacuum can the physicist easily use electric and magnetic fields to guide a stream of electrons in some particular path or against some particular target; only in a vacuum has the physicist been able to unravel the nature of the molecule and its constituents. The great machines of today's nuclear laboratories—the cyclotrons and synchrotrons and betatrons—are simply devices for speeding isolated particles around and around a carefully planned interlacing orbit in a vacuum. A television tube must contain a good vacuum, else the narrow stream of electrons which so rapidly and precisely paints the image on the screen would become impossibly distorted and diffuse through random collisions with the molecules of gas. The ever-present radio tube in all its variants provides the ready-made sealed-off vacuum where the delicately controlled motion of electrons can serve the innumerable purposes of the circuit-maker's art.

It should be remembered that even in a good vacuum isolation is a relative term when we speak of molecules. In our best attainable vacuums there are still tens of millions of molecules in every cubic centimeter. Each molecule flies back and forth across the enclosure, making thousands of collisions with the walls of the system, traveling several miles before encountering another molecule. This is possible only because each molecule is so extremely small that even tens of millions in a cubic centimeter present in the aggregate only a tiny target. Beyond the edge of the galactic system there are lonely hydrogen molecules which may travel for millennia and through billions of miles between encounters with their neighbors. Here is the very highest vacuum of all, in that grandest of containers: the universe.

THE physicist's standard of a good vacuum has changed with the years. When the debonair English physicist William Crookes presented what his renowned colleague J. J. Thomson described as the "striking and beautiful spectacles with which he delighted, almost yearly, crowded audiences at the Friday Evening Discourses at the Royal Institution," Crookes had removed all but one out of every ten thousand molecules from his electrical discharge tubes. At the time this was considered an extremely good vacuum. The history of progress in vacuum is essentially a history of the development of pumps. Up until the middle of the 19th century the only practical air pump was a piston device, an improved version of the kind that von Guericke and Boyle had developed. In a physics textbook published in 1860 the Yale chemist and geologist Benjamin Silliman (the younger) described an "excellent form" of the piston pump made in Boston with valves of oiled silk! But it was with mercury pumps that the monumental work of Cambridge University's Cavendish Laboratory was done, from James Clerk Maxwell's study of the viscosity of gases to J. J. Thomson's discovery of the electron.

Descendants of the Torricellian barometer, these early mercury pumps were painfully tedious to use, requiring the continual raising and lowering of a reservoir of mercury by hand. Lord Rayleigh described as the central object of his father's laboratory at their home in Essex "a large Töpler mercury pump which at the time it was procured (about 1885) was regarded with satisfaction as the last word in efficiency for the rapid production of high vacua. Yet it took a whole morning of intermittent attention to exhaust one of the two-litre globes used for weighing gases." Crookes, who was not on the staff of any university, used in his own independent laboratory an improved Sprengel mercury pump, made somewhat more automatic than the Töpler but still uncomfortably slow. At "the Cavendish" itself, Rayleigh noted in 1897 that the "ubiquitous



TÖPLER PUMP exhausts globe (*top*) when vessel of mercury (*bottom*) is repeatedly raised and lowered. When vessel is raised, mercury in system rises to force gas out of chamber at top center. When vessel is lowered, check valve below the globe allows gas to flow down from it.

Töpler pump" was the only method of exhaustion available. It was not until this century that the first satisfactory pumps for high vacuum were designed by the inventive German professor W. Gaede, who produced a whole series of improvements: rotary mercury and oil pumps (1905), a molecular pump (1912) and a vapor diffusion pump (1915). The Gaede pumps, together with the indispensable form of vapor-condensation pump developed by the U. S. physicist Irving Langmuir in 1916, form the basis of modern techniques of vacuum production.

J. J. Thomson believed that the commercial introduction of electric light was the important factor that led inventors to develop automatic and rapid pumps. Although it is not perfectly clear which came first, the pumps or the bulbs, the exact sequence of events is not so important as the fact that pumps and bulbs were largely interdependent in their development. Incandescent lighting was little more than an amusing laboratory possibility until the Sprengel pump was invented and men like Crookes worked out techniques for using it.

At the high temperatures required to make them glow brightly, most objects would oxidize away in a flash if exposed to air. Once it was clear that a vacuum-sealed glass globe could be made to hold the glowing material aloof from air, there remained only the problem of finding some efficient material in a practical form. This Thomas Alva Edison—and others—solved with a high-resistance carbon filament. Electric lights then became commercially feasible. There followed a flood of refinements in production technique which have culminated in today's great industry. Today filaments are made of tungsten; the lamp bulbs are filled mainly with argon gas, but the bulbs must be well evacuated of air before the argon can be introduced. Vacuum tubes for television, radio and other electronic applications are made in much the same way as electric lamps, though generally with a much better vacuum. More than half a billion dollars is spent each year for such commercial packages of vacuum and the delicate structures they enclose.

MAKING a good vacuum is basically the problem of eliminating air and other gas from the complicated set of bulbs, tubes and valves the experimenter calls his vacuum system. (Glass vacuum systems have come to be the standard photogenic background for shots of "the scientist at work.") Gas appears within his system in three principal forms: as free air, as captured gas and as gas released by evaporation. The air of the ever-present atmosphere is the main thing to be removed. In addition every solid—even the purest metal—contains some molecules of captured gas, either as a more or less continuous layer coating its surface or scattered thinly within its bulk. This gas gradually escapes from its captivity, slowly if the solid is very cold, more rapidly when it is heated. Organic materials such as rubber contain large quantities of such captured gas, and even glass and metal may contain troublesome amounts.

If the experimenter were able to eliminate all of the free gas and captured gas, he would still have to deal with the gas molecules released by evaporation. Even a pure solid gives up molecules at a fixed rate at a given temperature—the rate at which its own vibrating outermost molecules burst free of their bonds. Just as glare ice on a cold day evaporates slowly without melting, so at room temperature even as stable a solid as iron loses molecules from its surface layers at a steady though imperceptibly slow rate. For liquids and for soft solids such as wax or rubber, which are near their melting point at room temperature, the rate of evaporation is enormously higher. The "goodness" of the vacuum that an experimenter obtains depends on the balance he strikes between the rate at which gas enters his system from all possible sources, and the rate at which his pumps force gas to leave. The ultimate limit is reached when the pumps can remove gas no faster than it is formed by evaporation. To obtain his vacuum the experimenter may choose to decrease the amount of gas that enters his system, or he may increase the speed and size of his pumps. This choice has led to the growth of two schools of vacuum builders characterized by their typical skills. One school employs the skill of the glass blower, the other that of the plumber.

The school of glass blowers is the more traditional of the two; its adherents believe in reducing to a minimum the amount of gas that enters the system. They depend on small, low-speed pumps operated with modest power. Their systems are small and complicated and usually glass; it is they who achieve the highest vacuums known today. The standards of cleanliness for an experimenter of this school would drive the most meticulous of housewives to frenzy: a careless thumbprint can mean hours of extra pumping. The experimenter struggles in a vicious circle: he cannot make a good vacuum unless his system is absolutely clean, and his system cannot be absolutely clean unless he has a good vacuum. He begins by thoroughly washing every square inch of the inner surface of the system to be evacuated, ending usually with a bath of pure acetone. He degasses each part by baking it separately in a vacuum to drive off as much of the captured gas as possible before assembling his system. The system is first evacuated crudely by some type of mechanical pump which removes all but one out of every ten thousand molecules in a few minutes. Only after this preliminary vacuum has been reached does he switch on his high-vacuum pump, usually a mercury-vapor or oil-vapor pump. Long pumping and additional baking now take care of most of the gas.

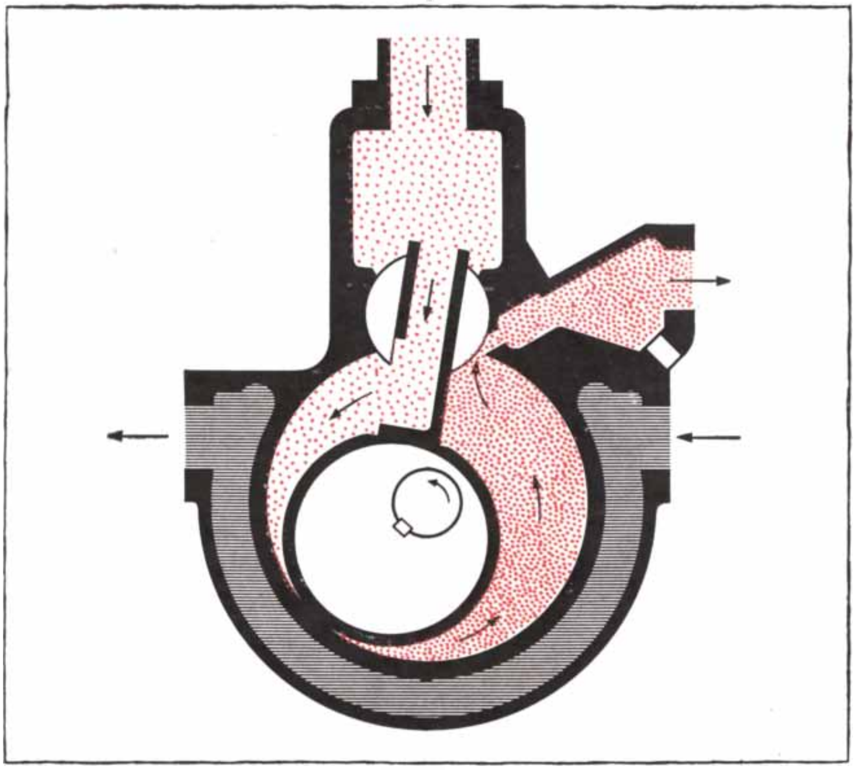
For the difficulties caused by gas continuously supplied by evaporation the experimenter has many dodges. For example, he inserts between the system to be evacuated and the surface of the pumping liquid a trap with walls cooled by liquid air. Vapor molecules that leave the pump will stick to the cold walls of the trap whenever they collide with them; the vapor is frozen fast. He eschews the convenient rubbery or plastic insulators; ceramics, quartz and glass are his austere though often expensive choice. Wherever he can he avoids moving parts with their lubricated bearings or ground joints; when he must have lubricants and seals he uses specially made compounds: vacuum greases with very low evaporation rates. He fuses together his glass parts, solders or welds his metal parts and even fuses joints between glass and metal. With a magnet on the outside, he is able to direct the motion of what has sometimes come to resemble a miniature machine shop within the vacuum, adjusting, cutting or turning, all by remote control. Thus he substantiates Crookes' description of vacuum as "a new world . . . where we can never enter, and with which we must be content to observe and experiment from the outside."

If the experimenter is building a system which is to be sealed off from his pump once it has been evacuated, he has one more trick at his disposal, a trick indispensable to the lamp and radio-tube industry. He "cleans up" the vacuum with a "getter." Getters are substances which get and keep by chemical combination the gases that escape from any part of the system. A great lore has developed as to what substances make the best getters for particular systems. Although the exact mechanisms by which they work are not completely understood, getters are very useful for maintaining the vacuum once the system has been sealed. The silvery mirror you see inside a radio tube is a getter; usually it is a film of barium evaporated on the glass. Even at very high vacuums it would take only a few minutes for the entire surface of a tube to be covered with a single layer of molecules. Precise measurements on the chemistry and physics of surfaces of any kind can be properly made only during the few minutes when the surface is still really clean, still free of the molecules that strike the walls and stick to them. Only the best vacuums allow this short time of real cleanliness. No comparable standards of cleanliness are conceivable outside of a high vacuum, because almost every surface we can touch in the world, no matter how spotless it appears, is covered with a patchy layer of molecules—water, oil or air.

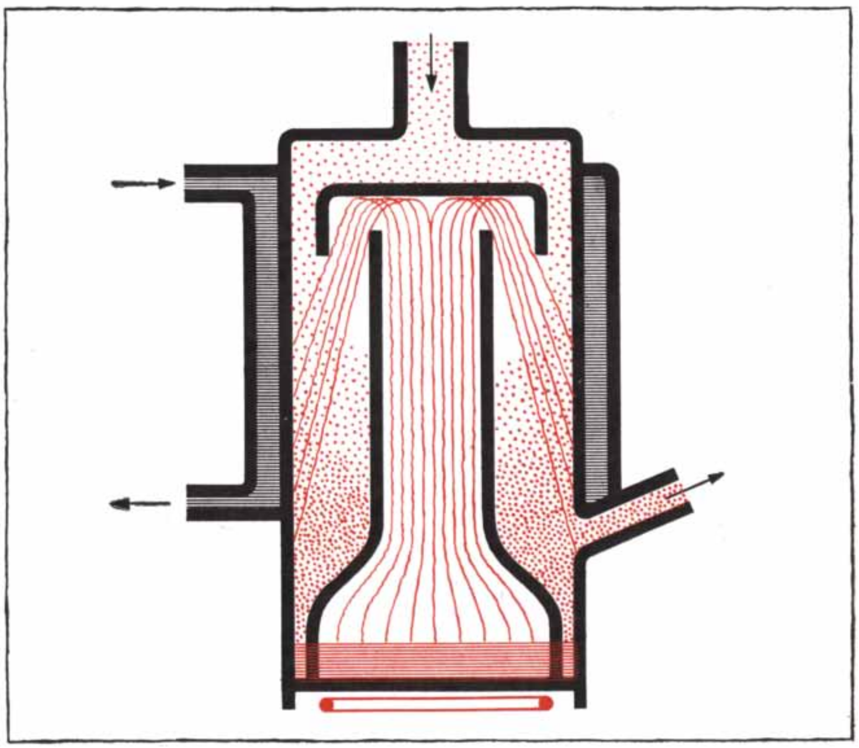
QUITE different is the approach of the plumbers. The experimenter of this school does not worry much about degassing or getters or the vapor pressure of his materials. His system is not a few feet of glass tubing and a couple of flasks, but a big steel or brass chamber, sometimes large enough to walk into. His diffusion pumps are the same in principle as those of his more painstaking colleagues, but run up to a yard in diameter. He relies upon the great speed of his enormous pumps to bring his system to a reasonably good vacuum in a short time. His valves may be commercial high-pressure steam valves, his connections plumber's piping sealed with a little giyptal varnish in the threads. Everywhere he has adjustable shafts and ports with removable lids. These are sealed by tightly compressed rubber gaskets, usually made so that atmospheric pressure wedges the rubber securely into place. He may lift off heavy steel lids with a chain hoist many times a day, exposing the surfaces of the whole great system to air, but an hour or two of fast pumping restores the vacuum. Sources of vapor within the system, short of puddles of water or real air leaks, are of no great concern. (One eminent practitioner has been known to demonstrate an unorthodox confidence in his pumps, to the alarm of cautious onlookers, by knocking his pipe ashes into the system before closing it up.)

To be sure, the plumber cannot achieve as high a vacuum as the glass blower. The slow evaporation of the rubber in his gaskets and the big gassy surfaces of his system set a limit to the quality of the vacuum, a limit which would be disdained by the builder of an immaculately degassed ceramic and glass system. But the sheer quantity of the plumber's vacuum plainly justifies the latter-day school. In 15 years, since the rapid evolution of the cyclotron and the other big nuclear machines began, the nuclear laboratory has gradually swung over from the finicky glass blowing to the brash plumbing technique for vacuum. The laboratory glass-blower is conspicuously absent in many nuclear laboratories today. His intricate art is becoming the property of the high-purity chemist and the surface physicist.

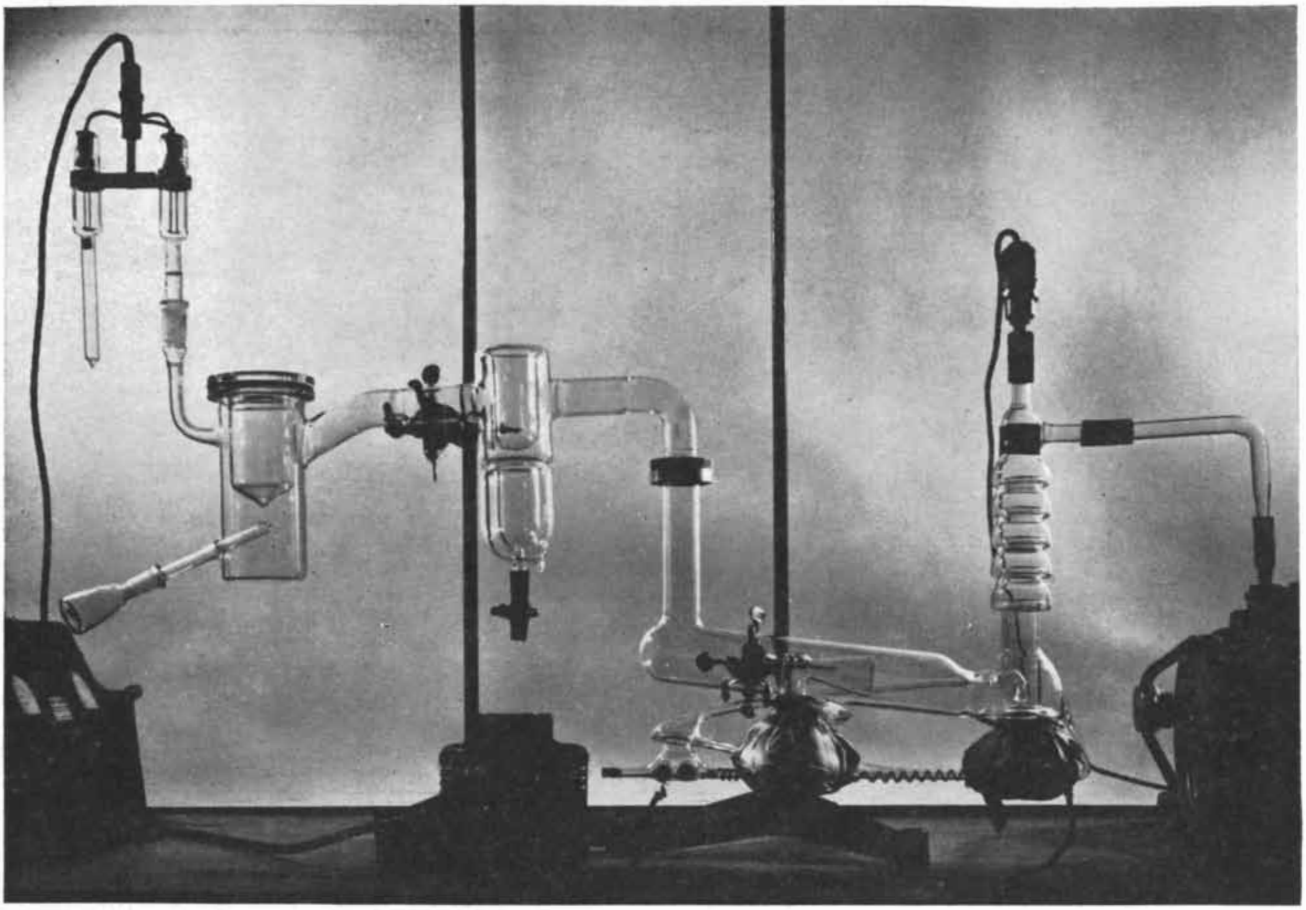
It is from nuclear physics and its vacuum plumbing that the present industry of high vacuum has grown. Vacuum has spread from the light-bulb industry to a thousand industrial and commercial uses, the description of which would make a fascinating article in itself. One might mention as examples the dehydration of frozen foods and the vacuum distillation at room temperatures of heat-sensitive organic compounds



MECHANICAL PUMP evacuates most of the gas from a modern high-vacuum system. Shown in this schematic drawing is the principle of a rotary oil pump. Gas from the system to be evacuated enters the pump from the top. A rotating eccentric then sweeps the gas out to the right. The shaded area around the pump cylinder indicates the circulation of cooling fluid.



VAPOR PUMP, often called a diffusion pump, is used to evacuate much of the remaining gas left by a mechanical pump. The gas to be evacuated from the vacuum system enters the pump from the top and is swept out at the lower right by a stream of mercury or oil vapor. The vapor originates in the pool of liquid at bottom of pump, to which it returns upon condensation.



GLASS VACUUM SYSTEM has several essential organs. At upper left is a Pirani gauge for measuring very low pressures. Second from left is a vessel to be evacuated for a delicate distillation. Third from left is a chamber which traps vapor that might escape into the system from the distillation vessel. Fourth from left is a two-stage oil-diffusion pump. The first stage of the pump is represented by the glass funnel within the horizontal glass tube. The second stage is in the base of the vertical column farther to the right. At the far right is the silhouette of a mechanical pump. The apparatus was built by Distillation Products Industries, a firm which principally manufactures much bigger vacuum systems for large-scale laboratory and industrial purposes.

which are today large-scale processes, putting vacuum-concentrated orange juice on every breakfast table and vacuum-dried penicillin crystals in every drugstore.

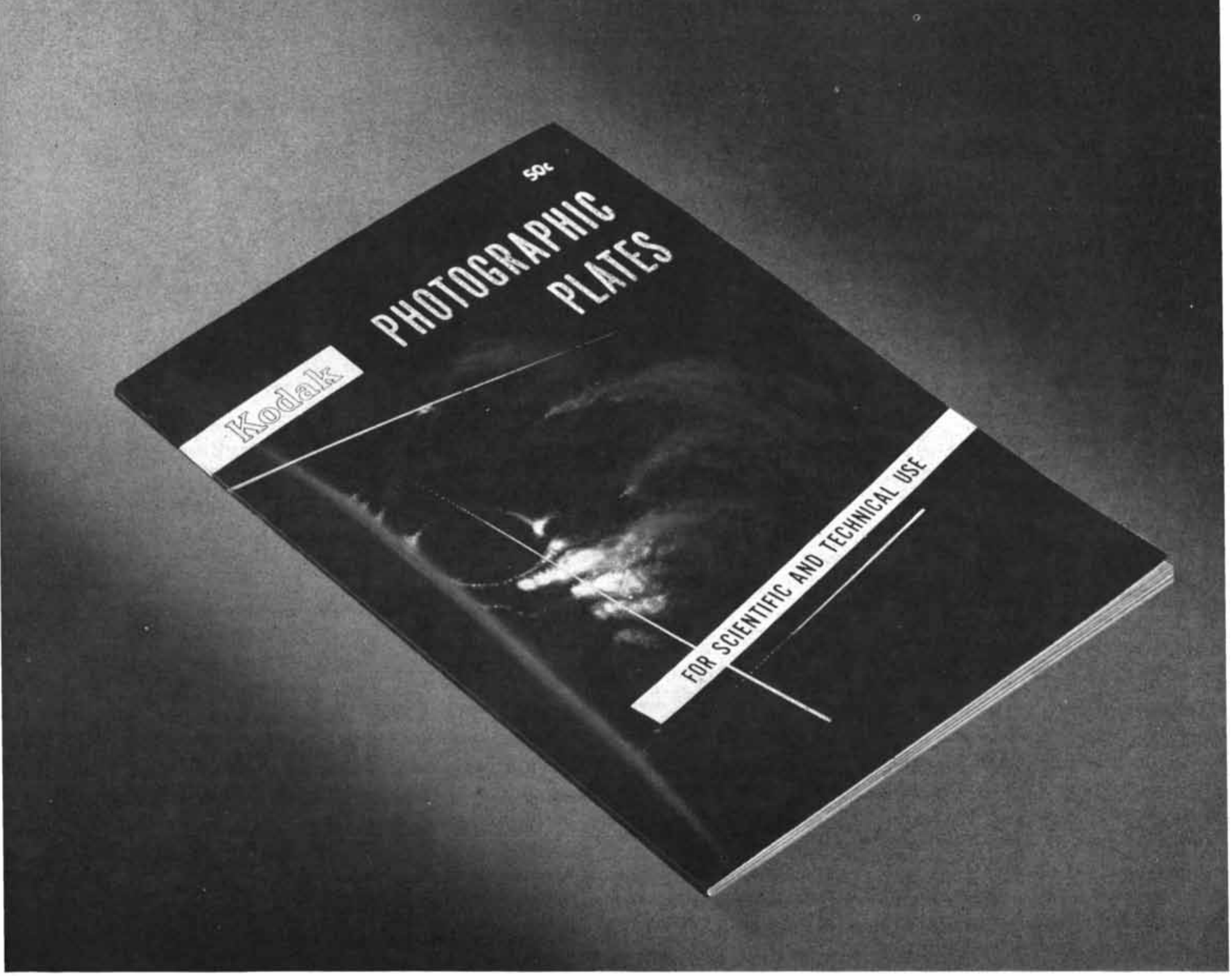
To compare the vacuum technique of today with that of 50 or 100 years ago we have only to think of Rayleigh's Töpler pump, which could exhaust a two-liter flask in half a day, and then look at a picture of one of the oil-diffusion pumps at Oak Ridge, 32 inches in diameter, which, in combination with a big mechanical pump, has a capacity of 30,000 cubic feet per minute. With the development of large pumps the vacuum plumber's technique was made possible, and with the development of this technique vacuum graduated from the laboratory to the factory. Diffusion pumps are no longer the home-made product of the physicist but are highly developed products of skilled and specialized firms. Many more vacuum systems are used out of the laboratory than in it. The physicist today draws upon this industry for a wide range of easily available components of his vacuum system.

Building the system is not quite the whole story; it must be kept tight and leakproof. The enemy air is everywhere, eager to slip in through any tiny flaw. The job of leak detection is never finished. A crude leak is easy to detect; it simply whistles as the air rushes in! Most leaks are more sly than that. To locate them the experimenter releases small amounts of a test gas, area by area, all around the outside of his system, stopping at each point to see whether his detector has found any of the released gas inside. To detect gas in simple glass systems the experimenter may use a Tesla coil outside and watch the color of the spark discharge that identifies a gas within.

There is a whole range of other detectors. For large metal systems by far the most sensitive method is the mass spectrometer. This complex piece of apparatus, with its own internal vacuum system, is capable of scenting the test gas (helium) admitted through even a microscopic flaw. When the leak has been precisely spotted, a dab of glyptal varnish or a new gasket or a resoldered joint may cure the trouble. Leaks are the principal torment of experimental physicists, who spend more hours than they care to remember tediously searching out invisible holes.

From Torricelli onward the physicist has worked on the practical problem of making a vacuum. And the very techniques by which he makes and measures the vacuum are themselves both the agents and the fruits of a deeper understanding of physics; insight and technique thus grow together. By making a vacuum and by using it, the physicist has gained real insight into the deeper nature of vacuum in the philosophic sense. Like any tool of the physicist, a vacuum system represents his active intervention in the workings of the world. With such tools the physicist more and more will come to understand the nature of space and matter, of atoms and the void.

Philip Morrison is a theoretical physicist at Cornell University. Emily Morrison is his wife.



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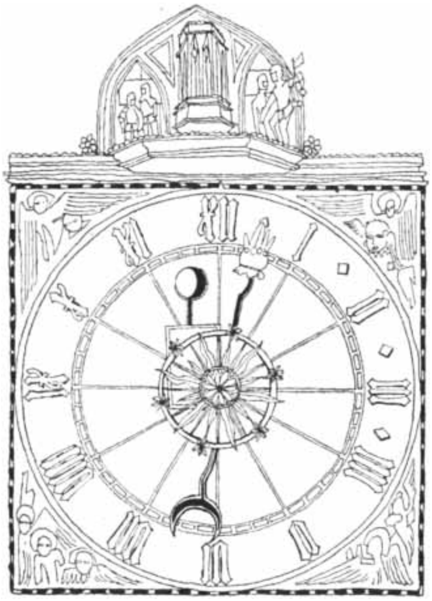


Concerning H-Bomb Reactions

THE first major extension of censorship over scientific information in the U. S. since the end of the war was instituted last month. The Atomic Energy Commission directed its employees and consultants to cease public discussion of thermonuclear reactions in relation to the projected hydrogen bomb. The Commission explained that its request applied to unclassified as well as classified information. It was addressed to all persons now or recently associated with the atomic energy project, which would include most of the atomic physicists of the U. S.

This policy was made known in telegrams sent on March 14 and 20 to AEC managers. The second telegram explained that the purpose was "to avoid release of technical information which, even though itself unclassified, may be interpreted by virtue of the project connection of the speaker as reflecting the Commission's program with respect to thermonuclear weapons."

The Commission applied the policy last month to censor an article written for SCIENTIFIC AMERICAN and the *Bulletin of the Atomic Scientists* by Hans A. Bethe, professor of physics at Cornell University, who is a consultant to the Commission. Dr. Bethe had sent copies of his manuscript to a number of his colleagues in physics, among them a member of the Commission. Neither the author nor the editors of the two publications considered it appropriate to submit the article to the AEC for review, since all the technical information in it was well known to physicists the world over and had been widely published. Physicists who read Dr. Bethe's original manuscript, including several associated with the atomic energy program, concurred in the view that it involved no question of security of information. On March 15, after the April issue of SCIENTIFIC AMERICAN containing Dr. Bethe's article, titled "The Hydrogen Bomb: II," had gone to press, a telegram was received from the Atomic Energy Commission requesting that the technical part of the article be withheld from publication. SCIENTIFIC AMERICAN stopped its presses and asked the Commission to specify its objections. After reviewing the article the Commission requested the deletion of several sentences. In order to proceed with publication of the issue, the editors complied with the Commission's request. The Commission then asked that all copies of the original article be destroyed. An AEC security officer visited the printing plant and supervised the destruction of the type and printing plates with the deleted material and the burning of 3,000 copies of the magazine which had been printed before the presses were stopped.

In response to inquiries from the press after the incident had become known, Gerard Piel, publisher of SCIENTIFIC AMERICAN, observed that the material deleted by the Commission included "statements which had already been widely quoted in the press and statements which have since been made by Robert Bacher, a former member of the Commission, in a speech in the Los Angeles Town Hall on March 27." Piel added:

"We consider that the Commission's action with regard to the Bethe article and the sweeping subsequent prohibition issued to the nation's atomic scientists raises the question of whether the Commission is thus suppressing information which the American people need in order to form intelligent judgments on this major problem. While there are certainly areas of information which must be protected for reasons of national security, there is a very large area of technical information in the public domain which is essential to adequate public participation in the development of national policy, and on which the American people are entitled to be informed by such recognized authorities as Dr. Bethe."

SCIENTIFIC AMERICAN is continuing the discussion of the hydrogen bomb with the article by Dr. Bacher in this issue (*see page 11*). A fourth article in this series of discussions will be published in June.

Civil-Defense Hearings

ON March 17 the Joint Congressional Committee on Atomic Energy began its long-awaited series of public hearings on civil defense against the atomic bomb. First to testify were representatives of the Atomic Energy Commission.

Research on methods of counteracting the effects of nuclear radiations was described by Shields Warren, director of the AEC's Division of Biology and Medicine. He reported that six per cent of the survivors of Hiroshima who were less than 1,000 meters from the center of the explosion now show evidence of radiation cataracts. With the exception of these persons, said Warren, "those surviving the acute effects of irradiation from an atomic explosion can . . . expect a reasonably normal life thereafter."

The immediate effects of exposure to a lethal dose of radiation are:

1. Infection by organisms already present in the body, caused by the body's loss of the ability to produce antibodies and white blood cells. "This leads to ulcerations all along the gastro-intestinal tract and the upper respiratory passages. These ulcerations tend to produce hemorrhage just like a stomach ulcer. A frequent cause of death is pneumonia and/or blood poisoning."
2. Anemia, caused by destruction of the power of the bone marrow to produce new red blood cells, and aggravated by bleeding from ulcerations.
3. Injury to the blood-clotting mechanisms and possibly to the capillaries, the smallest blood vessels.
4. Changes in the excretion of sodium and potassium salts and in the amounts of water present in the tissues, and general disturbances of nutrition resulting in loss of weight.

AEC workers have developed several protective measures. Before exposure, large doses of female sex hormones or of the amino acid cysteine can increase resistance to the effects of irradiation. During exposure, shielding of certain parts of the body greatly increases the survival rate, as shown by experiments on animals. After exposure, the recommended treatment is several weeks of rest, administration of antibiotics, blood and plasma transfusions and the use of antiheparin substances to combat hemorrhage.

Warren reported that the AEC has started a program of training of instructors to teach radiation detection. At universities throughout the country physicians are being given training in "medical aspects of atomic warfare." AEC technicians have developed an inexpensive new Geiger counter for measuring high levels of radiation; it could be mass-produced for $10 to $15.

In New Jersey a state-wide program of atomic defense was promulgated by

CITIZEN

Governor Alfred E. Driscoll last month. Local defense councils will blood-type every resident of the state, arrange for emergency beds, organize police and fire reserves, provide for emergency water supplies, list heavy road machinery available for clearing debris and instruct the public on the seriousness of atomic warfare. In New York preparations are under way to make specialized training in the clinical and biological effects of atomic bombs available to the state's 30,000 physicians.

New AEC Commissioner

THOMAS E. MURRAY, a New York business executive and engineer, has been appointed to the Atomic Energy Commission by President Truman to replace David E. Lilienthal, who left the Commission on February 15. Murray, best known as a former receiver of New York City's Interborough Rapid Transit Company, is president of the Metropolitan Engineering Company, a director of the Chrysler Corporation and trustee of the Bank of New York and the Fifth Avenue Bank.

Sumner T. Pike continues as acting chairman of the Commission. A permanent chairman is expected to be chosen when President Truman appoints a member to the vacancy created by the resignation of Lewis L. Strauss.

Element 98

A FEW days after SCIENTIFIC AMERICAN had gone to press with the article in the April issue entitled "The Synthetic Elements," which stated that "at the moment the list of identified elements stands at 97," the number was raised to 98. The creation of element 98, the sixth synthetic addition to the periodic table, was announced at the University of California by Glenn T. Seaborg, Stanley G. Thompson, Albert Ghiorso and Kenneth Street, Jr. They named it californium, after the state and the University.

The new element was produced in Berkeley's 60-inch Crocker cyclotron by bombarding a few millionths of a gram of curium 242 with alpha particles with an energy of 35 million electron volts. The 60-inch cyclotron, in which five other synthetic elements were also first created, is used for this work in preference to the giant 184-inch because the 400-mev alpha particles produced in the latter would shatter the nuclei of the target material instead of being captured by them.

Element 98 has a half-life of only 45 minutes, and the tiny amount produced was difficult to detect. It was identified only because the California workers had been able to predict its half-life and chemical properties. Although the element will probably never be made in visible amounts, its properties are of considerable theoretical importance to chemists. It is a homologue of dysprosium, element 66, which is part of the rare-earth series that begins with lanthanum. The successful identification of element 98 on the basis of the predictions bears out the theory that the synthetic elements beyond uranium are part of a second rare-earth series whose prototype is element 89, actinium. If this theory is correct, five more new elements may be expected to complete the series.

It is customary to name new elements on the same basis as their homologues; thus element 97 was named berkelium, after the city of Berkeley, because the corresponding rare-earth element terbium, number 65, had been named for Ytterby, Sweden, where it was discovered. Dysprosium, the homologue of element 98, was named from a Greek word meaning "hard to get at." In justification of the name californium for the new element, the Berkeley workers pointed out that "the searchers for another element a century ago found it difficult to get to California."

Radio's Circumnavigation

A RADIO engineer has finally succeeded in sending a radio signal completely around the earth and detecting it near the point of transmission. The feat was accomplished by Jack N. Brown of the National Bureau of Standards. Using a signal of very low frequency (18 kilocycles) and the powerful 350-kilowatt transmitter of the Naval Radio Station at Annapolis, Md., he found that the signal took a little more than a tenth of a second to circle the earth.

Brown detected the signal at a Bureau of Standards field station at Sterling, Va., 50 miles from the transmitter. His receiver had a large loop antenna 150 feet high. The circumnavigating radio pulse was identified and timed by the fact that it arrived as an identical delayed signal a certain interval after the direct signal from Annapolis to Sterling.

Brown estimated that on a normal day a low-frequency radio signal bounces back and forth between the earth and the ionosphere a total of 55 times in its trip around the world. Each hop is about 450 miles long.

Spectrographs

THE spectrograph, the instrument that splits light into its spectrum of wavelengths, is one of the most powerful tools of modern research. Industry uses it for quick, accurate analysis of materials; the chemist, the physicist and the astrophysicist find it indispensable. But production of the instrument has not been able to keep up with the present-day demand. Word now comes from Johns Hopkins University of a major improvement in technique that will relieve the shortage.

In the classical spectrograph the element used to disperse light into a spectrum is a quartz prism. In modern instruments the prism is increasingly being replaced by a diffraction grating, both because of a scarcity of optical quartz and because of certain advantages in gratings. The ruling of diffraction gratings is perhaps the most exacting and difficult of all high-precision tasks, and the construction of machines that do this work is an extraordinarily delicate problem. To rule straight, parallel and equidistant grooves on aluminum with an accuracy of a millionth of an inch the parts of the ruling machine must remain fixed and stable to a high degree; its work may easily be ruined by microscopic changes in the shape of the machine due to temperature variations, friction, elasticity and internal strain. Henry A. Rowland of Johns Hopkins was the first to manufacture diffraction gratings on a production basis, 70 years ago. The Hopkins has remained the chief source of the large gratings needed in basic research. The supply of large gratings has recently fallen about a year behind the demand.

Now John D. Strong of the Hopkins, aided by a group of skilled instrument makers, has developed an improved version of the classic Rowland machine that rules gratings with less difficulty and greater speed. The machine started production two months ago, and the very first gratings ruled proved suitable for use. It is producing gratings six inches in diameter with a focal length of 21 feet. The fundamental improvements in the Strong design promise even more: they indicate a likelihood that larger machines built on this model will be capable of making larger diffraction gratings than any now produced.

Antihistamines

SINCE the U. S. Food and Drug Administration approved the unrestricted sale of antihistamines last September they have become the most advertised and fastest-selling patent medicines in the U. S. It has been estimated that the American public will spend $100 million this year for antihistamines to "stop colds."

Antihistamines such as Pyribenzamine and Benadryl have been prescribed for over a decade in cases of allergy. Their use as "cold-stoppers" was first proposed by Capt. John M. Brewster of the Navy Medical Corps, who found that "the abortion of the common cold [by the use of antihistamines] is so truly unique it must be seen to be appreciated." More carefully controlled studies by other investigators have failed to confirm his findings. The Council on Pharmacy and Chemistry of the American Medical Association "does not believe that the data prove that the antihistaminics are useful for the prevention of the common cold or for the treatment of those who are ill with this affliction." Medical writers in *Lancet* and in *The Journal of the American Medical Association*, and most recently Samuel M. Feinberg, head of the Allergy Research Laboratory at Northwestern University Medical School, have reported that a number of children are known to have been fatally poisoned by the drugs, and that their sedative effect has caused accidents to persons who were driving vehicles or operating machinery.

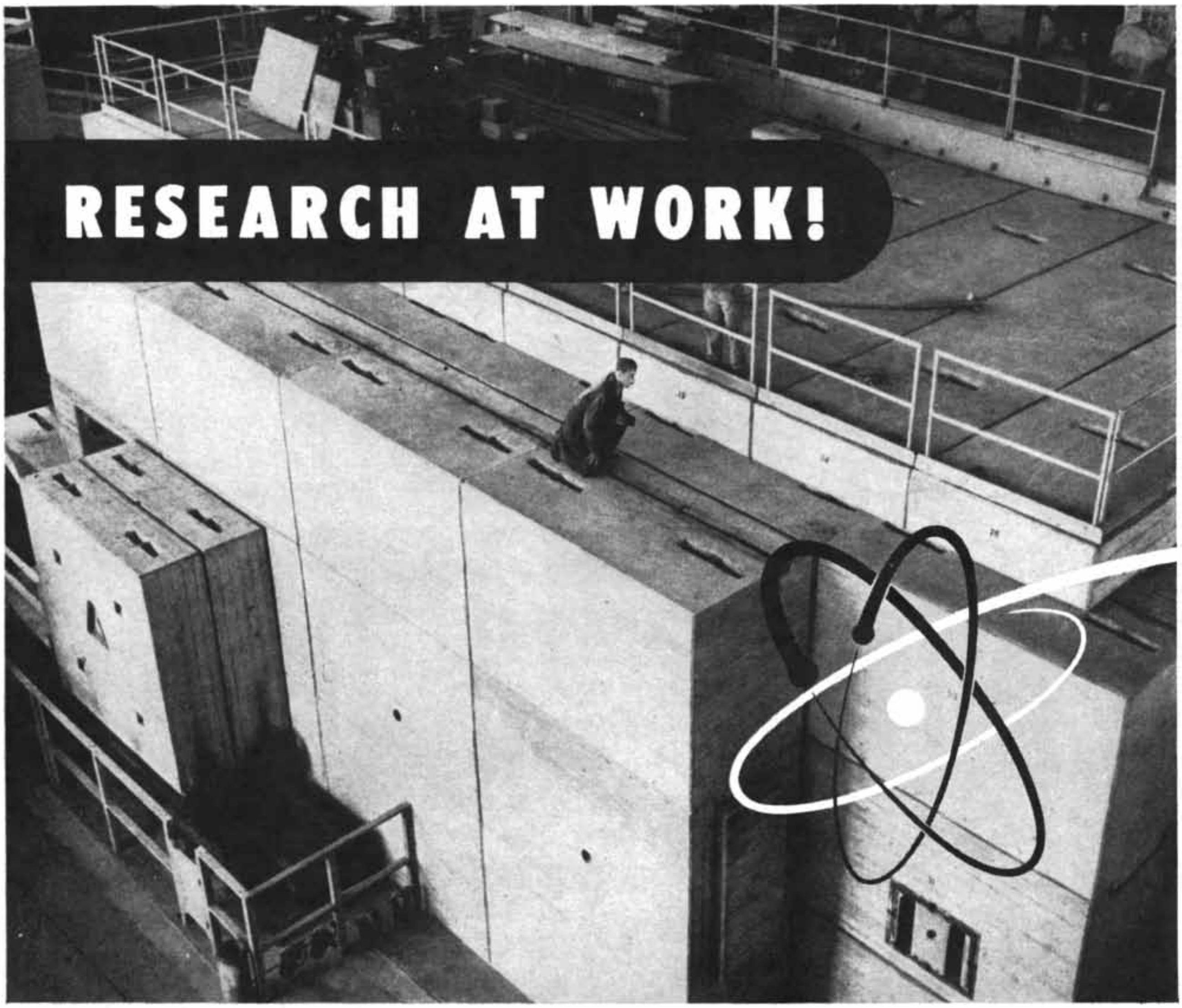
Last month the Federal Trade Commission issued complaints against four manufacturers of antihistamines for "false and misleading" advertising. The companies are Bristol-Myers, makers of Resistabs; the Anahist Company, makers of Anahist; the Whitehall Pharmacal Company, makers of Kriptin; the Union Pharmaceutical Company, makers of Inhiston.

Locust Navigation

AIR-MINDED man has lately begun to take a more intimate interest in the flying machines of nature. There are Karl von Frisch's studies of the directional sense of bees, numerous investigations of the navigation of birds, and the American Museum of Natural History's research on the "gyroscopic" stabilizers of flies, to mention but a few examples. The latest news in insect aerodynamics has to do with locusts. T. Weis-Fogh, a worker in the Copenhagen laboratory of the late Nobel prize physiologist August Krogh, has found out how locusts navigate.

The locust has five tiny patches of hair on each side of its "forehead." Weis-Fogh discovered that when a locust is suspended by a string and a fine jet of air is blown at the patches, the insect flaps its wings violently. The flapping stops as soon as the jet is turned off. If the hairs are covered with paint, the air stream produces no effect. Weis-Fogh further established that a large nerve whose function was previously unknown serves to transmit electrical signals from the wind-bent hairs to the locust's brain. When the insect, flying against a headwind, is blown around from its course, the unequal stimulation by the wind of the hair patches on the two sides of its head enables it to orient itself and reset its course in the original direction.

Weis-Fogh believes that the locust also possesses a built-in "altimeter," and he has started a search for the mechanism. He is pursuing this study by suspending locusts in an insect-sized wind tunnel.



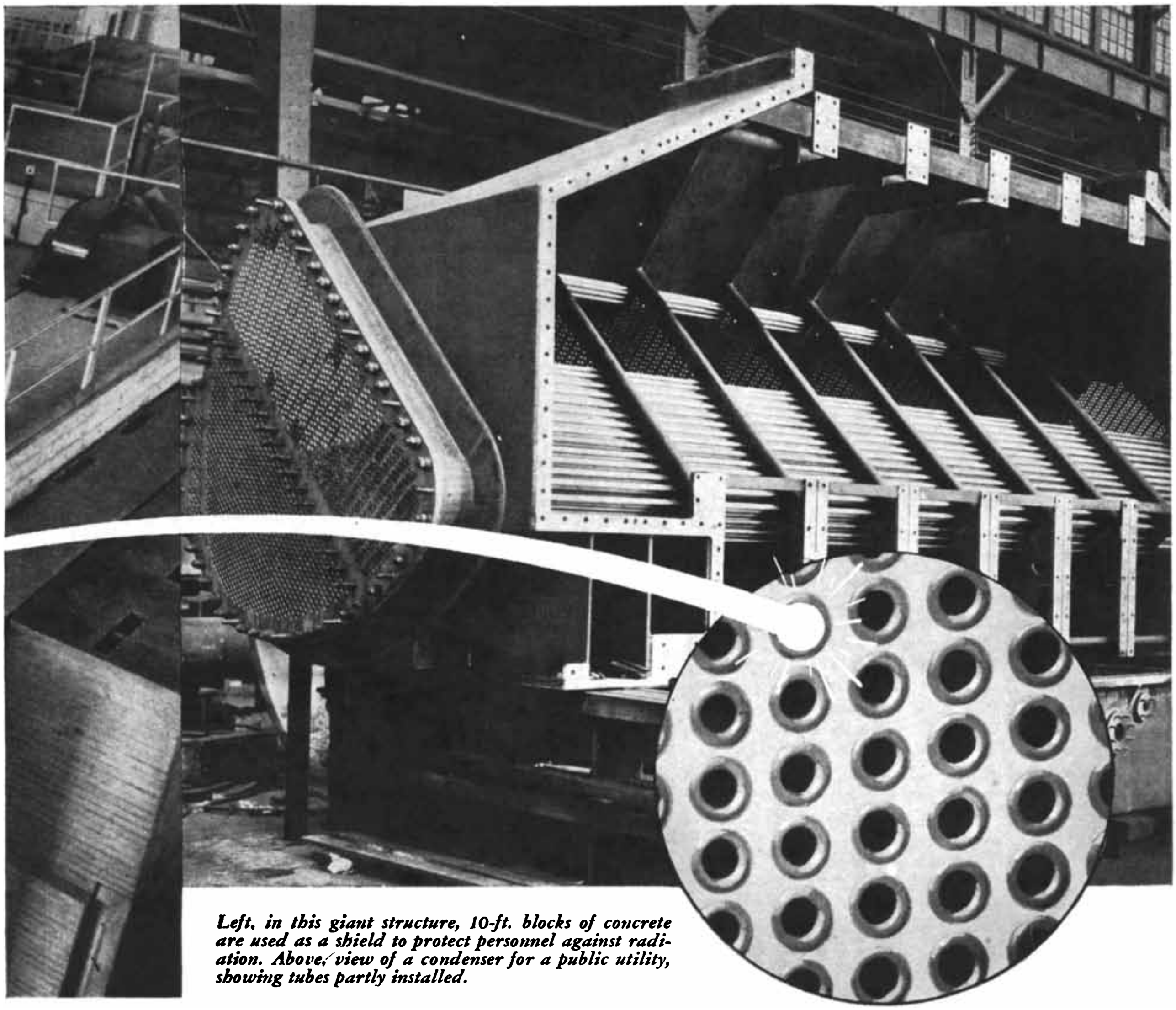
Long before Hiroshima, Revere used the atom—constructively

BEFORE the first atomic pile was built, before the first atomic bomb was exploded, Revere used the effects of the disintegrating atom for constructive research. It was in 1941 that radio-active tracer elements were employed in a Revere-sponsored investigation into the destructive process known as dezincification. This is a form of corrosion formerly of chief concern to users of copper-zinc alloy condenser tubes. In this process the alloy seems to be dissolved from localized areas, the zinc going off in solution while the copper is re-deposited as a porous plug.

A number of years ago it was found by experiment that the addition of small amounts of some other element would prevent or inhibit this electro-chemical action. Nobody knew just why or how, nor what was the best percentage for the third element. Revere decided to find out, and commissioned two able scientists in a famous Eastern technical school to conduct the necessary experiments.

In this work, radio-active elements or isotopes were produced in a cyclotron, and were used in order to determine the function of those elements in rendering the alloy more resistant to corrosion.

Briefly, the method was this: The desired radio-active element was dissolved in an acid, and the solution's radio-activity calibrated by means of a Geiger counter. A standard sample of the alloy was immersed in the solution, and from time to time the amount of the active element deposited upon it was measured with the counter. The nature of the deposited film was also checked by the electron diffraction method. This



Left, in this giant structure, 10-ft. blocks of concrete are used as a shield to protect personnel against radiation. Above, view of a condenser for a public utility, showing tubes partly installed.

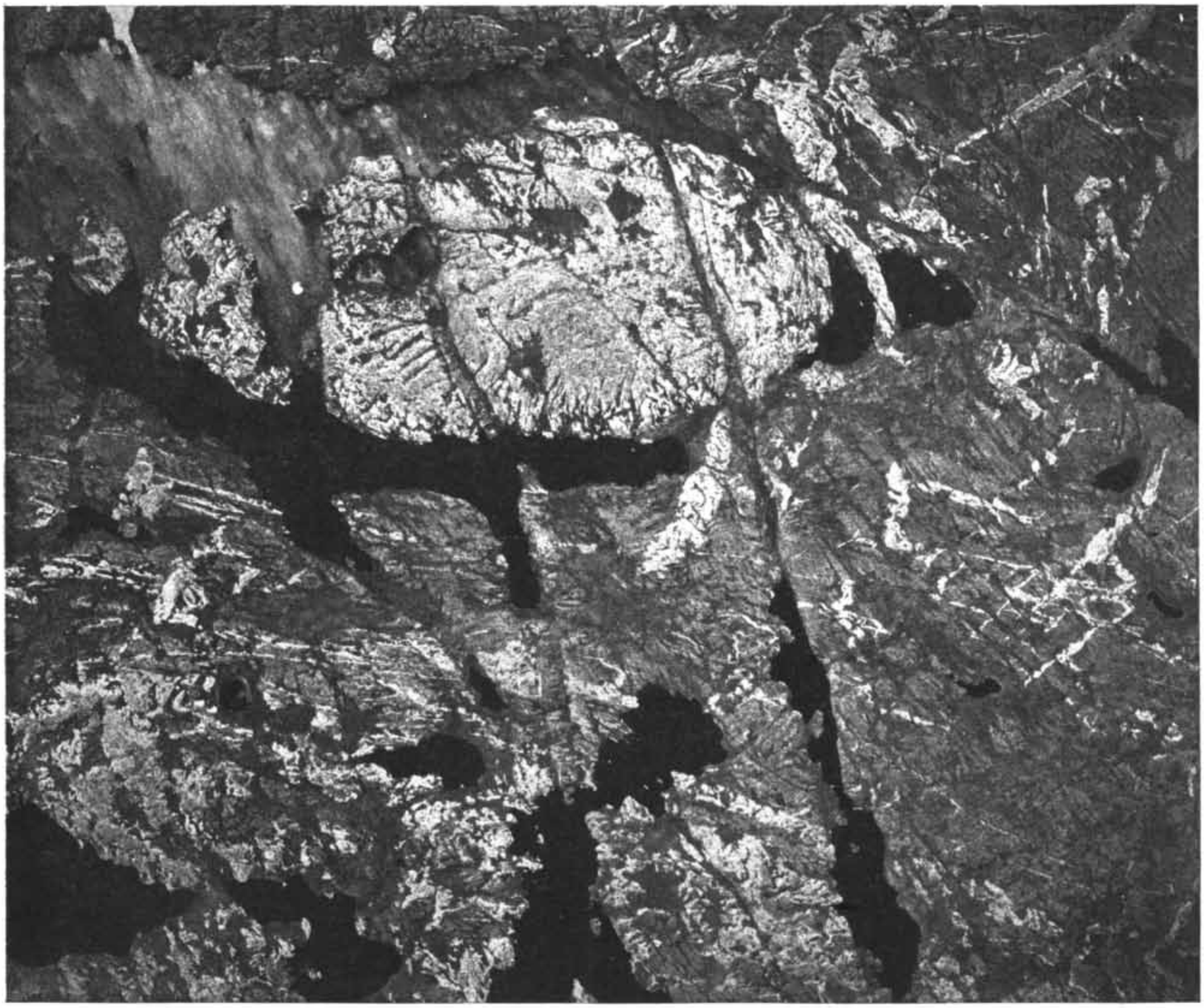
was in effect an accelerated test for dezincification and its inhibition. It was repeated many times with solutions of various concentrations. This, mind you, was in 1941, before radio-active tracer procedures were of any interest except to a comparatively few scientists.

The conclusions reached as a result of these tests can be summarized as follows: The corrosion of uninhibited copper-zinc condenser tubes occurs by solution of the alloy as an entity. When an inhibitor is present, however, in the percentages revealed by the experiments, the inhibitor is re-deposited on the alloy as a film which has about the same effective electrical potential as copper. The deposition of copper is thereby prevented. One of the key processes in dezincification having been thus interrupted, the process itself is effectively stopped, or at least so reduced in activity as to provide corrosion resistance, and commercial service, for extremely long periods of time. Thus the inhibited copper-zinc alloy condenser tube has become reliable and economical to an extent heretofore unrealizable.

THE CRUST OF THE EARTH

The traditional view of the architecture of continents and ocean floors is in process of being revised by some resourceful new methods of probing beneath the surface

by Walter H. Bucher



PRE-CAMBRIAN SHIELD of Canada illustrates one of the riddles of the earth's crust. This aerial photograph of the shield in Canada's Northwest Territories reveals areas of lighter and darker rock. The dark areas are metamorphosed sedimentary rocks. The light areas are granite. The problem: How did the granite get there?

GEOLOGY is in a period of unprecedented discovery. Systematic explorations of the earth's crust by geophysicists and geologists, working in close cooperation and using new methods of investigation, are yielding wholly new knowledge about the ocean floors and the deeper parts of the continents, and a more precise understanding of regional geology. As a result, traditional views concerning the physical and chemical processes that have produced and are now molding the earth's crust are being challenged. What processes created the contrasting formations of continents and oceans? Are they still going on, forming future continents? In the search for the answers to these fundamental questions there is an atmosphere of fascinated suspense today such as has always marked the high points on the growth curve of a science. This article deals with some of the changes in outlook that are suggested by the work of the past few decades.

The "crust" of the earth is a cool, relatively rigid shell which is probably not much more than 30 miles deep, *i.e.*, less than eight thousandths of the distance from the surface to the earth's center. The idea that the earth has such a "crust" rests on the assumption that under the high temperatures and large confining pressures below a certain level all rock materials must lose the power to resist deformation under the action of long-continued stress. Measurements of the rate of temperature increase in drill holes and mine shafts indicate that 30 miles below the earth's surface under the continents the temperature must reach 1,000 degrees Centigrade. Somewhere below that depth the rocks are thought to be unable to resist relatively small stress differences and to yield to stress plastically.

Only a small fraction of the crust's thickness lies exposed. The sections that we can observe have been brought into view by uplift, tilting and erosion on continents and islands. Wherever enough of the crust is revealed, the diversity of materials and the folding and fracturing they have undergone indicate a dynamic activity in the earth that contrasts greatly with the prevailing static concept of the crust as a series of concentric "shells." This activity must be brought about by powerful changes going on below the crust, which suggests that there is more life in the old earth than one would guess from the diagrams in textbooks. To explain that dynamic activity is one of the baffling problems of earth physics.

A satisfactory answer will not be possible until we know more about the structure of the deeper parts of the crust. This calls for geophysicists working hand in hand with geologists—the teamwork of our day. The geologist's methods of study apply to the visible parts of the lands, *i.e.*, about one quarter of the earth's surface. The three quarters that lie hidden beneath water and ice, and the deeper parts of the crust everywhere, must be probed indirectly by the geophysical measurement of such quantities as the local value of gravity, the velocity of elastic waves at various levels and the direction and intensity of the local lines of force in the earth's magnetic field. The results of such abstract measurements must then be translated into the terms of concrete geological reality.

Under the Continents

It is convenient to consider the subcontinent and subocean structures separately. What is the structure of the crust beneath the continents? The first evidence about it is provided by analysis of the travel times of earthquake waves through parts of the crust from known source points. Such measurements show that beneath all the continents the crust consists of an upper part in which the elastic waves travel with relatively low velocity and a lower one through which they pass more rapidly. The magnitude of these differences in velocity proves that they are due to differences in the rock materials at the upper and lower levels. And laboratory studies of the speed with which elastic waves travel through various types of rock give a clue to the type of rock that prevails at each level.

The primary rocks of the earth, the so-called igneous rocks formed by cooling and crystallization from an original molten condition, fall into two general groups. One is relatively rich in silicon (Si) and aluminum (Al), and hence is called "sialic." The other is poor in those elements but rich in magnesium (Mg) and iron (Fe), and this type is called "mafic." The most common sialic rock is granite; the most common mafic rock is basalt. In this article the terms granite and basalt will be used in a broad sense to represent the two groups of igneous rock.

When these rocks are tested in the laboratory, it turns out that elastic waves travel faster through basalt than through granite. Since the speed of earthquake waves is greater in the lower parts of the subcontinent crust than in the upper parts, the deeper parts of the crust must everywhere consist of basalt, and granite must be limited to the upper crust. Large areas of the ocean floors seem to have no granite at all; below the mantle of young sediments basalt forms the surface of the crust.

This distribution suggests that the granite of the earth's crust formed as a kind of "scum" on the fundamental basalt, and for a long time that was the prevailing view. But a peculiarity about the distribution of granite throws doubt on this idea. Not one of the great bodies of granite in the earth is found lying simply on top of basalt. Instead the granite invariably appears in intimate relation with great bodies of older sedimentary rocks, which it seems to have invaded and altered into the so-called metamorphic rocks at high temperatures and pressures.

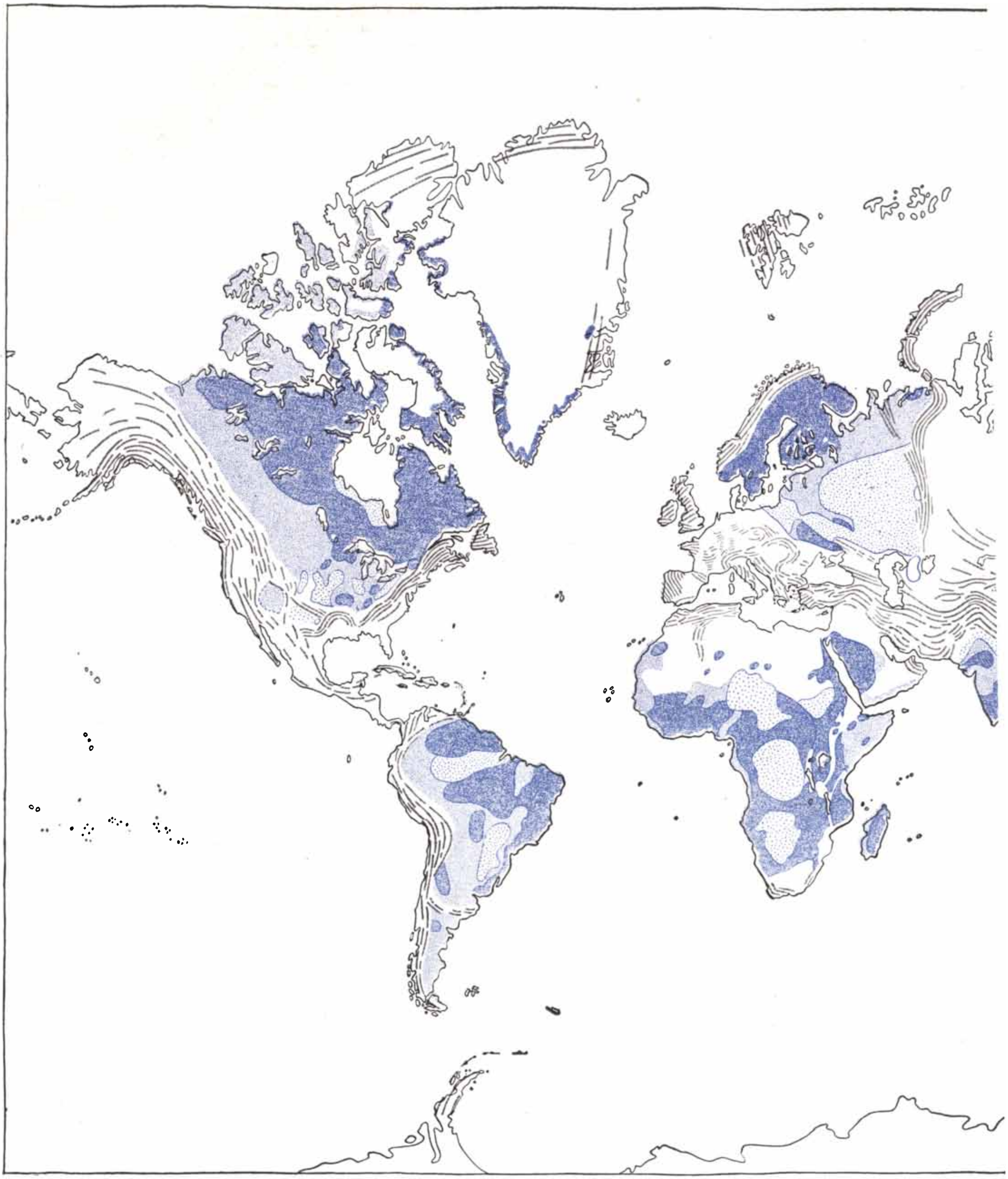
In this contrast between the structural relations of granite and basalt lies the key to the problem of crustal structure. To see the problem in proper perspective we must take a closer look at the structure of the continents as it is seen at the surface.

All continents exhibit the same major elements of structure. Each contains at least one "Pre-Cambrian shield," a large region of low uplands consisting essentially of ancient rocks made up of metamorphosed sediments and associated intrusive rocks, chiefly granite. This is the "basement complex" of the continents. Formed originally at considerable depths below the surface, it now lies exposed on the continental shields, having been bowed up in the shape of a buckler by regional uplift and then planed down by erosion.

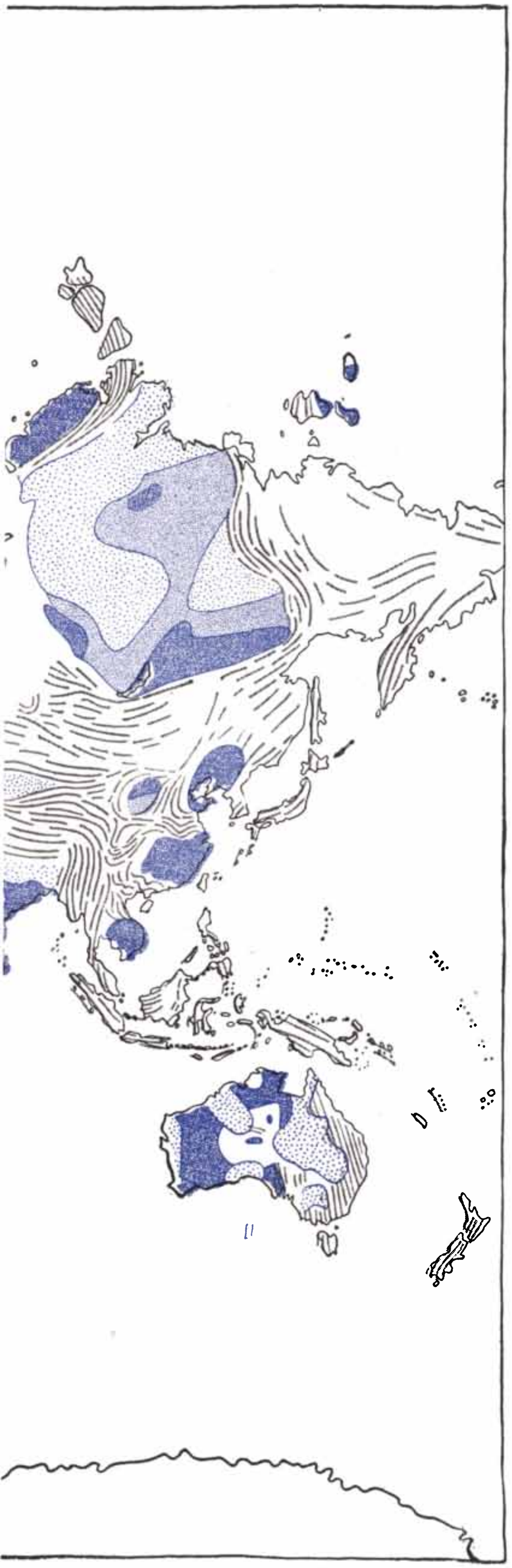
In every continent the basement complex, exposed only in part, passes out of sight beneath sheets of early Paleozoic sediments that were deposited upon it. This "sedimentary platform" overlying the Pre-Cambrian basement constitutes the second structural element. It generally consists of a few thousand feet of limestones, shales and sandstones. Finally in all continents there are belts of folded mountains—great masses of sedimentary rocks, largely of marine origin, compressed into folds and broken by a multitude of fractures.

"Floating" Mountains

As early as 1859 the U. S. geologist James Hall observed that when one goes from the plateaus of the sedimentary platform toward a mountain belt, the sediments progressively thicken and the top of the basement complex below them plunges to unknown depths. In the midst of these thick sediments granite comes to light. This granite is not part of the "dead" basement complex but "live" igneous rock that has invaded the sediments in bodies of immense size and has altered them far and wide into the same kinds of metamorphic rocks that are associated with the granites of the continental shields. If the granite-invaded parts of the great new mountain belts were shaved off to sea level, they would be indistinguishable in rock types and structure from corresponding stretches of the continental shields. In fact, the more the complicated structure of the continental shields is studied, the clearer it becomes that they consist of the stumps of former folded mountain belts, formed during the first billion and



GEOLOGICAL MAP OF THE CONTINENTS outlines their principal crustal features. The darkest blue areas on every continent are the Pre-Cambrian shields. The lighter blue areas that adjoin them are platforms of younger rock that lie on top of a Pre-Cambrian basement, *i.e.,* those parts of the Pre-Cambrian shield that dip beneath the surface. The lightest blue areas are where the younger rocks lie on top of a basin-shaped depression in the Pre-Cambrian basement. The areas marked with long gray striations are regions of folding



or mountain building since the end of Pre-Cambrian time. Features of the ocean floor are not shown. Some important features of the Atlantic and Pacific floor appear on page 41.

a half years of the earth's history. If we want to know how the crust beneath the continents was formed, we must study not only these eroded remnants but also the younger folded mountain belts of today.

Before there was an organized science of geology, a discovery of far-reaching importance was made by accident in the Andes of Peru, one of the mightiest of the young folded mountain belts. Around 1740 a French expedition that went to Peru to measure the length of a meridian arc found that the gravitational attraction of the High Andes caused a much smaller deflection of the plumb line, and therefore of the bubble in the surveyor's level, than was to be expected from so large an excess of mass on the earth's surface. Pierre Bouguer, the French mathematician who made the discovery, concluded that the rocks in the mountains and below them to some distance were lighter than their surroundings. He thought this might be due to thermal expansion of the underlying rock.

A hundred years after Bouguer's discovery the English astronomer George B. Airy, having measured the gravitative deficiency of the Himalaya Mountains, suggested the correct explanation: the rocks beneath a mountain belt have a lower density than their surroundings. He postulated that below a mountain belt the light granite rock of the outer crust extends far down into the heavier underlying basalt. From this suggestion came the theory that mountains have "roots." Airy suggested that the young mountains and their "roots" float in their environment like icebergs in water, the lighter mountains projecting higher than the heavier ones.

In recent years efficient new methods of measuring the local value of gravity have shown conclusively that in a general way the value of gravity does indeed decline with altitude faster than the mere change in elevation could explain. The difference between the theoretical value of gravity, assuming a uniform density for all rocks, and the observed values is called the Bouguer gravity anomaly. Typical Bouguer anomalies are illustrated in the gravity profile across the Eastern Alps shown on page 36. Across this whole range the gravitative attraction is everywhere less than it would be if the mean density were assumed to be the same as in non-mountainous regions. What is more remarkable is that the discrepancy grows larger as the elevation of the range increases; it reaches a maximum at the crest. This indeed suggests the existence of a mountain "root." Seismic studies provide a clinching proof. At deep levels of the crust beneath the Eastern Alps earthquake waves travel at a noticeably slower rate than at comparably deep levels in other regions, indicating that the light, low-velocity rocks here extend far down to levels normally occupied by denser rocks. In other words, the Alps do have a granitic root. So do other young folded mountain ranges that have been similarly studied.

Do these mountain roots "float" in the heavier basaltic and ultrabasic rock material of the lower levels, or are they more like the roots of teeth anchored in a jaw? That question cannot be answered by any known geophysical method. An answer can come only from an examination of the mountains themselves.

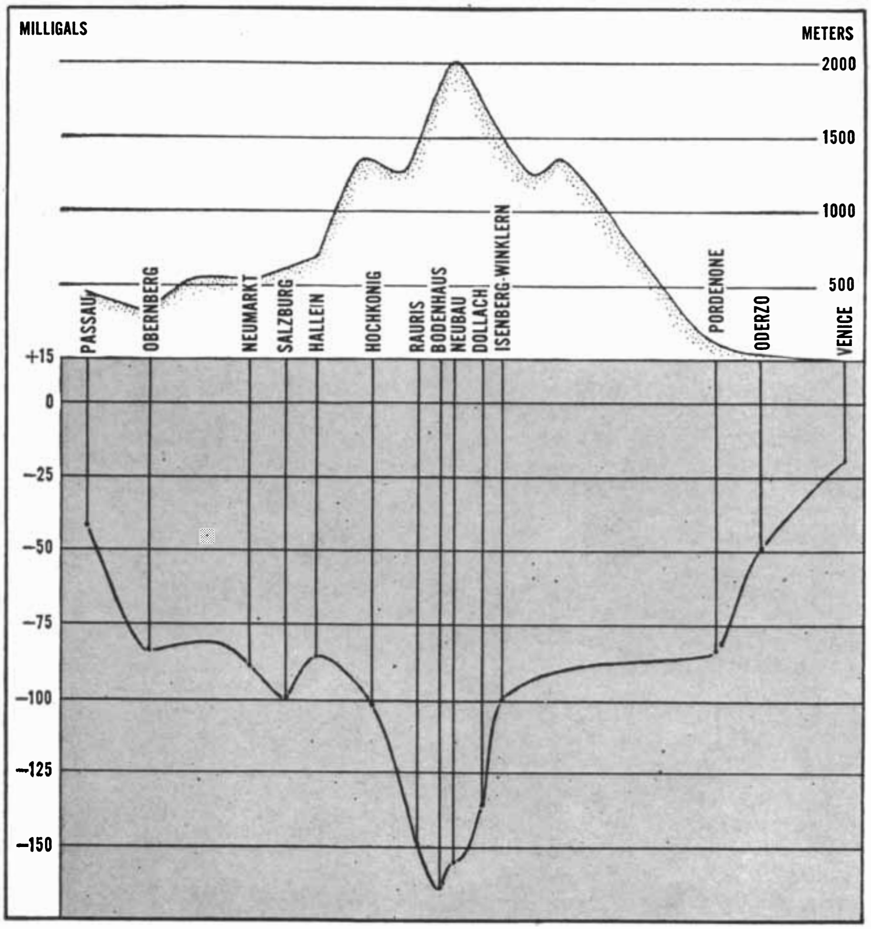
Whence Comes the Granite?

The Sierra Nevada of California is the classic U. S. example of a young mountain-building zone with a proved granitic root. It also offers one of the best exhibits of the invasion of sediments by granite. Here, as in all young folded mountains, the Pre-Cambrian basement must lie many miles below the surface. The range consists of marine sediments, chiefly shales, which have been compressed into a complicated pattern of tight folds. But more than half the bulk of the sediments deposited there has entirely disappeared, and their place is now occupied by granite, which forms the vast inner core of the Sierra Nevada. Where did the granite come from, and where did the sediments go?

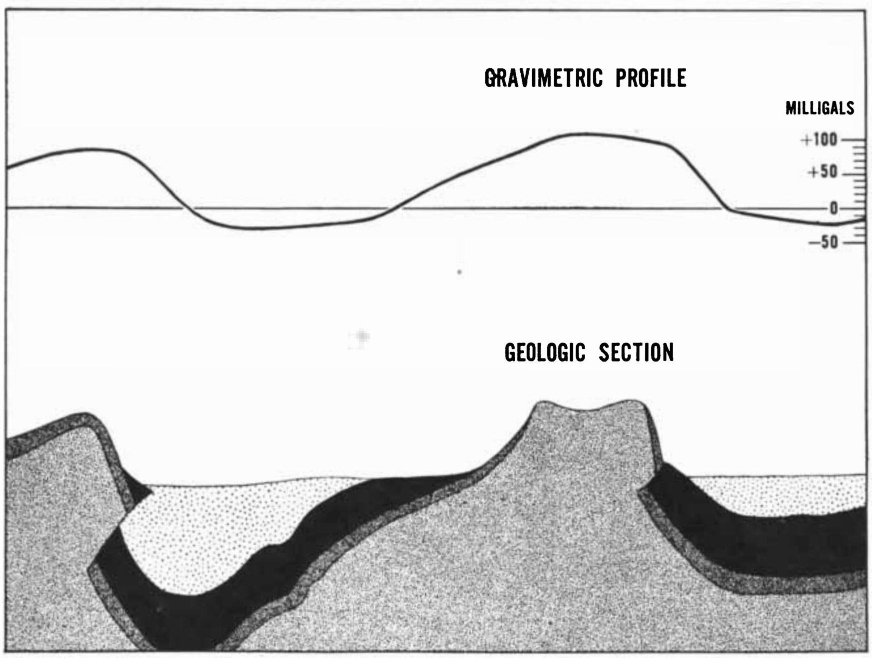
The traditional answer to the first question is deceptively simple. Ever since the infancy of geology it has been an axiom that granite formed the uppermost layer of the original crust of the earth and that it constitutes the foundation on which all sediments must rest. The traditional theory holds that the process of lateral compression of the crust which forms mountains forces the granitic part of the crust downward to form a solid root and upward to invade the thick sediments of the mountain-forming belt as molten rock.

This implies a strange dual behavior. To cause the young mountain range to float, the granitic root must be able to hold its shape and resist deformation to a higher degree than the underlying basaltic materials, which must behave as a yielding matrix at depths where temperatures and pressures are high. Yet at shallow depths, low temperatures and low pressures this same granite must melt readily and displace and push down out of sight huge volumes of sediments. No known properties justify the assumption of such a dual behavior. Wherever basaltic and granitic rocks are seen deformed side by side in deeply eroded parts of the earth's surface, it is always found that the granitic rocks have behaved more plastically than the basalt. Moreover, granitic materials have a considerably lower melting point than basaltic rocks.

One must assume, therefore, that when a young mountain system is



GRAVITY ANOMALIES of the Alps were mapped by measuring the force of gravity at various locations. Gravity was found to be less than it should be at the height of these locations, suggesting that a root of relatively light rock projected beneath the mountains. Milligals are a measure of gravity.



ISOSTATIC ANOMALIES of the Big Horn Basin (*left*) and Big Horn Mountains (*center*) reveal structure of Pre-Cambrian basement (*light gray*). An isostatic anomaly is the variation from the predicted value of gravity corrected for isostasy, *i.e.*, the tendency of the crust to equalize its weight.

formed by the compression of the crust of a continental area, the primary granitic part of the crust is squeezed down into and molded with the stiffer and heavier basaltic part of the crust as a plastic mass. As such it would form a root all right, but not one that floats in its environment. The granite would merely make up a larger proportion of the stiff, plastic crust than it does in other places.

We are no longer sure that granite formed an essential part of the original crust of the earth. This venerable axiom of geology is now being challenged in one of the most significant controversies of contemporary petrography. The argument has to do with the second question asked above: Where did the sediments go when the granite took their place?

In the Sierra Nevada granite has replaced the folded sediments up to an elevation three miles above sea level in a region some 400 miles long and in some places 70 miles wide. Detailed mapping proves that the granite was not all emplaced at one time; it invaded the sediments in a series of successive advances, and the structural relations are not what might be expected if the granite had merely pushed the sediments aside. It rather appears in their midst as if it had carved out the space it occupies. Every major granite body is set in a belt of metamorphosed sedimentary rocks and is surrounded by a zone in which granite material has infiltrated the surrounding rocks in an intricate manner. In such border zones granitic material, ranging in thickness from layers of thousands of feet to paper-thin seams, is interlaced with layers of metamorphosed sediments and cuts across them in a network of dikes. Even in the spaces between these granite seams and dikes, potash and soda feldspars, which are characteristic minerals of granite, appear scattered through the rock as well-defined, newly formed crystals or irregular clusters of them. The crystals occupy space once occupied by sedimentary rock, but they show no signs of having been introduced forcibly. They must have been formed by recrystallization of the original sedimentary material, into which was introduced relatively small amounts of alkalis and perhaps some silica in the gaseous state or in solution. Detailed petrographic studies have proved beyond reasonable doubt that whole bodies of granite have been produced by this process, known as "granitization."

Transformation of Rocks

The evidence for such transformation of sediments and even lavas into granite is so convincing that no petrographer now denies that some granite has been produced by granitization. The question is: How much of the world's granite has been formed by such processes, and how do they operate?

There are two schools of thought about it. The orthodox hold that granite is the *agent* of local granitization, the heretics that it is the general *end-product* of granitization. The former believe that in the typical case granite bodies are nothing more than parts of the primeval granite of the earth's crust which have remelted locally and reached their present position by mechanically displacing other rocks; they contend that chemical granitization occurred only incidentally along the borders of the granite bodies. The heretics hold that the original crust of the earth consisted of basalt, and that the granite bodies were created by the transformation of sediments. They argue that the process goes something like this: Whenever disruption of the crust produces belts of folded mountains at the surface and stresses and frictional heat at deeper levels, hot gases and solutions carrying silica, alkalis and other elements rise toward the earth's surface from the lower parts of the crust or the subcrustal layers. These "emanations" change basalt to rocks richer in silica and convert shales and sandstones into schists and gneisses and ultimately into granite.

Because this issue is crucial in connection with the new view of the earth's crust, let us consider the chief arguments in favor of the origin of granites through granitization. The first argument is that if granites were merely parts of the primeval liquefied sialic crust, they might be expected to make their appearance outside the limits of mountain belts, as basalt and related lavas do. But granite is never found outside such belts. The reason generally given by the traditionalists is that sialic melts are too viscous to move as freely as mafic melts. They are indeed viscous, but if it is viscosity that prevents the sialic melt from behaving like basalt in bulk movements, why is it that granite succeeds in penetrating into the capillary spaces of sedimentary rocks and altering them chemically? Nothing remotely comparable is ever observed where the far more fluid basalt has intruded sediments. It is highly improbable that a granitic melt could be injected forcibly, layer by layer, between the delicate, flaky layers of mica schist—a typical metamorphic rock—to produce its characteristic structure.

A rock specimen in the writer's possession demonstrates that recrystallization can produce the characteristic structural relations between an intruding granite and the invaded rock, in this case an altered shale. The specimen has delicate seams of granite that look as if they had been injected between the layers of shale, and dikes that cut diagonally and vertically across the bedding. The seams and dikes connect with the main body of the apparently intrusive material. Yet the field relations show conclusively that in this specimen there has been no intrusion, no forcible injection of fluid, in fact, no melting at all. The light material consists of the substance of the shale recrystallized under the influence of the heat supplied by a sheet of basalt.

This hand specimen points to the crux of our problem. No one objects to granitization on a small scale. But most geologists balk at extending the process to larger bodies of granite, even though every detail of our miniature model can be matched in typical granite regions on almost any scale. We are awed by the magnitude of the scale on which the necessary processes would have to take place.

Nevertheless we face the stubborn fact that in all mountain belts vast volumes of granite have appeared precisely where vast volumes of sediments have disappeared, in many cases leaving a structure pattern that makes displacement of the sediments by mechanical means highly improbable, if not impossible. Moreover, these large bodies of substituted granite occur only in those parts of the earth's crust (*i.e.*, mountain belts) where intense mechanical deformation has taken place. This deformation must produce heat and create paths in the rock for the rapid diffusion of the "emanations" which are believed to play a part in granitization.

Finally there is the strange fact that at least one half of the earth's crust—beneath the oceans—apparently does not possess a granitic upper layer. We geologists are hard pressed to explain the absence of so much of what we used to think was once a universal part of the crust. Many of us are beginning to think that instead of asking, "Why is granite absent from the oceans?" we should be asking, "Why is granite present in the continents?"

To the writer these arguments seem impressive enough to command attention. Yet granitization on this world-wide scale is still only a bold hypothesis. The concept of "emanations" from the subcrust is vague and has as yet no accepted place in geochemical thinking. It is rejected by some eminent petrographers. But knowledge of the behavior of substances under extremely high pressures or temperatures is still in its infancy, and thinking about the unruly matter beneath the crust is undergoing changes as new facts are brought to light by geophysicists. It looks at present as if the concept of granitization fits into the complex jigsaw puzzle of crustal structure better than the traditional view does.

Basins and Swells

We have been considering changes in the earth's crust in the young folded mountain belts. The sedimentary platforms of the continents reveal, in a more indirect way, that changes and resulting movements of the crust take place even outside these belts. The surface of the platforms is warped into irregular basins separated by low swells. The North American Mid-Continent has several basins (*e.g.*, the Michigan Basin and the Illinois-Kentucky Basin), which measure a few hundred miles in diameter and one to two miles in depth (*see map on page* 39). Of the swells that separate them, the "Cincinnati arch" is the best known.

Little thought has been given as yet to the reason for such warping. The tendency has been to blame the sediments, the theory being that the crust beneath the continents is so weak that it gives even under small local loads, and therefore the weight of sediments laid down on it would cause a downbuckling to form basins. But intensive gravity surveys carried out in recent years have brought conclusive evidence that the crust beneath the continents is much stronger than was formerly supposed. Isostatic equilibrium prevails only in a broad sense over very wide areas. Many of the smaller basins, notably the Big Horn and Powder River basins of the Rocky Mountain region, are much too light to remain so low, and adjoining mountain ranges are too heavy to maintain their height if the crust were weak. In such cases the crust must be strong enough to support large local stresses. There is evidence that even the largest of our Mid-Continent basins cannot owe their existence to the weight of the sediments in them. The sinking of the land surface to form basins must be due to processes that take place at depth. Until we know what these processes are, we cannot hope to solve the largest problem of all—the origin of the ocean basins.

In the smaller basins of the sedimentary platform the old Pre-Cambrian land surface lies bent down to depths of one to four miles below sea level, *i.e.*, depths which we associate with the oceans. Does this mean that parts of the modern ocean floor may be merely downbent portions of old continents? With this question we turn to the structure of the earth's crust below the oceans.

Under the Oceans

On the coasts of continents bordering the Atlantic, Indian, Antarctic and Arctic oceans, and on some coasts of the Pacific, the continental structure lines run out beneath the sea as if the surface were indeed bent down or had broken off. On a geologic map they end abruptly. The presence of identical or similar marine shallow-water organisms and terrestrial animals and plants on opposite shores of an ocean often suggests that shallow water or land connections once existed where now there is deep sea. Such observations led many geologists in the 19th century to the conclusion that in the course of geological history large sections of continents or even whole continents sank to oceanic depths.

In 1846 the U. S. geologist James D. Dana first suggested the opposite view: that the continents have stood high since the earliest part of the geologic record. He thought that the continents were parts of the crust that consolidated early; hence they were thicker and sank less as the earth shrank, while the thinner parts became the oceans. Later, when it became known that basalt is by far the most common rock found on oceanic islands, while the lighter granite is confined to the continents and nearby islands, many geologists came to the same conclusion as Dana, but for a different reason. Since the parts of the earth's crust appeared to be in gravitative equilibrium, they thought that the ocean floors are low because they consist of heavy rock, and the continents are high because they are light. Once a continent, always a continent. But that left unexplained the world of facts that had led others to the opposite conclusion.

About 40 years ago the German geophysicist Alfred Wegener advanced his spectacular continental-drift hypothesis. Contrary to all the available physical and geological evidence, he blandly postulated that the basalt of the ocean floor is so weak that it cannot resist deformation even under the action of almost infinitesimal forces. This would make it possible for granitic continental masses to drift through the basalt of the sea floor like cakes of ice through water. According to Wegener the sea separates great land masses that were once in contact, and the solid basalt of the present sea floor flowed plastically into the spaces it now occupies. His book, a masterpiece of special pleading, fired the imagination: by one bold stroke it seemed to explain a number of baffling problems of world geology. Wegener's work drove home to all concerned the need for new, crucial information on the physical properties of rocks and the topography and structure of the ocean floor. Some of the much-needed information on the geology of the ocean floor is beginning to come in through the work of a small group of brilliant and indomitable investigators, among whom F. A. V. Meinesz of the Netherlands and Maurice Ewing of Columbia University stand out as leaders.

The Atlantic

In the last years before World War II Ewing set out to determine how the granitic crust of the North American Continent connects with the floor of the deep sea along the western border of the North Atlantic Basin. Off the Atlantic coast of the U. S. the sea bottom at first drops very slowly, forming a continental shelf which reaches a depth of around 360 feet below sea level at its outer edge, some 60 to 80 miles off New Jersey and Maryland. Beyond the edge the bottom drops off relatively fast (about 400 feet per mile) to the deep sea, forming the continental slope.

Ewing faced two questions: 1) What makes the continental shelf? 2) What becomes of the sialic crystalline (granitic) basement as one goes toward oceanic depths? Wegener had suggested that the outer edge of the shelf marked the end of the granitic continental crust—the sharp edge along which it had torn away from the Continent of Europe. If that were true, beneath the shelf the crust should consist of rocks of the basement complex, with no more than a veneer of young sediments, and this structure should end abruptly.

To find the answers to his dual question, Ewing adapted the seismic method to work below the sea by means of several masterly devices that would make a thrilling story in themselves. What he found is illustrated in the chart at the bottom of page 39. He showed that the granitic basement does not end at the continental shelf but slopes down continuously to depths of about two miles below sea level. This was a crucial discovery. It demonstrated that here at the edge of a continent the basement of crystalline rocks, which are identical in character with the older rocks of the continental shield, falls away to form an oceanic basin in exactly the same way as the shield bends down to form the Michigan Basin 700 miles inland. Like this basin, the descending North Atlantic basement is covered with sediments, which are the seaward continuation of the formations exposed on the coastal plain. This discovery proves that parts of the deep sea may well consist of continental crust brought to a low level and held there. Presumably this was accomplished by the same unknown processes that produced the basins within the continents.

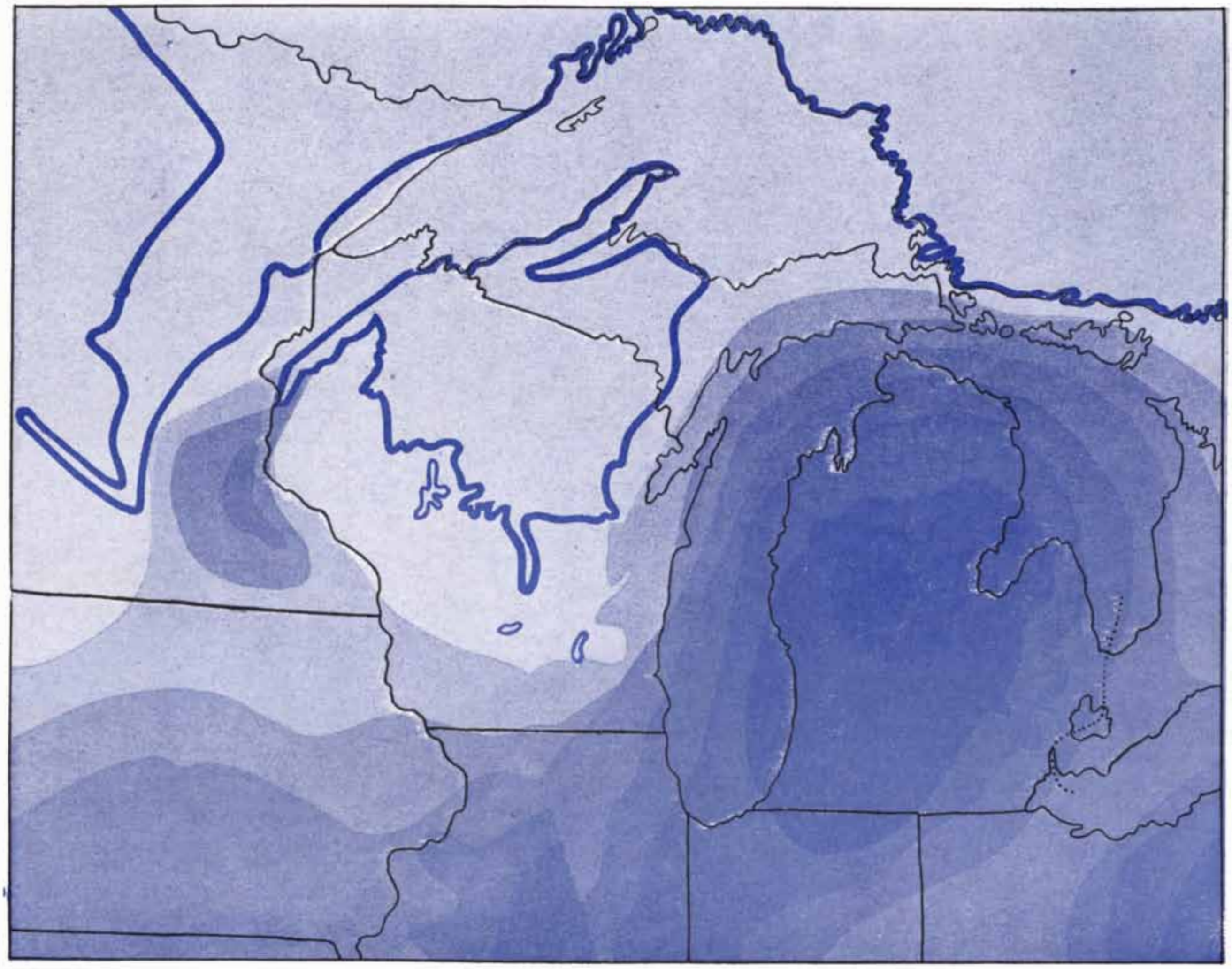
How much of the Atlantic Ocean floor had such a history? The best answer one can give at present is that probably only a small fraction of the "North American Basin" of the Atlantic Ocean is underlain by crustal material of the continental type. This is contrary to a widely held belief. Old interpretations of the velocity of earthquake waves traveling across ocean floors had suggested that all oceans except the central part of the Pacific are covered by a layer of granitic material not over some six miles thick. But Ewing and his co-workers have developed a new theory about the travel of earthquake surface waves along ocean floors which, while not necessarily disproving the presence of "continental" crustal material on the floor of the North Atlantic Ocean, makes it unnecessary to assume it. And direct seismic refraction measurements recently made by Ewing at over a dozen points in the North Atlantic Ocean have shown only the wave velocities characteristic of basalt. Moreover, gravity measurements across the North Atlantic by Meinesz lead to the same conclusion: they show dominant positive anomalies which indicate the absence of light granitic material.

The Atlantic's Mountains

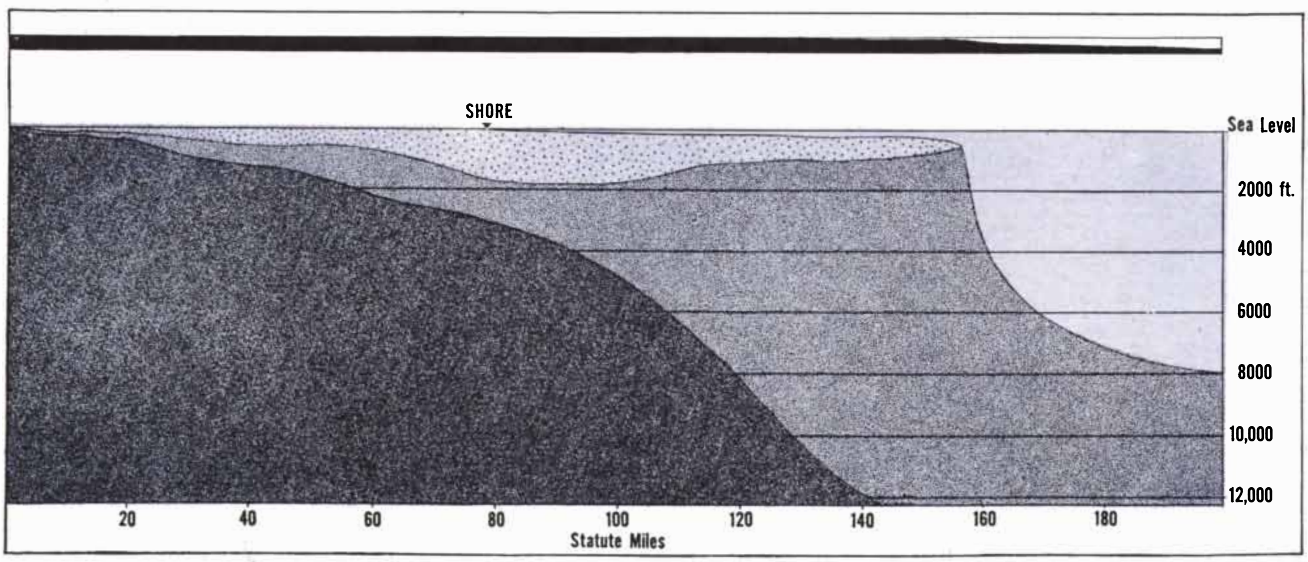
These considerations make it appear probable that beneath the North Atlantic and under large parts of the other oceans the crust consists wholly of basalt without any sialic material. We recall that Wegener built his hypothesis of the continental drift on the premise that this was the case. But what about the properties of this basalt? According to Wegener's theory, the basalt must be so weak that it yields to very small pressures. This means that the basalt formation would have to be essentially flat; it could not support the weight of hills or mountains. What are the facts?

In the summer of 1947 Ewing started a systematic mapping of the topography of the North Atlantic sea floor with modern echo-sounding devices from the research ship *Atlantis*. This exploration shows in precise detail what had been known before in a general way: that the surface of the sea floor is the exact opposite of what Wegener's hypothesis demands. The floor has a rugged topography. From the plain of the North American Basin at the bottom of the Atlantic more than five miles below sea level there rise large mountains ("sea mounts") which in some cases are more than 6,000 feet tall. Many of these undersea mountains have sharp peaks; others are flat-topped. From Iceland south to the Antarctic Ocean runs a complex submarine mountain belt—the Mid-Atlantic Ridge. Its central part forms a rugged highland 60 to 200 miles wide, with peaks that rise to less than a mile below the surface of the sea. On both sides of this central highland the flanks of the Mid-Atlantic Ridge exhibit a remarkable pattern of tilted flat surfaces, underlain by thick, unconsolidated sediments. The pattern suggests tilted fault blocks. Large, angular blocks of basalt were dredged by Ewing from the foot of an abrupt declivity which must be a fault scarp. Other features in the North Atlantic are suspected to be the result of faulting. It is probable that the edge of the continental shelf is produced by a fault zone along which the other half of the sedimentary basin suggested by Ewing's cross sections has dropped to deep-sea level.

Much the same picture characterizes



BASINS AND SWELLS of the Pre-Cambrian basement are shown in this map of the Great Lakes region. The outlines of the Great Lakes and the states are shown in black. The heavy blue line shows the edge of the Pre-Cambrian formation at the surface. The blue shading shows in 1,000-foot contour intervals the depth to which the formation plunges beneath the surface. In central Michigan the basement is more than 5,000 feet down.



CONTINENTAL SHELF is an important clue to the structure of the earth's crust. This cross section of the shelf off the coast of southern Virginia was plotted by a group headed by Maurice Ewing of Columbia University. The dark gray area is the Pre-Cambrian basement. The lighter gray area is younger sediments; the stippled area unconsolidated sediments atop it. The vertical scale of the section is exaggerated; the actual profile is at top.

the floor of the great central region in the Pacific, which apparently consists wholly of basalt and related rocks. Flat-topped sea mounts in large numbers have been found there. The Hawaiian Islands are the top of a great basalt range which rises above sea level from an ocean floor over three miles deep. The topography of the surrounding sea floor suggests that the weight of the range is held up by the elastic strength of the crust, somewhat as a weight is supported by a sheet of ice covering a body of water. This ability to support heavy local loads points to a thick crust of great strength—the exact opposite of the conditions demanded by Wegener.

In short, everything that is now known concerning the configuration and structure of the floors of the oceans proves conclusively that Wegener's hypothesis of continental drift is wholly untenable. It also suggests that Dana was wrong in his idea that the continents were formed by the thicker parts of the crust. Actually the crust beneath the continents appears to be thinner and weaker than that beneath the oceans.

The crust beneath the ocean floors is as much a part of the earth's solid "armor" as that beneath the continents, if not more so. This being the case, the same crustal processes that are at work in the continents should also be in operation in the oceanic areas. Can these processes explain the contrast between the two levels of the earth's surface? The writer believes that they can.

Furrows and Welts

To begin with, the two major types of deformation found on the continents are also seen on the ocean floors. One type of deformation is the succession of basins and swells. The floor of the Atlantic has a basin-and-swell pattern which in principle is the same as that in the sedimentary platform of the North American Mid-Continent, except that in the ocean the pattern is developed on a gigantic scale. The other type of deformation is the one that has given rise to great folded mountain belts. The largest development of this process on earth occurs along the borders of the Pacific Ocean and on the floor of the western half of the ocean itself; there the peaks of submarine mountains form the great island chains of the Pacific. The pattern is characterized by long, narrow, asymmetrical mountain ranges, closely paralleled by deep, narrow trenches along their steeper sides. The trenches are called "furrows" and the mountain ranges "welts." This furrow-and-welt pattern is evident in the island chains of the north and west sides of the Pacific and in the great cordilleras of Central and South America with their accompanying offshore, deep-sea trenches. In the mountain belts around the Pacific have originated over 40 per cent of the earth's near-surface earthquakes, about 90 per cent of those recorded from intermediate depths, and all the deep earthquakes. Here, then, is mountain-making on a vast scale actively going on today.

Perhaps the most significant of the young, active welts is the mighty submarine mountain belt which extends southward from Japan through the Bonins and Marianas to Palau—a range comparable in length and height to the Himalayas. Among its peaks are the islands of Iwo Jima, Saipan, Guam and Yap. This range has the same asymmetric profile, the same deep-sea trench along its steeper side and the same chains of volcanoes on its gentler back as the most active welts on the continents bordering the Pacific. But it differs in two significant ways: 1) It stands alone on the deep-sea floor; 2) The only metamorphic rocks that have been found in the rock body of the range are derived from basalt or from other oceanic rock types that are even richer than basalt in iron and magnesium. The types of metamorphic rocks characteristic of continents (those derived from ordinary sediments such as shales and sandstones) seem to be absent. Here is a young mountain range, as mighty as any on land, that seems to have been formed by deformation of the ocean bottom.

Suppose there were no ocean and we were standing on the bottom lowlands of the Pacific looking westward toward this towering mountain range. Beyond it westward lies a deep sea plain that extends for more than 600 miles. There the great submarine mountain chains that form the Philippine Islands rise in precisely the same manner from the ocean deep, and behind them, covered by younger sediments, emerges the edge of the Asiatic Continent itself. From this perspective it would seem incomprehensible to us that men should ever ask: "How did the ocean basins come to be?" Instead we might well ask: "How did the continents come to be?"

From this point of view the very expression "ocean basins" becomes meaningless. The continents now can be seen clearly as deformed belts of the earth's surface which have been raised at intervals through geologic time and joined together in various ways. The oceanic areas, on the other hand, must be the undisturbed portions of the earth's surface. They are underlain by the original basaltic crust, covered here and there with a blanket of diverse sediments.

This reasoning deviates considerably from current doctrine. The purpose in presenting it is to indicate possible new directions of thinking and to suggest crucial areas in which these ideas may be tested systematically by geophysicists and geologists.

One of these crucial areas is the Bonin-Marianas-Palau folded mountain belt. Despite the fact that tens of thousands of square miles of the crust west of this range lies at deep-sea level, the current view is that the range marks the eastern, outer edge of the granite-bearing, "continental" type of crust in the Pacific Hemisphere. This interpretation was derived from studies of the composition of the most common type of lava that has poured from the numerous volcanoes of the island belt. The rocks formed from this lava, known as andesite, are different in mineral composition from any rock types that can be derived from the typical basalts of the Pacific. They are richer in silica, for one thing. To explain their relatively high silica content and other nonbasaltic components, the prevailing interpretation suggests that these andesite rocks were created by contamination of basaltic lava with the granitic material of a layer of primeval granite that is assumed to lie on top of the crust where andesite is found. This is the same kind of reasoning that presupposes the existence of a primeval layer of granite to account for the presence of granite bodies in the metamorphosed sediments of the continental mountain belts.

But we have seen that there is an alternative explanation for the presence of granite bodies in the continental sediments—namely, the transformation or granitization of sediments by emanations of silica and other elements from lower levels. The same type of activity may account for the production of andesite; that is, the so-called contamination of the basaltic source material may be due to the introduction of silica and other elements in the same manner and for the same reason as is postulated for granitization. So the andesite lavas of the Pacific may represent not an essentially static heritage of the past but the dynamic front along which belts of the old basaltic crust are being actively molded into young mountain welts.

Here in the western Pacific, then, we have the stage for a crucial test of the great issues of crustal evolution. Surveys must be made to obtain an adequate picture of the topography of the ocean floor; seismic, magnetic and gravity measurements must be made from surface ships and submarines to explore the nature of the crust in the suboceanic mountain ranges and on both sides of them; the steep submarine slopes must be dredged in the search for sample rock materials; the island structures and rocks must be studied in detail; analyses must be made of the physical chemistry of the pertinent elements in the gaseous state, in solutions and in melts.

Conclusions

From all this it is plain that we still know little about the structure of the crust beneath the continents and much less about that below the oceans. All our concepts necessarily rest on extrapolations far beyond the scanty data that can be considered reliable. All are but tentative hypotheses waiting to be tested. Yet we must have hypotheses to test, and we must constantly seek to combine them into a consistent over-all picture that shows the parts in relation to the whole. The essence of a possible picture of the earth's crust that emerges from the observations and thoughts presented in this article may be summed up as follows:

The complexity of the crust beneath the continents is the result of major crustal folding, *i.e.*, the formation of upbowed welts and downbowed furrows that filled with sediments. Compression of these belts drew out the sediment-filled furrows into roots of mountains, and set in motion the physical and chemical processes that transformed part of the sediments into metamorphic rocks and ultimately into granite. The idea that the rocks in the crust lie in essentially horizontal layers is a purely statistical concept which does not reflect the actual complexity of the crustal structure.

The shields and their continuation beneath the sedimentary platforms of the continents are the eroded stumps of earlier folded mountain ranges; their level is therefore related to sea level. Their existence is proof that the position of the sea level with reference to land has not changed radically since Cambrian time. Parts of the old Pre-Cambrian surfaces of the continents have been warped into basins and swells, and the floors of some of these basins have sunk to depths comparable to those of the oceans.

Between the typical continental and oceanic areas lie regions where the basin-forming process has brought sections of the continental granitic crust down to oceanic depths. Crustal deformation, on the other hand, has produced belts of folded mountain ranges from the basaltic crust beneath the ocean floors as well as from continental levels. This process, to which the continents owe their existence, is still going on actively on the borders of the Pacific Ocean and within the ocean's western part.

Such an abstract, overgeneralized picture is but the framework into which the realities of crustal structure must be fitted. It defines the scope of some of the great questions that call for answers, and of the stirring possibilities for work on one of the great frontiers of modern science—the geology of the deeper parts of the earth's crust.

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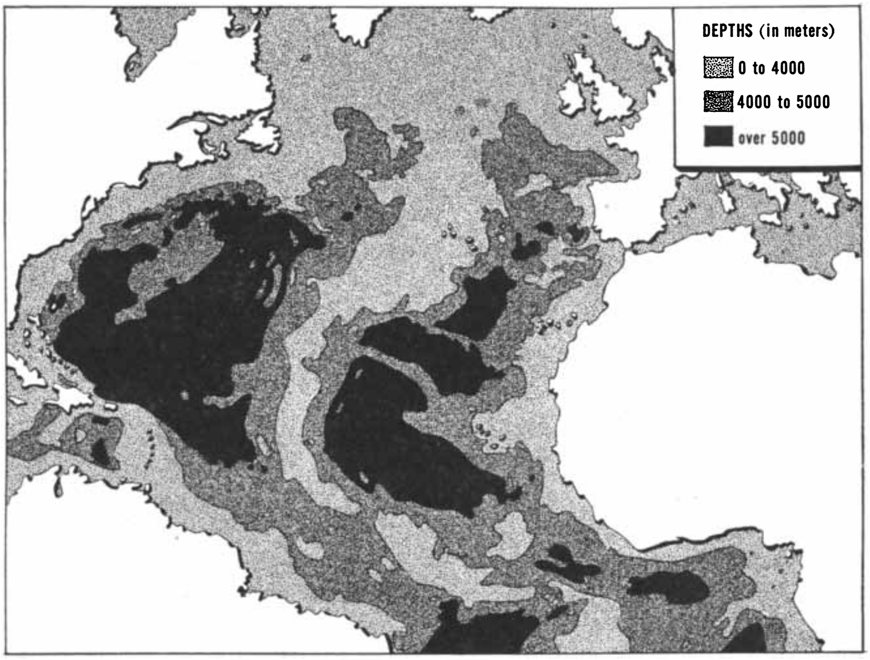
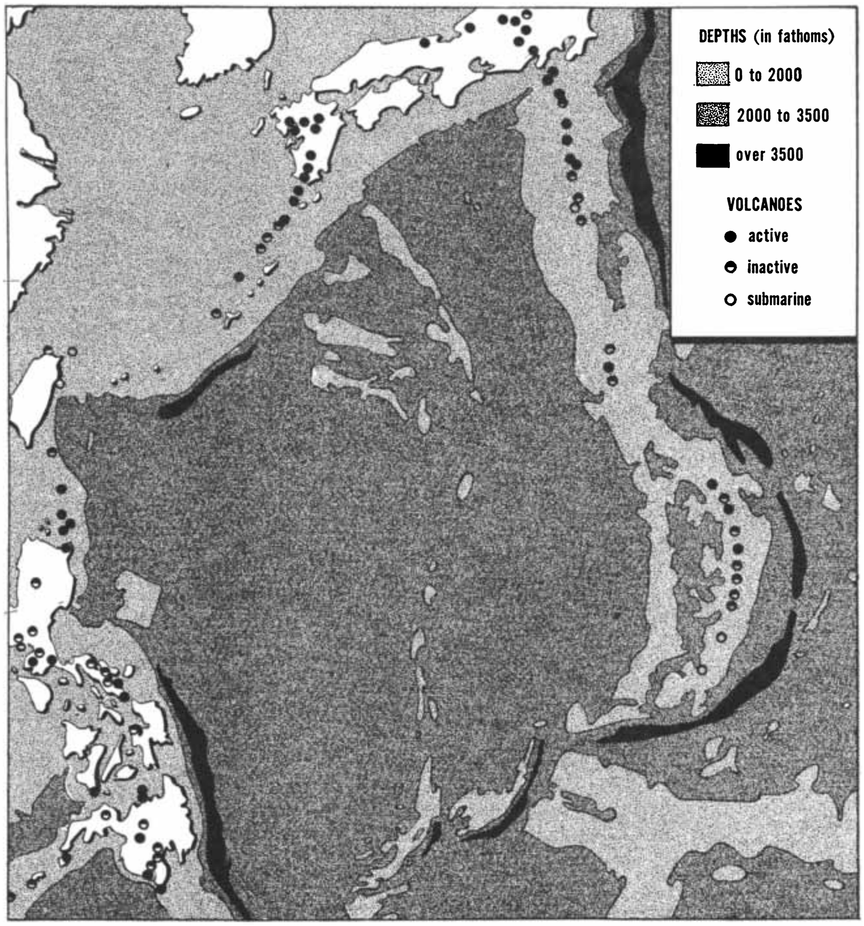


FLOOR OF ATLANTIC has rugged features. On this map parts of North and South America are at left; parts of Europe and Africa at right. Running down the middle of the ocean's floor is the Mid-Atlantic Ridge, the central part of which forms a broad highland that is some 60 to 200 miles across.



FLOOR OF THE PACIFIC, of which only a small part is shown here, shows evidence of significant change. Some landmarks are the Philippines (*lower left*) and southern Japan (*top center*). Running south from Japan is a submarine ridge, surmounted by volcanoes and paralleled by great deeps.

An Imitation of Life

Concerning the author's instructive genus of mechanical tortoises. Although they possess only two sensory organs and two electronic nerve cells, they exhibit "free will"

by W. Grey Walter

"When we were little . . . we went to school in the sea. The master was an old Turtle—we used to call him Tortoise."

"Why did you call him Tortoise if he wasn't one?" Alice asked.

"We called him Tortoise because he taught us," said the Mock Turtle angrily. "Really you are very dull!"

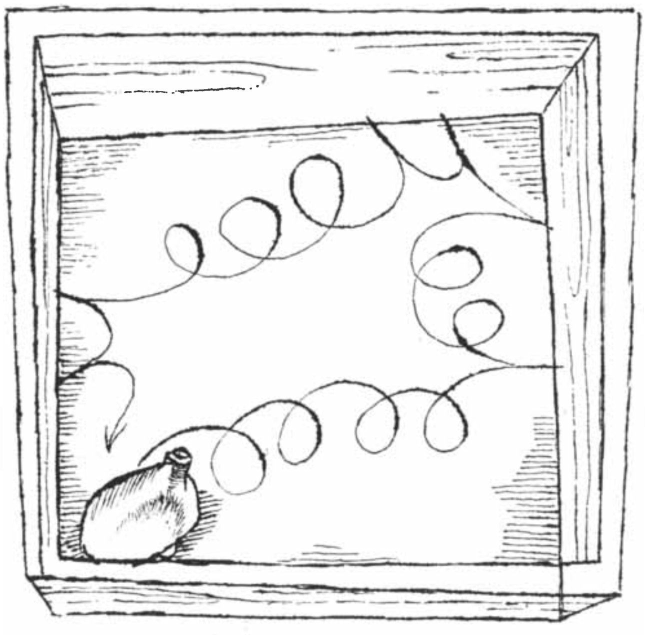
—Lewis Carroll,
Alice's Adventures in Wonderland

IN THE DARK AGES before the invention of the electronic vacuum tube there were many legends of living statues and magic pictures. One of the commonest devices of sorcerers and witches was the model of an enemy which somehow embodied his soul, so that injury to the model would be reflected by suffering or death of the original. Even today it is not very uncommon to find in the cottages of European peasants wax statuettes of hated rivals stuck with pins and obscenely mutilated. One has only to recall the importance of graven images and holy pictures in many religions to realize how readily living and even divine properties are projected into inanimate objects by hopeful but bewildered men and women. Idolatry, witchcraft and other superstitions are so deeply rooted and widespread that it is possible even the most detached scientific activity may be psychologically equivalent to them; such activity may help to satisfy the desire for power, to assuage the fear of the unknown or to compensate for the flatness of everyday existence.

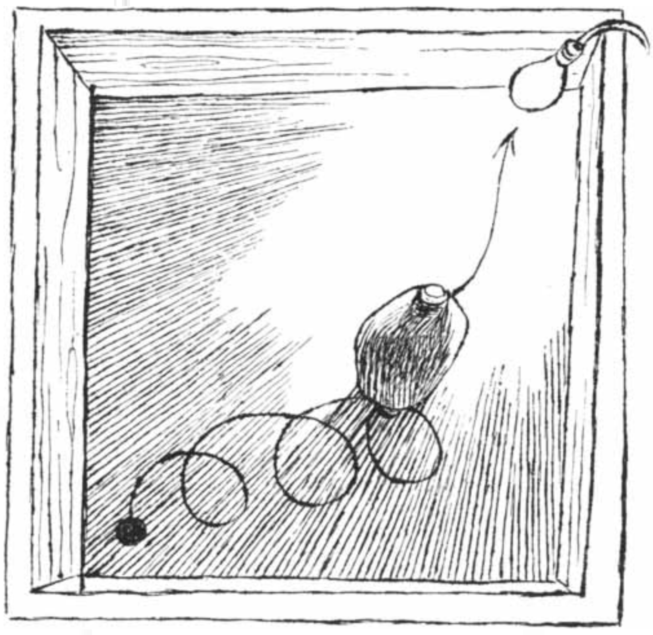
In any case there is an intense modern interest in machines that imitate life. The great difference between magic and the scientific imitation of life is that where the former is content to copy external appearance, the latter is concerned more with performance and behavior. Except in the comic strips the scientific robot does not look in the least like a living creature, though it may reproduce in great detail some of the complex functions which classical physiologists described as diagnostic of living processes. Some of the simpler of these functions can be duplicated by mechanical contrivances. But it was not until the electronic age that serious efforts were made to imitate and even to surpass the complex performance of the nervous system.

The fundamental unit of the nervous system is the nerve cell. In the human brain there are about 10,000 million such cells of various types, mostly concentrated in deep masses of "gray matter" or on the surface of the brain—the much-folded cerebral cortex. Between the cells run skeins of white matter, the interconnecting fibers. The unit of function is the nerve impulse, a miniature electrochemical explosion that travels along the outside of a nerve fiber as a vortex ring of negative ions.

All the gradations of feeling and action of which we are capable are provided by variations in the frequency of nerve impulses and by the number of nerve cells stimulated. The brain cipher is even simpler than Morse code: it uses



TORTOISE IN BOX describes a cycloidal path, backing up when it encounters a wall. In these drawings the tortoise features are somewhat exaggerated for clarity.



LIGHT IN BOX, picked up by the photoelectric "eye" of the tortoise, causes it to steer in that direction. When tortoise comes close to light, however, it backs away.

only dots, the number of which per second conveys all information. Communication engineers call this system "pulse-frequency modulation." It was "invented" by animals many millions of years ago, and it has advantages over other methods which are only just beginning to be applied. The engineers who have designed our great computing machines adopted this system without realizing that they were copying their own brains. (The popular term electronic brain is not so very fanciful.) In the language of these machines there are only two statements, "yes" and "no," and in their arithmetic only two numbers, 1 and 0. They surpass human capicity mainly in their great speed of action and in their ability to perform many interdependent computations at the same time, *e.g.*, to solve simultaneous differential equations with hundreds of variables.

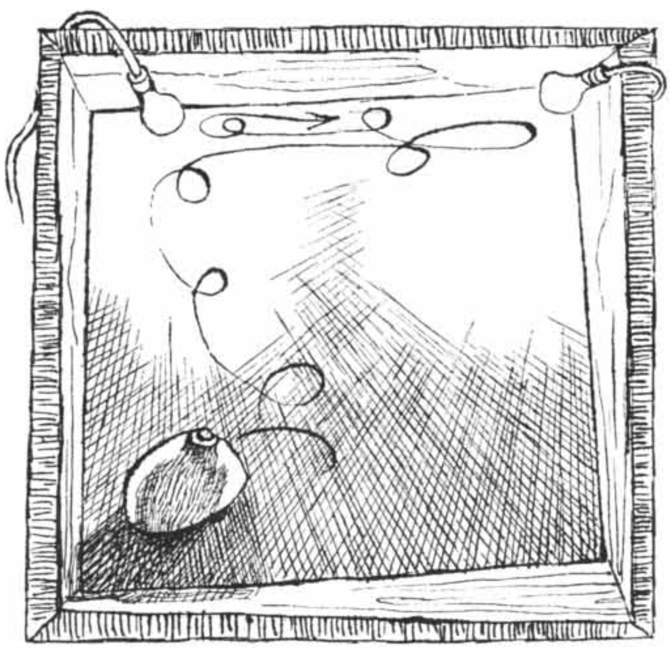
Magical though these machines may appear to the layman, their resemblance to living creatures is limited to certain details of their design. Above all they are in no sense free as most animals are free; rather they are parasites, depending upon their human hosts for nourishment and stimulation.

IN a different category from computing machines are certain devices that have been made to imitate more closely the simpler types of living creatures, including their limitations (which in a computer would be serious faults) as well as their virtues. These less ambitious but perhaps more attractive mechanical creatures have evolved along two main lines. First there are stationary ones—sessile, the biologist would call them—which are rooted in a source of electric power and have very limited freedom. The prototype of these is the "homeostat" made by W. R. Ashby of Gloucester, England. It was created to study the mechanism whereby an animal adapts its total system to preserve its internal stability in spite of violent external changes.

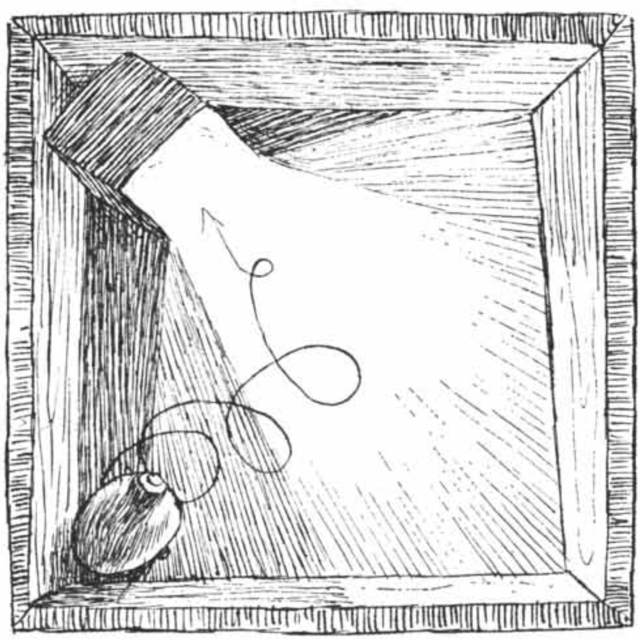
The term "homeostasis" was coined by the Harvard University physiologist Walter B. Cannon to describe the many delicate biological mechanisms which detect slight changes of temperature or chemical state within the body and compensate for them by producing equal and opposite changes. Communication engineers have rediscovered this important expedient in their grapplings with the problems of circuits and computers. They describe a system in which errors or variations from some desirable state are automatically neutralized as containing "negative or inverse feedback" ("Cybernetics," by Norbert Wiener; SCIENTIFIC AMERICAN, November, 1948). In their machines an error in performance or output is fed back into the input in such a sense that it opposes the signal responsible for the error. In an animal most of what is called reflex activity has exactly this property.

In Ashby's homeostat there are a number of electronic circuits similar to the reflex arcs in the spinal cord of an animal. These are so combined with a number of radio tubes and relays that out of many thousands of possible connections the machine will automatically find one that leads to a condition of dynamic internal stability. That is, after several trials and errors the instrument establishes connections which tend to neutralize any change that the experimenter tries to impose from outside. It is a curious fact that although the machine is man-made, the experimenter finds it impossible to tell at any moment exactly what the machine's circuit is without "killing" it and dissecting out the "nervous system"; that is, switching off the current and tracing out the wires to the relays. Nevertheless the homeostat does not behave very like an active animal—it is more like a sleeping creature which when disturbed stirs and finds a comfortable position.

ANOTHER branch of electromechanical evolution is represented by the little machines we have made in Bristol. We have given them the mock-biological name *Machina speculatrix*, because they illustrate particularly the exploratory, speculative behavior that is so characteristic of most animals. The machine on which we have chiefly concentrated is a small creature with a smooth shell and a protruding neck carrying a single eye which scans the surroundings for light stimuli; because of its general appearance we call the genus "Testudo," or tortoise. The Adam and Eve of this line are nicknamed Elmer and Elsie, after the initials of the terms describing them—ELectro MEchanical Robots, Light-Sensitive, with Internal and External stability. Instead of the 10,000 million cells of our brains, Elmer and Elsie contain but two functional elements: two miniature radio tubes, two sense organs, one for light and the other for touch, and two effectors or motors, one for crawling and the other for steering. Their power is supplied by a miniature hearing-aid B battery and a miniature six-volt storage battery, which provides both A and C



TWO LIGHTS IN BOX cause tortoise first to head for the nearest, then to back away from it and head for the other. Tortoise finally strolls between the two lights.



"KENNEL" IN BOX has light of certain brightness that attracts the tortoise only when its storage battery is run down. Battery is then recharged from contacts in kennel.

current for the tubes and the current for the motors.

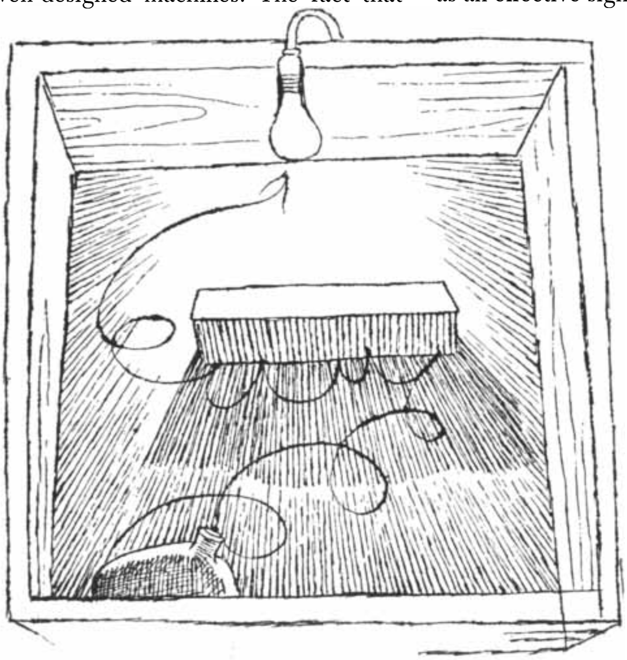
The number of components in the device was deliberately restricted to two in order to discover what degree of complexity of behavior and independence could be achieved with the smallest number of elements connected in a system providing the greatest number of possible interconnections. From the theoretical standpoint two elements equivalent to circuits in the nervous system can exist in six modes; if one is called A and the other B, we can distinguish A, B, A+B, A→B, B→A and A⇌B as possible dynamic forms. To indicate the variety of behavior possible for even so simple a system as this, one need only mention that six elements would be more than enough to form a system which would provide a new pattern every tenth of a second for 280 years—four times the human lifetime of 70 years! It is unlikely that the number of perceptible functional elements in the human brain is anything like the total number of nerve cells; it is more likely to be of the order of 1,000. But even if it were only 10, this number of elements could provide enough variety for a lifetime of experience for all the men who ever lived or will be born if mankind survives a thousand million years.

So a two-element synthetic animal is enough to start with. The strange richness provided by this particular sort of permutation introduces right away one of the aspects of animal behavior—and human psychology—which *M. speculatrix* is designed to illustrate: the uncertainty, randomness, free will or independence so strikingly absent in most well-designed machines. The fact that only a few richly interconnected elements can provide practically infinite modes of existence suggests that there is no logical or experimental necessity to invoke more than *number* to account for our subjective conviction of freedom of will and our objective awareness of personality in our fellow men.

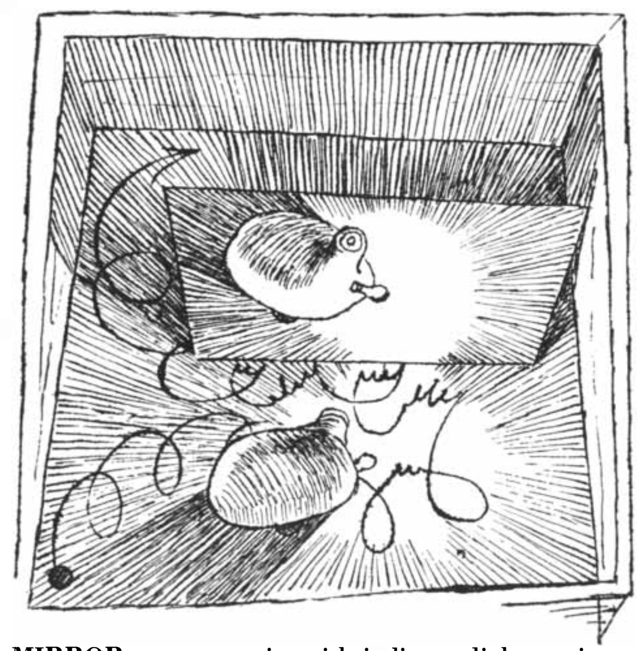
The behavior of Elmer and Elsie is in fact remarkably unpredictable. The photocell, or "eye," is linked with the steering mechanism. In the absence of an adequate light-stimulus Elmer (or Elsie) explores continuously, and at the same time the motor drives it forward in a crawling motion. The two motions combined give the creature a cycloidal gait, while the photocell "looks" in every direction in turn. This process of scanning and its synchronization with the steering device may be analogous to the mechanism whereby the electrical pulse of the brain known as the alpha rhythm sweeps over the visual brain areas and at the same time releases or blocks impulses destined for the muscles of the body. In both cases the function is primarily one of economy, just as in a television system the scanning of the image permits transmission of hundreds of thousands of point-details on one channel instead of on as many channels.

The effect of this arrangement on Elmer is that in the dark it explores in a very thorough manner a considerable area, remaining alert to the possibility of light and avoiding obstacles that it cannot surmount or push aside. When the photocell sees a light, the resultant signal is amplified by both tubes in the amplifier. If the light is very weak, only a *change* of illumination is transmitted as an effective signal. A slightly stronger signal is amplified without loss of its absolute level. In either case the effect is to halt the steering mechanism so that the machine moves toward the light source or maneuvers so that it can approach the light with the least difficulty. This behavior is of course analogous to the reflex behavior known as "positive tropism," such as is exhibited by a moth flying into a candle. But Elmer does not blunder into the light, for when the brilliance exceeds a certain value—that of a flashlight about six inches away—the signal becomes strong enough to operate a relay in the first tube, which has the reverse effect from the second one. Now the steering mechanism is turned on again at double speed, so the creature abruptly sheers away and seeks a more gentle climate. If there is a single light source, the machine circles around it in a complex path of advance and withdrawal; if there is another light farther away, the machine will visit first one and then the other and will continually stroll back and forth between the two. In this way it neatly solves the dilemma of Buridan's ass, which the scholastic philosophers said would die of starvation between two barrels of hay if it did not possess a transcendental free will.

For Elmer hay is represented, of course, by the electricity it needs to recharge its batteries. Within the hutch where it normally lives is a battery charger and a 20-watt lamp. When the creature's batteries are well charged, it is attracted to this light from afar, but at the threshold the brilliance is great enough to act as a repellent, so the model wanders off for further exploration. When the batteries start to run down, the first effect is to enhance the sensi-



LOW OBSTACLE prevents tortoise from heading straight toward light. Shell is mounted on a switch so that tortoise backs and "feels" its way around obstacle.



MIRROR causes tortoise with indicator light, again exaggerated for clarity, to flicker and jig. The light goes out when tortoise "sees" a light, even its own reflection.

tivity of the amplifier so that the attraction of the light is felt from even farther away. But soon the level of sensitivity falls and then, if the machine is fortunate and finds itself at the entrance to its kennel, it will be attracted right home, for the light no longer seems so dazzling. Once well in, it can make contact with the charger. The moment current flows in the circuit between the charger and the batteries the creature's own nervous system and motors are automatically disconnected; charging continues until the battery voltage has risen to its maximum. Then the internal circuits are automatically reconnected and the little creature, repelled now by the light which before the feast had been so irresistible, circles away for further adventures.

INEVITABLY in its peripatetic existence *M. speculatrix* encounters many obstacles. These it cannot "see," because it has no vestige of pattern vision, though it will avoid an obstacle that casts a shadow when it is approaching a light. The creature is equipped, however, with a device that enables it to get around obstacles. Its shell is suspended on a single rubber mounting and has sufficient flexibility to move and close a ring contact. This contact converts the two-stage amplifier into a multivibrator. The oscillations so generated rhythmically open and close the relays that control the full power to the motors for steering and crawling. At the same time the amplifier is prevented from transmitting the signals picked up by the photocell. Accordingly when the creature makes contact with an obstacle, whether in its speculative or tropistic mode, all stimuli are ignored and its gait is transformed into a succession of butts, withdrawals and sidesteps until the interference is either pushed aside or circumvented. The oscillations persist for about a second after the obstacle has been left behind; during this short memory of frustration Elmer darts off and gives the danger area a wide berth.

When the models were first made, a small light was connected in the steering-motor circuit to act as an indicator showing when the motor was turned off and on. It was soon found that this light endowed the machines with a new mode of behavior. When the photocell sees the indicator light in a mirror or reflected from a white surface, the model flickers and jigs at its reflection in a manner so specific that were it an animal a biologist would be justified in attributing to it a capacity for self-recognition. The reason for the flicker is that the vision of the light results in the indicator light being switched off, and darkness in turn switches it on again, so an oscillation of the light is set up.

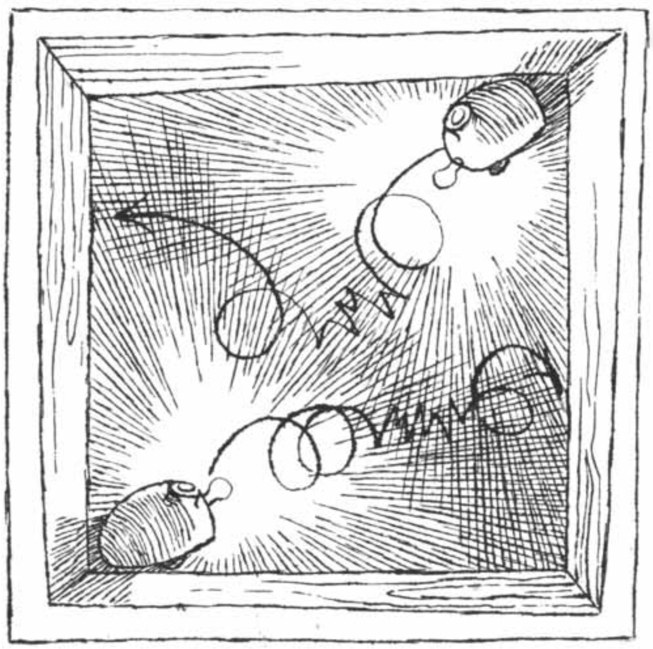
Two creatures of this type meeting face to face are affected in a similar but again distinctive manner. Each, attracted by the light the other carries, extinguishes its own source of attraction, so the two systems become involved in a mutual oscillation, leading finally to a stately retreat. When the encounter is from the side or from behind, each regards the other merely as an obstacle; when both are attracted by the same light, their jostling as they approach the light eliminates the possibility of either reaching its goal. When one machine casually interferes with another while the latter is seriously seeking its charging light, a dog-in-the-manger situation develops which results in the more needy one expiring from exhaustion within sight of succor.

THESE machines are perhaps the simplest that can be said to resemble animals. Crude though they are, they give an eerie impression of purposefulness, independence and spontaneity. More complex models that we are now constructing have memory circuits in which associations are stored as electric oscillations, so the creatures can learn simple tricks, forget them slowly and relearn more quickly. This compact, plastic and easily accessible form of short-term memory may be very similar to the way in which the brain establishes the simpler and more evanescent conditioned reflexes.

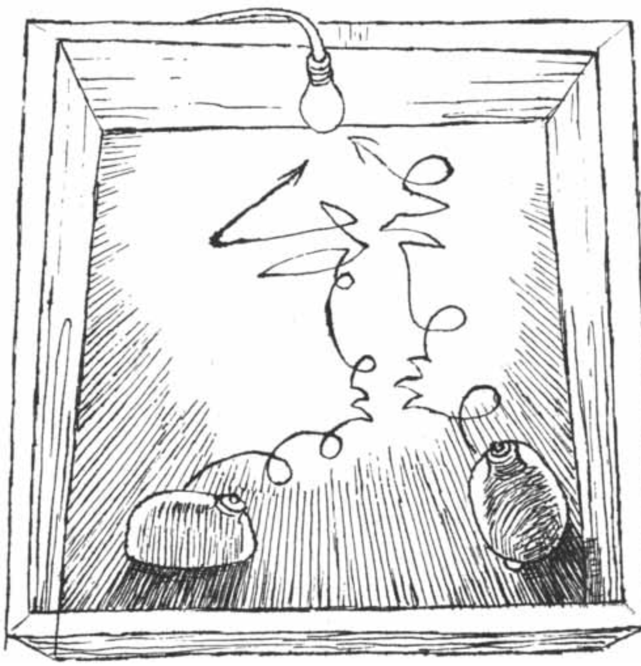
One intriguing effect in these higher forms of synthetic life is that as soon as two receptors and a learning circuit are provided, the possibility of a conflict neurosis immediately appears. In difficult situations the creature sulks or becomes wildly agitated and can be cured only by rest or shock—the two favorite stratagems of the psychiatrist. It appears that it would even be technically feasible to build processes of self-repair and of reproduction into these machines.

Perhaps we flatter ourselves in thinking that man is the pinnacle of an estimable creation. Yet as our imitation of life becomes more faithful our veneration of its marvelous processes will not necessarily become less sincere.

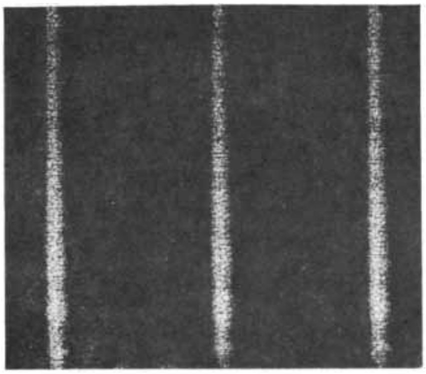
W. Grey Walter is director of the physiological department at the Burden Neurological Institute in Bristol, England.



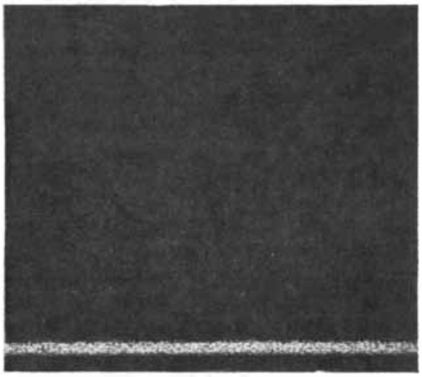
TWO TORTOISES WITH LIGHTS oscillate back and forth until they retreat from each other. The lights flicker as the steering motor of each is turned on and off.



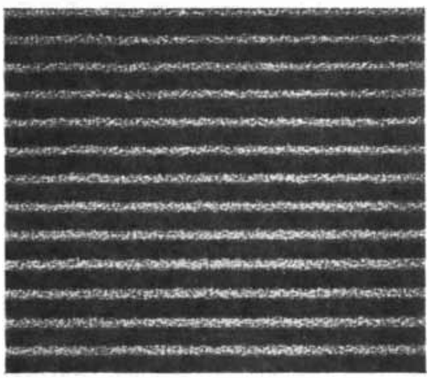
TWO TORTOISES WITHOUT LIGHTS head toward a single light in a jostling manner. When their shells come in contact they briefly back away from each other.



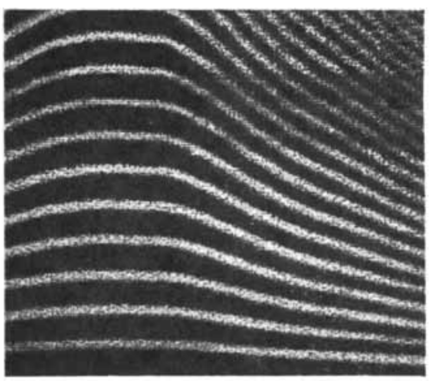
THREE CLICKS appear as three vertical bars on a sound spectrogram.



PURE TONE of 250 cycles a second appears as a single horizontal line.



OVERTONES of a 250-cycle fundamental have equally spaced lines.



DROPPING PITCH causes fundamental and overtones to slant down.

FROG CALLS

The musical patterns produced by various species on a summer night are made visible in traces produced by the sound spectrograph

by Ralph K. Potter

THE night croakings of various species of frogs and toads are highly distinctive, as many a country dweller has noted. Recently 26 frog and toad calls were studied by means of the sound spectrograph, an instrument developed by Bell Telephone Laboratories for the visual investigation of human speech. The calls were supplied by "Voices of the Night," a series of phonograph records made by the Albert R. Brand Bird Song Foundation of Cornell University.

The sound spectrograph converts sounds into pictures called spectrograms that have dimensions similar to those of the familiar musical staff. In these pictures time extends from left to right and the constituents of sound are laid out vertically in the order of their pitch: low-pitched tones at the bottom and high-pitched tones toward the top. The elementary sound patterns at the left will help the reader to interpret the frog-call patterns on the opposite page. Three sharp sounds like the clicks of a bouncing ping-pong ball produce the three vertical bars in the first picture. The time between these clicking sounds is about .15 seconds. In all the patterns the relative strength of the trace is a measure of loudness.

The second picture shows the trace of a single pure tone of 250 cycles a second (near middle C). Ordinarily such a fundamental tone is accompanied by a series of overtones, or harmonics. A 250-cycle fundamental with overtones of nearly equal loudness appears in the third picture. To the ear the pitch of the sounds in the second and third pictures would be the same.

The pitch can also be measured just as accurately when the fundamental is missing from the sound pattern, because the frequency space between any two of the overtones is equal to the fundamental frequency. Thus the spacing of the overtones in the third picture is 250 cycles. When the pitch changes, the overtone spacing changes. In the fourth picture there is a rise in pitch followed by a decrease in pitch—a falling inflection.

The steadiness of these patterns is altered by any harshness in tone quality, resulting from instability in the vocal cords or other sound-generating mechanism. The tone traces become irregular and are even interrupted. Effects of this kind appear in the tone patterns of the human voice when it is "rough" or "harsh" because of the interruption of vocal-cord oscillation by an accumulation of mucus. They are also common in the call patterns of frogs, possibly for a similar reason.

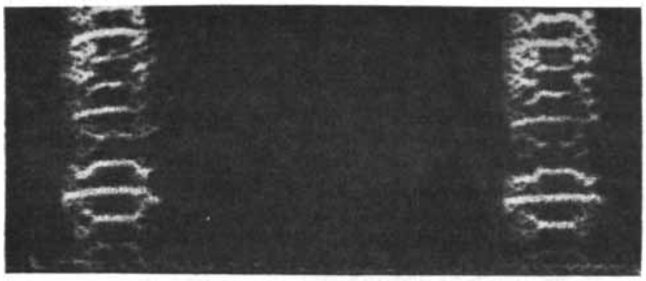
A study of spectrograms such as those on the opposite page reveals some piquant facts. For example, some frogs appear to yodel; at least their voice patterns contain sudden harmonic shifts in pitch that resemble pitch changes in the voices of human yodelers. Such shifts appear at the beginning and end of the Green Tree Toad call and in the second part of the Anderson's Tree Frog call.

There is a rich variety of inflections in frog calls. The Oak Toad pattern reveals a sudden rise of pitch followed by a gradual fall. The Spadefoot Toad also has a peculiar pitch inflection. The pitch starts high and slopes downward rapidly, flattening off toward the end. For some reason such a pitch change has a melancholy sound.

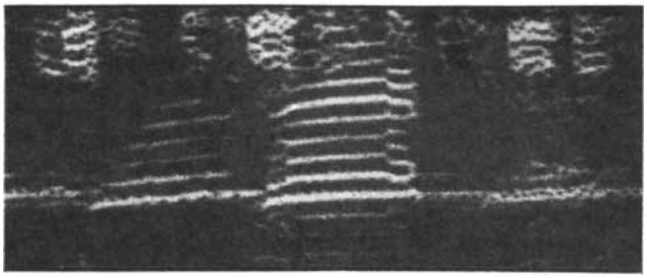
Another call of particular interest is that of the Bullfrog. The Bullfrog's voice is rich in overtone; it is not difficult to find 30 or more harmonics. Generally the tonal quality seems to be rather stable, but occasionally it is garbled so that it sounds as if the Bullfrog has a "frog in its throat."

The pitch of the 26 frog and toad calls varies over a wide range of frequencies. The range of the 26 calls is from 80 to 6,000 cycles a second, and the calls of the species are distributed over this range with remarkable evenness. Furthermore, where two or three species share the same calling band their calls are so distinctly different that they cannot be confused. Apparently an orderly use of the sound spectrum has been worked out in the process of evolution.

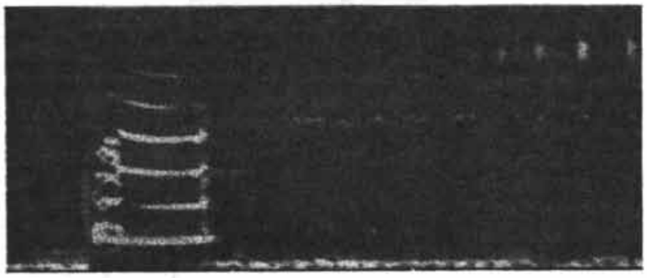
Ralph K. Potter is director of transmission research at Bell Telephone Laboratories.



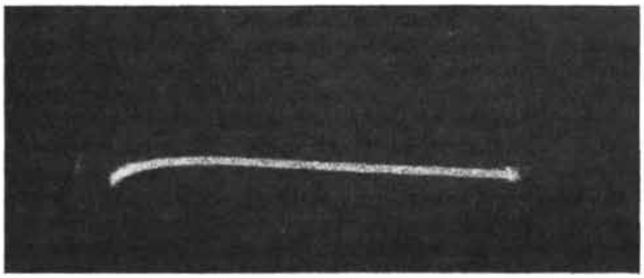
GREEN TREE TOAD (*Hyla cinerea*) makes two calls with yodel-like changes in pitch at beginning and end.



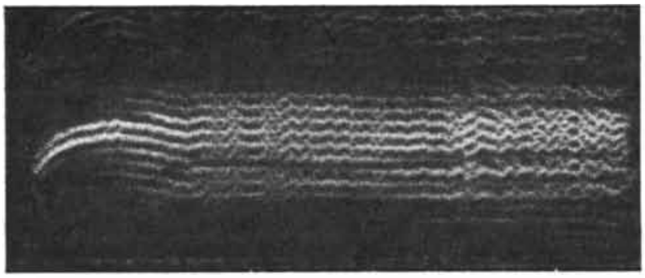
ANDERSON'S TREE FROG (*Hyla andersonii*) has "hee-haw" call. Trace at top is made by cricket-frog.



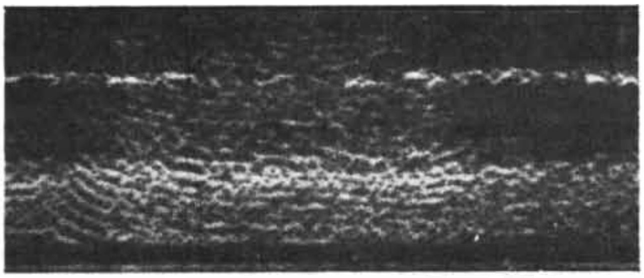
BARKING FROG (*Hyla gratiosa*) call resembles the barking of a dog only in the fact that it begins suddenly.



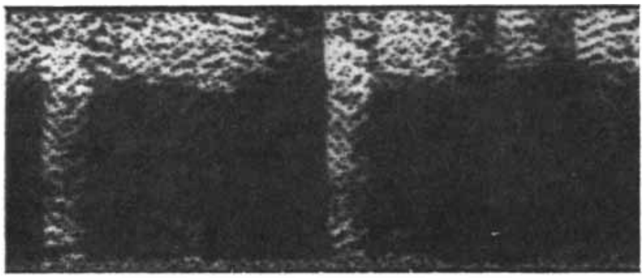
OAK TOAD (*Bufo quercicus*) has a single, high-pitched peep that rises quickly in pitch and falls off gradually.



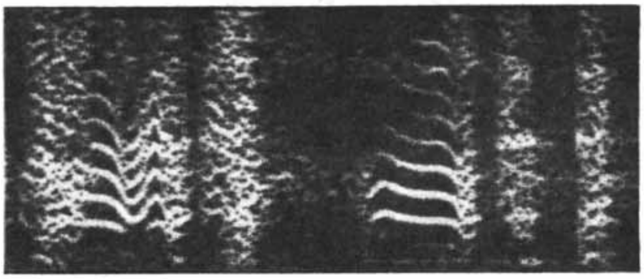
FOWLER'S TOAD (*Bufo woodhousii fowleri*) has call with arched inflection at the start followed by overtones.



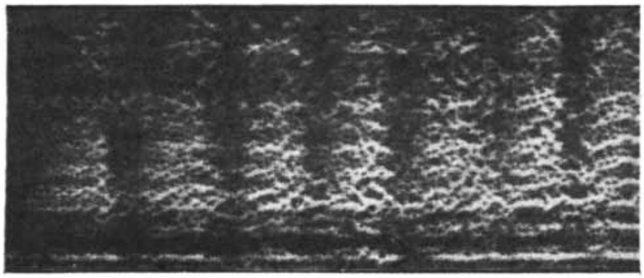
SPADEFOOT TOAD (*Scaphiopus holbrookii*) has a single raucous call. Band near top is a chorus of calls.



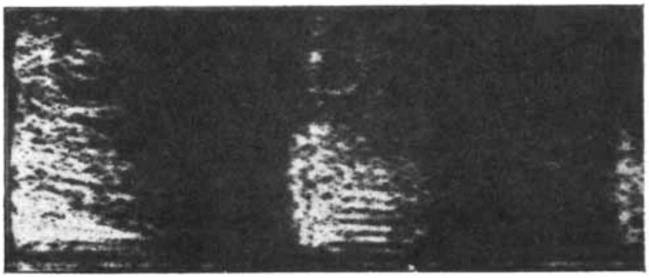
CRICKET FROG (*Acris gryllus*) emits two strong calls. Band at the top is composed of calls in the background.



WOOD FROG (*Rana sylvatica*) has a call that begins in a whine and ends in a cluck. Here two calls are shown.



BULLFROG (*Rana catesbeiana*) gives a deep call. Here the bullfrog call is repeated eight times within a second.



GREEN FROG (*Rana clamitans*) has banjolike call that begins with a sharp twang and fades off into overtones.

Aristotle's Physics

The famed Greek philosopher is recognized as one of the great early zoologists. But what about his reputation as a physicist?

by Carl B. Boyer

PORTRAIT of Aristotle is in 16th-century *Physics.* The inscription: "A true portrait of Aristotle the Stagirite, leader of the Peripatetic school."

FEW SCIENTIFIC reputations have undergone more violent gyrations over the centuries than has that of Aristotle. Aristotle has been to Western culture what Confucius is to Oriental, but his work has not been fully appreciated in all periods. The son of a Macedonian physician, he was born in 384 B.C., went to Athens as a young man and studied with Plato for 20 years. After the death of his master, Aristotle founded his own Lyceum in opposition to the Platonic Academy. His school were known as Peripatetics, from their custom of walking during discussions. When Aristotle died in 322 B.C., he bequeathed to posterity an intellectual system covering most branches of knowledge. His influence dominated the science and philosophy of the ancient world for hundreds of years. Then began a series of cycles in which his ideas were alternately treated with contempt and adulation.

His popularity reached an ebb in the early Middle Ages. The early medievalists were more attracted by allegorical interpretations of Plato's speculations than by Aristotle's glorification of common sense. By the year 1000, however, scholars in Arabia had redeveloped an intense admiration for Peripatetic philosophy, and 200 years later Aristotelian science was rediscovered by the Latin world of Europe. During the earliest years of the 13th century the doctrines of Aristotle were looked upon with suspicion in European universities. Then scholastic philosophers reconciled Aristotelian science with Christian theology so thoroughly that the two soon became well-nigh inseparable. Under the shadow of ecclesiastical authoritarianism there was fostered a sedulous apotheosis of Aristotle; Dante referred to him as "master of them that know." A new cycle began in 1536 when the French philosopher Ramus defended the audacious thesis that "everything Aristotle said is false."

By the time of Galileo and Newton the science of Aristotle had been thoroughly discredited. It became the fashion to ridicule Aristotelian science for its errors, more putative than real. Yet during the 19th century a new upswing in the cycle of Aristotle's reputation once more got under way. "The Philosopher" was rediscovered to be perhaps the greatest zoologist of all time. Aristotelian physics, however, continues to be unappreciated.

In our century the world still knows Aristotle as a great philosopher and biologist. Does his physics deserve the ridicule it receives?

In the modern estimate the physics of Aristotle is completely overshadowed by that of his successor Archimedes, history's most celebrated mathematician and chief ancient rival to Aristotle in scientific greatness. So we may gain some insight into Aristotle's accomplishments in physics by comparing them with Archimedes'. Much, but not all, of what these two wrote has been preserved. Among the surviving Aristotelian works is one entitled *Physics*. The word was used by the Greeks in a sense different from that of today: the Greek *physis*, meaning the essence or nature of things, was more concerned with the explanation of essential properties and relations than with quantitative description.

The *Physics* and other Peripatetic works contain some of the earliest known references to physical laws. It has been said that only three physical laws were correctly known to the ancients: the law of the lever, the optical law of reflection and the hydrostatic law of buoyancy. The oldest of these may well be the principle of the lever, the author of which is unknown. Undoubtedly the operation of the lever principle had been observed at a primitive level of civilization, long before it was clearly expressed. The first quantitative formulation of the principle has been widely attributed to Archimedes, but actually it had been stated at least a century before him in the Aristotelian *Mechanics: As the weight moved is to the weight moving it, so, inversely, is the length of the arm bearing the weight to the length of the arm nearer to the power.* Hence until further evidence is disclosed the earliest formulation is to be ascribed to Aristotle, even though it was Archimedes who dramatically applied the law in his mechanical contrivances and gave it vivid expression in his flamboyant boast that, given an appropriate lever and fulcrum, he could move the earth.

The statements of the principle by Aristotle and Archimedes were very similar, but the explanations they gave were distinctly different. Aristotle was more concerned with the question of speed and facility of movement than with the mathematical relationships between weights and distances. As he put it, in describing a suspended balance: *The same power moves the weight more easily and quickly the further away the fulcrum is.* The law was to Aristotle but an aspect of a more general theory of dynamics. Observation had led him to the plausible conclusion that terrestrial or "local" motions take place under quite different laws from those governing celestial movements. Natural motions on the earth appear always to be rectilinear, directed toward the center of the earth, their "natural place," whereas the natural orbit of a heavenly body is a circle or a combination of circles. For Aristotle, then, local motion in a circle was not natural, but resulted only from the continued application of a force. The more closely circular movement approximated to the natural rectilinear motion, the smaller was the force needed to initiate and maintain it. Consequently it would take less force to move an object along the circumference of a large circle than of a small one. Aristotle therefore reasoned that the longer arm of a lever could be moved more easily than the shorter one because its path came closer to being a straight line.

Archimedes, on the other hand, deduced the law of the lever from a basic principle of statics—the equilibrium of bilaterally symmetric systems. His deduction continues to be valid today, whereas that of Aristotle is vitiated by the untenability of his fundamental assumption. However, Aristotle's point of view continues to be applicable in modified form in the principle of virtual velocities or of statical moment.

THE concepts of center of gravity and of density generally are attributed to Archimedes, but the general notions go back at least as far as Aristotle. A Peripatetic astronomical treatise pointed out: "If, then, a weight many times that of the earth were added to one hemisphere, the center of the earth and of the whole will no longer be coincident." As to the concept of density, predecessors of Aristotle had dealt with "the relative heaviness and lightness of things possessing weight," but Aristotle himself seems to have published the first definition: *Dense differs from rare in containing more matter in the same cubic area.* The Peripatetics recognized that fresh water is less dense than salt water, and that "dense water finds a lower level than water which is not so dense." There is no indication, however, that Aristotle was familiar with the great Archimedean principle, the quantitative law of buoyancy. Aristotle incorrectly ascribed the greater buoying effect of salt over fresh water to the lifting power of salt particles, rather than to the increased fluid density.

Aristotle had a very definite interest in optics, which he included with harmonics and astronomy among "the more physical of the branches of mathematics." In the time of Empedocles, he writes, "there was no scientific knowledge of the general subject of the formation of images and the phenomena of reflection"; but by his own day the study had progressed sufficiently so that Aristotle could speak of "the theory of optics." He himself seems to have composed a treatise on optics, now lost. It is abundantly clear from surviving Peripatetic treatises that "The Philosopher" was acquainted with the law of reflection, both for sight and sound. With regard to the latter he wrote:

"Why is it that the voice, which is air that has taken a certain form and is carried along, often loses its form by dissolution, but an echo, which is caused by such air striking on something hard, does not become dissolved, but we hear it distinctly? Is it because in an echo refraction takes place and not dispersion? This being so, the whole continues to exist and there are two parts of it of similar form; for refraction takes place at the same angle." (The word refraction is of course to be taken as meaning reflection.)

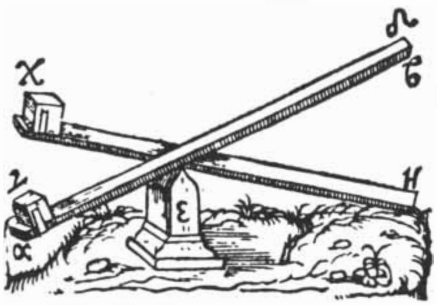
In another place Aristotle specifically states that the causes of the echo, reflection and the rainbow "are identical generically, because all three are forms of repercussion." The recognition of the equal-angle law of reflection in the acoustic case is itself an achievement, and it probably would not have been made without knowledge of the corresponding optical principle. Aristotle compared the reflection of light with a mechanical reflection, remarking that "objects which are traveling along, when they come into collision with anything, rebound in a direction opposite to that in which they are naturally traveling, and at similar angles." As an application of his optical ideas, he also correctly interpreted twilight and the light of dawn as due to the reflection of sunlight by the atmosphere.

The branches of science that were first given mathematical form were astronomy, music and optics, and to each of these Aristotle, although he was not primarily a mathematician, made contributions. Aristotelian cosmology, combined later with elements borrowed from the Ptolemaic system, enjoyed wide popularity in the Greek, Arabic and Latin worlds. Whereas the Pythagoreans had proposed the sphericity of the earth simply on grounds of geometrical perfection, Aristotle presented physical arguments which are still acceptable today. And it is in the works of Aristotle, almost 2,300 years ago, that one finds the first reasonable estimate of the size of the earth: "Those mathematicians who try to calculate the size of the earth's circumference arrive at the figure 400,000 stades [about 40,000 miles]. This indicates not only that the earth's mass is spherical in shape, but also that as compared with the stars it is not of great size."

ARISTOTLE was greatly interested in the numerical aspect of musical harmony, and presented ideas in this field which were more advanced than those of anyone, with the possible exception of Aristoxenus and Ptolemy, before the 17th century. To the Pythagoreans has been attributed the idea that the simpler the ratio of the two parts into which a vibrating string is divided, the more perfect is the consonance of the two sounds. Aristotle saw the operation of the same principle in reed pipes: "In the reed-pipe an accord in the octave is obtained by doubling the length, and this is how flute makers produce it. Similarly they obtain a fifth by means of a length in the ratio of 3 to 2 . . . and a fourth by means of a length in the ratio of 4 to 3."

The works of Aristotle also contain an early recognition of the importance of frequency, noting that "more frequent impacts upon the air are caused by the shriller note," and that "strings which are tightly stretched give a shriller note, for their movement is quicker." Since Aristotle held with Plato that proportion is order, which is naturally pleasant, it followed that "sounds in a concord stand in a proportion of movement to one another." The implication seems to be that the proportions here are the same as those for lengths. This is an anticipation of the relationship between tone and frequency, the discovery of which is usually ascribed to Galileo.

Nevertheless Aristotle (or his students) confused frequency of vibration with speed of transmission, and held to the view of Archytas that the higher the pitch, the greater the velocity of the sound. This would indicate that although Aristotle correctly described sound as a disturbance of the air, he had no idea of periodic vibrations or wave motions which on superposition might produce interference patterns. The analogy between sound and the circular waves formed when a stone is dropped into a tank of water appeared centuries later



LEVERS, which interested Aristotle as well as Archimedes, appear in a 16th-century edition of *Mechanics*.

in the work *On Architecture* by Vitruvius.

Aristotle made an acute observation about the pitch of echoes which was overlooked for some 2,200 years. The British physicist Lord Rayleigh in 1873 believed that he was the first to notice that in echoes the upper components of a complex note predominate, with the result that an increase in pitch frequently is observed. But Aristotle had remarked long before that "the sound of an echo is distinctly shriller," although he failed to note the quantitative relationships that led Rayleigh to refer to the phenomena of differential reflection as "harmonic echoes."

Aristotle's views on the nature of heat and light, like those on sound, have a touch of modernity. With respect to heat he said that "movement tends to create fire in wood, stone, and iron." He rejected earlier suggestions that light was corporeal, or due to visual rays emanating from the eye, substituting instead the idea that it is an activity of a sort of luminiferous aether or quintessence. But his statements, anticipating the kinetic theories of heat and light, remained unconvincing for well over 2,000 years because they had no quantitative basis.

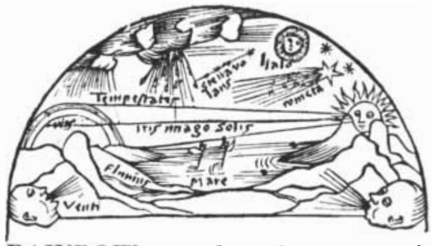
ARISTOTLE ambitiously attempted to explain the nature of color, proposing a theory akin to the one which was to be developed in the 18th century by the poet Goethe. Aristotle took color to be a relationship between, or a mixture of, the basic components white and black, or light and dark. He proposed the first three-element theory of color vision, maintaining that red, green and violet are the only true colors, the appearance of others resulting from contrast. Of the primary colors, he said, red contains the greatest proportion of white and violet the least, but yellow is more closely related to white than is red. Color can result also from a weakening of light energy or activity, so that as the sun sets and is somewhat obscured by haze and smoke it appears red.

One of the most interesting applications of his ideas on color is given by Aristotle in connection with an elaborately detailed theory of the rainbow. Here the pioneer position he holds in science again is exemplified by the fact that his work represents the first serious effort to supply a naturalistic and mathematical explanation of the rainbow, both as to shape and color. He recognized that sunlight and raindrops are both essential in the formation of the rainbow, and that the effect can be produced artificially by the dashing of an oar in water or by other methods of sprinkling water in tiny drops. He knew that the bow is semicircular if the sun is on the horizon and that it becomes smaller as the altitude of the sun increases. He sought to explain the circularity by saying that the observer is at the center of a sphere on which the cloud and the sun lie. He gave extensive geometrical arguments, but his explanation is fundamentally incorrect in that he overlooked refraction as the chief factor; he ascribed the colors and shape of the rainbow to reflection alone.

Aristotle pointed out that lunar rainbows are possible, but that these occur much more rarely, inasmuch as the moon must be full at the same time that all the other conditions for a bow are present. He reported that he himself had seen not more than two lunar bows in over 50 years. (Few semicentenarians of today can boast as many!)

The Aristotelian explanation of the rainbow exhibits a weakness of ancient optics. Whereas the theories of perspective and reflection were extensively studied from the geometrical point of view, the phenomena of refraction were scarcely recognized. It was not until 1637 that Descartes published a relatively satisfactory explanation of the shape and size of the bow, and it was still another generation before Newton disclosed the relationship between refraction and the formation of colors.

IF the significant contributions of Aristotle in the field of statics frequently are overlooked, his work in dynamics seldom escapes unthinking ridicule. Let it be pointed out that in the latter field Aristotle had practically no predecessors, and that it was a field where even the



RAINBOW is explained in terms of reflection by woodcut in a 16th-century German edition of *Meteorology*.

great Archimedes later feared to tread. There was in the Peripatetic approach a point of view that vitiated much of the school's efforts. The Aristotelian dynamics centered on the difficult question of real motions in resisting media, instead of beginning, as did Galileo, with a more elementary study of hypothetical or ideal motions in a vacuum. The air pump for producing a vacuum (*pages 20-24*) was unknown in antiquity, and Aristotle made the plausible assumption that the existence of a void is impossible. The familiar expression "Nature abhors a vacuum" is looked upon with good reason as typically Peripatetic.

There was nothing animistic, however, in the Aristotelian attitude: the existence of the void simply was inconsistent with Aristotle's view of the universe as well-ordered, with each element possessing a natural place. Against the contentions of the Greek atomists, he insisted that there was no random motion. Movement was "natural" in the case of an object seeking its proper place, "violent" if the object was compelled by an external force to move in any other manner. But in a void there could be no such thing as "place" or "proper place," and hence no motion was possible, for there could exist no reason why an object should move in one direction rather than in another.

This position granted, all motion must of necessity take place in a surrounding medium. For this situation Aristotle formulated the earliest mathematical law of dynamics, not in itself unreasonable: namely, that the velocity of an object varies directly as the motive power and inversely as the resisting effect of the medium. He naturally rejected the idea of perpetual uniform rectilinear motion, and developed instead the doctrine that continued motion was possible only through the application of a "force from behind." In this situation velocity—rather than acceleration—was proportional to force, and varied inversely as the density of the surrounding medium. This assumption implied that in a vacuum a body should fall with infinite speed—an obvious impossibility which confirmed Aristotle in his denial of the void.

The Aristotelian law also implied that bodies fall through a resisting medium with speeds proportional to their weights, a conclusion which Aristotle—and later Leonardo da Vinci—accepted, but which, even for terminal or limiting velocities, is not in close agreement with experimental evidence. This discrepancy has appealed so strongly to the modern imagination that it has overshadowed other more valuable portions of Aristotelian physical science. After all, even Galileo in his early treatise *On Motion* committed comparable errors, and in his mature and brilliant work on *Two New Sciences* very inadequate consideration was given to the effects of a resisting medium.

In the works of Aristotle are anticipations of the idea of uniform acceleration, widely but erroneously ascribed to Galileo, as well as a first approximation to the laws of falling bodies: "In rectilinear locomotion [vertically downward] the motion of things in leaving the starting-point is not uniform with their motion in approaching the finishing-point, since the velocity of a thing always increases proportionately as it removes itself farther from its position of rest." This idea that velocity is proportional to the distance fallen was also Galileo's first impression, but he later found that instead it is proportional to the elapsed time.

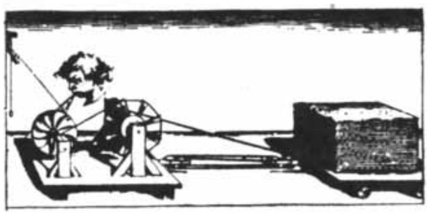
DURING the medieval period the works of Aristotle served as the center of discussions and commentaries on dynamics and other aspects of mathematical science. The ideas of uniform and nonuniform velocities, accelerations and other rates of change were freely used and even represented graphically on coordinate systems. In the course of these discussions some of the weak points of Aristotle's theory gradually gave way to the modern point of view. There had been an element of inconsistency in the Peripatetic idea that the medium through which a projectile moved should be the agent that continued the body in motion. Here the medium was viewed on the one hand as a necessary condition for the motion of projectiles and on the other as a factor impeding the motion. In the sixth century the Aristotelian commentator Simplicius cited with approval the opposing view of the astronomer Hipparchus: that the continued motion of a body, after it has lost contact with the initial impelling force, is due not to a push from the rear exerted by the medium but to an impetus or inertia inherent in the body itself. This new concept of inertia became popular among the scholastic Peripatetics in Paris in the 14th century, and from there it spread to Italy before the days of Galileo. Similarly the view of Aristotle that the speeds of falling bodies are proportional to their weights was refuted by the Peripatetic commentator Philoponus in the sixth century—long before Galileo is said to have performed his experiments from the Leaning Tower of Pisa.

There are Aristotelian passages which are suggestive of the first and third of the so-called Newtonian laws of motion:

Bodies which are at rest remain so owing to their resistance.

When one is running fast it is difficult to divert the whole body from its impetus in one direction to some other movement.

The force of that which initiates movement must be made equal to the force of that which remains at rest. For there is a definite quantity of force or power by dint of which that which remains at rest does so, just as there is of force by dint of which that which initiates movement does so; and as there is a necessary proportion between opposite motions, so there is between absences of motion . . . For as the pusher pushes so is the pushed pushed, and with equal force.



MECHANICAL ADVANTAGE is illustrated in a 17th-century Italian book about Aristotle's *Mechanics.*

The physical science of Aristotle is a coherent and systematic treatment which, while less accurate than that of Archimedes, is of far wider scope. In method there is a striking similarity between these two greatest scientists of antiquity. Both men began with careful observation unaided by the use of instruments, framed inductive generalizations and with these as premises built a deductive science. But while Archimedes, a mathematician, limited himself to a few observations comparable in exactitude to the axioms of Euclid's *Elements* of geometry, the philosopher Aristotle surveyed the whole of nature so that he might disclose the rational order in cause and purpose. For this reason Aristotle placed the inner consistency of his system above accuracy in detail, and in his eager search for certainty he failed to exercise the needed suspension of judgment. At heart Aristotle was a teleologist for whom the question "Why?" held greater attraction than the physicist's query, "How much?" He placed excessive confidence, as Sir James Jeans would have put it, upon "facts as they are revealed by our primitive senses," rather than upon those "revealed by instruments of precision."

It is customary to excuse the armchair physics of the Greeks as due to a deficiency of measuring instruments, but this condonation is perhaps too generous. After all, the ruled straightedge, the graduated water-clock and the scale or balance were well known in antiquity and could have been used to good advantage in physical experimentation. With these alone Aristotle might easily have detected his errors with respect to the speed of falling bodies and the velocity of sound. Had Archimedes used them for experiments, he might well have created a satisfactory science of dynamics.

The failure of the greatest minds of Greece to appreciate the significance of accurate measurement made their work of limited value. Nonetheless, the quantitative aspect of modern science can be traced back to sources springing directly from the Aristotelian tradition. The *Physics* of Aristotle came to Parisian universities in the 13th century, and during the 14th century it became subject to a thoroughgoing reconstruction. Certain qualitative changes, such as the introduction of the idea of inertia, took place, but more important than these was a shift from a qualitative to a quantitative physics. During the 15th century this tendency gained headway, and by the 17th century Johannes Kepler had established the value of precise measurements in formulating his valuable mathematical laws of astronomy. To the oft-quoted statement of Aristotle, "All men by nature desire to know," Kepler added a fitting complement: "To measure *is* to know." Had Aristotle appreciated this, he might have been known as "The Physicist" rather than "The Philosopher." As it was, the physical science of Aristotle is perhaps best described in his own words, engraved on the home of the National Academy of Sciences in Washington:

"Search for truth is in one way hard and in another way easy, for it is evident that no one can master it fully nor miss it wholly, but each adds a little to our knowledge of Nature, and from all the facts assembled there arises a certain grandeur."

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VOLVOX: A COLONY OF CELLS

The microscopic green globe that dwells in ponds is a significant member of the evolutionary line between the one-celled and many-celled organisms

by John Tyler Bonner

WHAT is the meaning of the word "one"? In the simple lexicon of one's early days at school, when the idea is painstakingly planted that two apples plus three apples make five apples, one acquires a clear idea of what "one" means. It means an individual—one individual apple. Later some questions are raised about halves and quarters, and by the time one encounters the problems of infinity, as for instance, the infinite subdivisibility of a line, one is not so sure about how one is to define "one."

Biologists, as well as mathematicians, have such problems. Of course there is no question that a tree or an elephant is one individual, and we have a very clear mental picture of what this means, for we ourselves are individuals. But there are lower forms in the borderland between one-celled organisms and multicellular organisms that are more bothersome in this respect.

A very good example of such an organism is Volvox, a curious inhabitant of fresh-water ponds which is a kind of cross between a plant and an animal. Volvox is a green, sphere-shaped organism made up of a group of flagellated cells. Its basic unit is an ovoid cell with two whiplike flagella protruding from the small end. These cells are bound together in a mass of jelly, and form a slightly elongated sphere about a millimeter in diameter.

The flagella, protruding from the colony like a forest of flails, beat in an organized way to give the whole colony a beautiful spinning motion. It spins like a top around the vertical axis, which is slightly longer than the horizontal axis. Periodically the ball reverses its spin and whirls in the opposite direction. As it spins the colony also glides slowly through the water. It is quite a sight to see a group of these colonies through the low power of a microscope; they suggest a whole planetary system in the small universe of a drop of water, with each spinning green planet gliding through its orbit.

A few minutes' close inspection reveals that the colony has a rather rudimentary differentiation into front end and hind end, or rather north and south pole, with the "front" end at the top. It never turns head over heels but always keeps right side up. The cells in the northern hemisphere differ slightly from those in the southern hemisphere: they are a little larger and have fuller, more intensely green chlorophyll spots. The reproductive cells of the colony always arise in the southern hemisphere.

Now if you cut out any single cell from the colony and isolate it from its neighbors, it will round off slightly into the shape of a teardrop and swim about actively by means of its two flagella, apparently quite undismayed by its solitude. In this state it closely resembles Chlamydomonas, a one-celled form that is considered to be the ancestral type of Volvox. The only deficiency of this isolated cell is that it cannot reproduce and perpetuate itself; after a time it dies.

If the cells can live either independently or in a definitely organized community, which is the individual, the cell or the colony? I suppose one could argue that both are—or that neither is. It depends entirely upon how one defines "individual." The simple word that we have so often used must now, if it is to survive, be chained by a more precise—and more cumbersome—definition. This always follows in the wake of an advance in knowledge, and it is the reason that scientists have collected such large quantities of unpoetic jargon. But we are not quite cornered; there is a way out. We can simply forget the semantic problem and consider the nature of this colonial organism as a step in the evolution of life from simple to more complex forms.

It was the Dutch microscopist Anton van Leeuwenhoek who first saw and described Volvox. His observations are recorded in a series of remarkable letters written in colloquial Dutch (he was not a learned man and knew no Latin) to the English Royal Society. Van Leeuwenhoek, who by extraordinary skill and ingenuity constructed microscopes of very high power, described in a delightful rambling fashion all the new things he could see that had been hidden from the naked eye. In 1700, at the age of 70, he wrote of his discovery of Volvox:

"I had got the foresaid water taken out of the ditches and runnels on the 30th of August: and on coming home, while I was busy looking at the multifarious very little animalcules a-swimming in this water, I saw floating in it, and seeming to move themselves, a great many green round particles, of the bigness of sand grains. When I brought these little bodies before the microscope, I saw that they were not simply round, but that their outermost membrane was everywhere beset with projecting particles [the flagellated cells] which seem to me to be triangular, with the end tapering to a point: and it looked to me as if, in the whole circumference of that little ball, eighty such particles were set, all orderly arranged and at equal distances from one another; so that upon so small a body there did stand a full two thousand of the said projecting particles. This was for me a pleasant sight, because the little bodies aforesaid, how oft soever I looked upon them, never lay still; and because too their progression was brought about by a rolling motion . . ."

Van Leeuwenhoek went on to describe daughter colonies within the mother colony and, even further, daughter colonies within daughter colonies. As we shall see, his observations were quite correct; the only difference between his pioneer description and a modern one is that besides having more observations we also now have elegant names for everything.

A number of people have noticed that Volvox moves toward the light; this property is often quite readily observable in nature. How can the colony achieve an orientation toward the light when it spins constantly about its vertical axis? In 1927 S. O. Mast of Johns Hopkins University found the answer. He showed that the flagella beat in different directions when they are on the shaded and on the sunny sides of the spinning colony. On the sunny side the beat is sideways and merely causes the rotation, but on the shady side the beat pushes away from the colony, giving the colony a thrust toward the light. Since the organism depends on sunlight for food by the process of photosynthesis, the utility of this mechanism is clear. Apparently in the dark of the night Volvox "sleeps"; when deprived of light for a prolonged period, it sinks to the bottom of a dish or a pond.

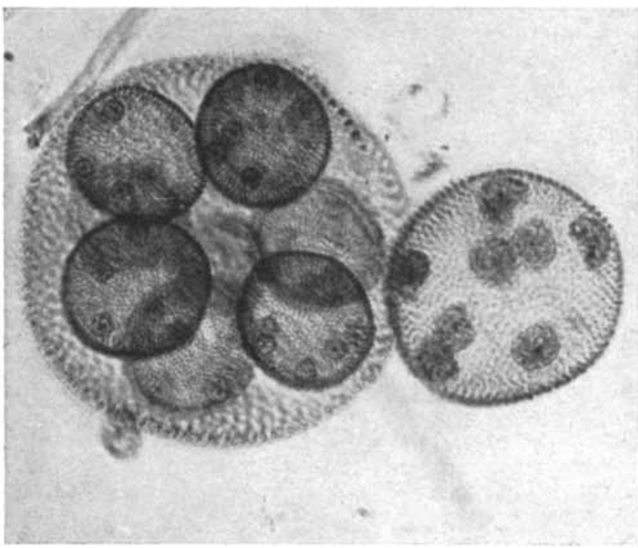
VOLVOX reproduces by both the sexual and asexual methods. In the asexual process certain cells in the lower half of the colony become enlarged and begin to divide. The daughter cells formed from each original cell all lie in one plane and would form a sheet of cells if it were flattened out, but they are held together like the mouth of a purse with the strings pulled tight. As the cells continue to divide, they bulge inward to form a pocket—the daughter colony. The total number of cells in each daughter colony varies, depending on the species, from around 500 to 50,000 cells. Apparently during this dividing process very little if any growth of the total colony takes place, so the dividing cells become progressively smaller and are closely packed in the daughter sphere.

Now this process places the daughter colonies in an awkward position. The flagellar ends of their cells—those from which the flagella are destined to come—are turned inward, which means that the future flagella would sprout on the inside of the daughter colony. Such an arrangement would be all wrong from the standpoint of the colony's locomotion; it would be like having the propeller of an airplane madly churning the air inside the cabin.

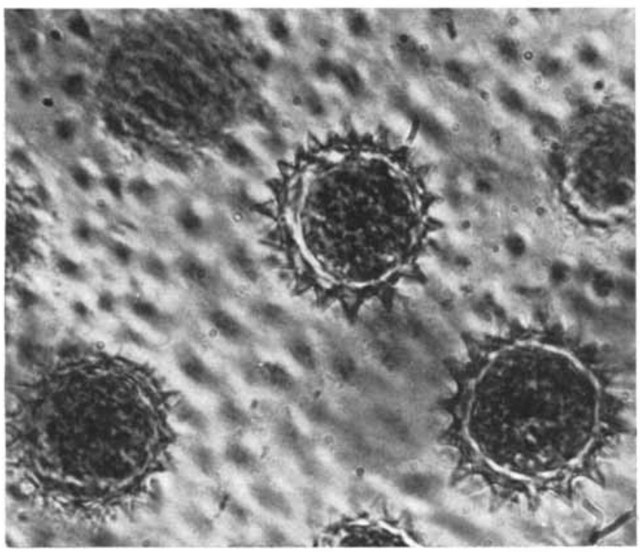
Nature solves this topological problem in a simple and satisfying manner by doing what obviously needs to be done: it turns the spherical daughter colony inside out. The sphere has a hole at the point where it touches the mother colony; the hole is called the phialopore. If you had a tennis ball with a round hole the size of a nickel cut somewhere in it, you would have a fair model of the colony. Now take the ball and push in the wall opposite the hole; with a little struggling you may be able to turn the tennis ball inside out by pushing it through the hole. This is precisely what the daughter colony does. In the course of an hour or so it turns itself inside out —without assistance, of course. First one can see a preparatory crinkling of the walls, and then it suddenly inverts. In doing so it frees itself from the mother wall: its phialopore end becomes the south pole; it sprouts flagella that point outward; and the colony begins to swim about merrily inside the mother. Eventually the aged mother, no longer capable of holding its kicking brood, splits open to die and gives birth to the young colonies, which rush out into the world.

This process of turning inside out, or inversion, is not unique with Volvox. As Libbie Hyman of the American Museum of Natural History has pointed out, inversion is also found in the primitive sponges; she suggests that the sponges and Volvox might have come from a common stock. And indeed it is well known that all other animals go through a comparable process during their embryonic development—the process called gastrulation. Gastrulation often resembles inversion, except that instead of turning completely inside out the embryo stops halfway and forms a half-sphere two cell-layers thick; it is as though a tennis ball collapsed into a half-sphere. The inner layer becomes the digestive canal, and the outer one the skin and nervous tissue. It would be rash to say that gastrulation and inversion are necessarily related; the two processes may well have arisen independently. Nevertheless one may speculate about the possibility that the mechanisms involved are actually similar. At present neither process is really understood.

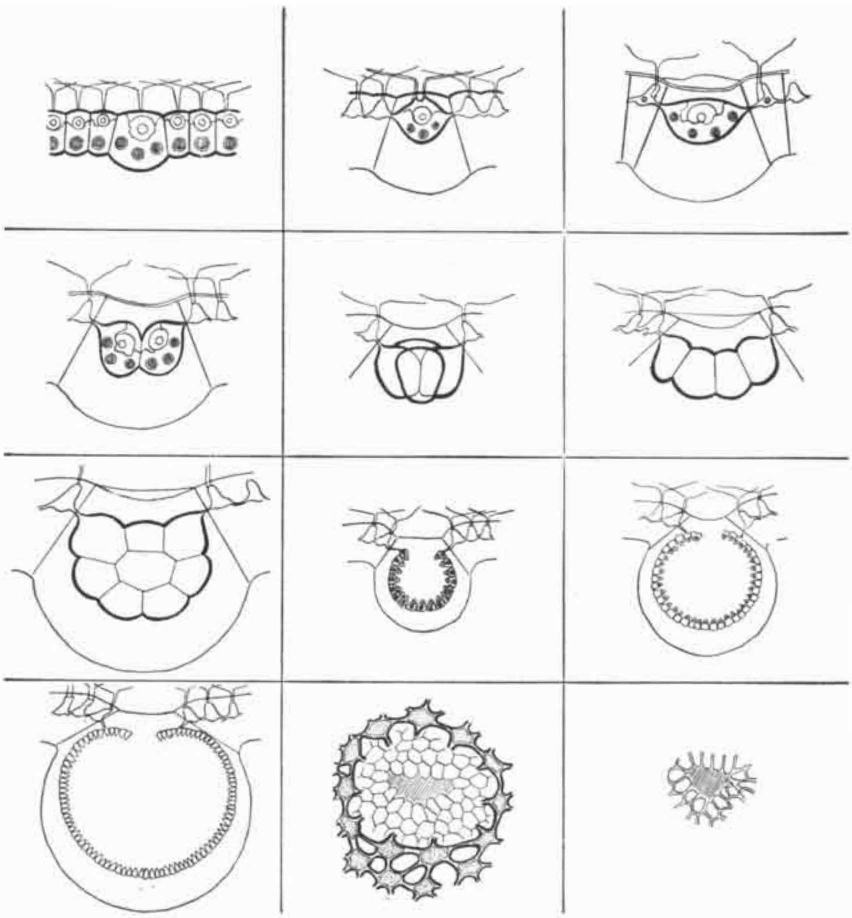
THE most beautiful and detailed account of Volvox, including its process of inversion, has been given by Mary A. Pocock of Rhodes University College in Grahamstown, South Africa; much that I write here has its origin in Dr. Pocock's papers. Of the discovery of inversion she says: "It is hardly creditable that in so well known an organism as Volvox, which has been investigated again and again during the last two centuries, a phenomenon so striking as that of inversion of daughter colonies should have been completely overlooked. Yet such is apparently the case. No mention of it can be found in the extensive Volvox literature until Powers (1908) recorded its occurrence in his description of species of Volvox from Nebraska, and photographed some of the stages." It was not until the 1920s that biologists



MOTHER COLONIES of ***Volvox globator*** are filled with daughter colonies. Magnification: 200 diameters.



DAUGHTER COLONIES of ***V. globator*** at an earlier stage than those at left are magnified 1,000 diameters.



DEVELOPMENT OF DAUGHTER COLONY begins with cells dividing to form an inward bulge on the wall of the mother colony (*first three drawings*). Daughter colony finally becomes a hollow ball (*next seven drawings*). Last two drawings show structure of opening through which colony inverts.

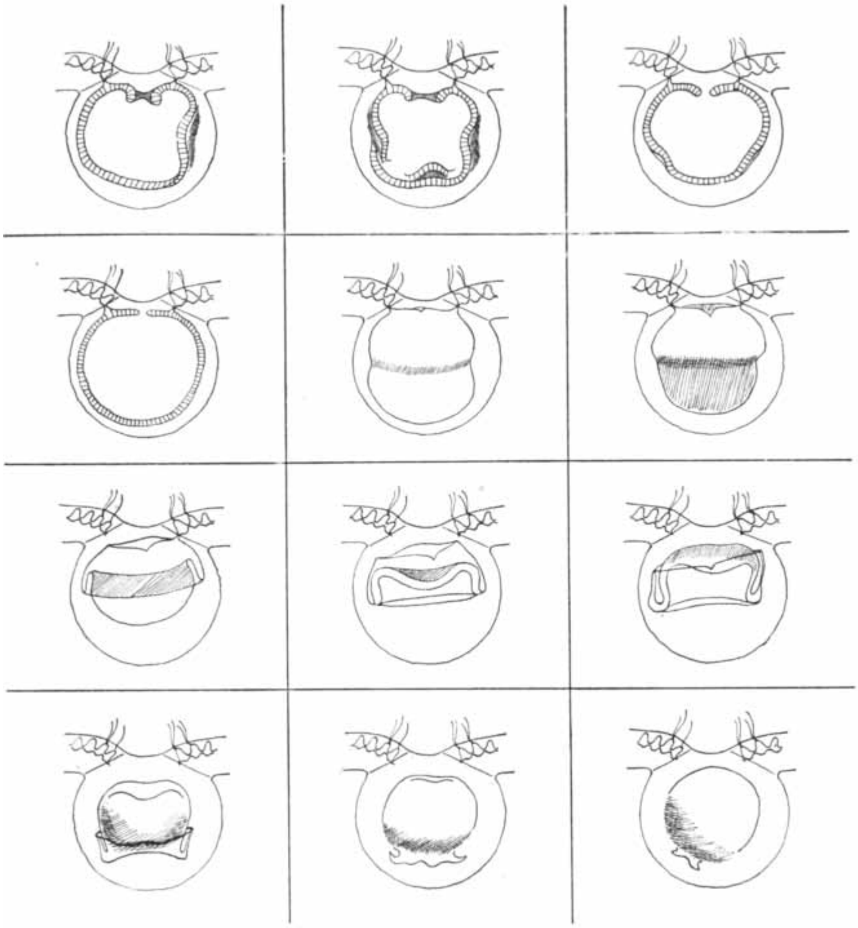
finally obtained a clear picture of the process. It was then found in other forms related to Volvox. It is my impression, however, that even today there are more biologists who have never heard of inversion than there are who have.

Sexual reproduction of Volvox follows after a period of asexual division. The asexual process described above occurs at the beginning of warm weather in the spring and may last for some time. Often, as van Leeuwenhoek saw, there will be daughter colonies within daughter colonies—three generations not yet separated. Then suddenly sexual colonies begin to appear. In some forms of Volvox separate male and female colonies develop; in others the colonies are hermaphroditic.

In the genesis of a male colony the cell that is to form the sperm, like the cell that forms a daughter colony in asexual reproduction, first grows larger than its neighbors. It divides similarly by successive bipartitions and soon develops into an inward bulge of many small cells. Also—and this is quite remarkable—this sphere of future sperm cells undergoes inversion exactly as the asexual colonies do. By the time inversion is complete, each cell has sprouted two very long flagella and the sperm ball begins to move. After some time it pushes its way gently through the wall of the "father" colony and liberates itself. The sperm then separate from one another and swim about freely.

On the other hand the young cells that are to become a female colony (essentially an egg) do not divide; starting as cells slightly larger than their neighbors they enlarge still further until they are ready for fertilization. Unfortunately the fertilization itself has never been observed, despite all the work done on Volvox and despite painstaking and repeated attempts by Dr. Pocock to detect it. There is no question that it must take place, but it is hard to see.

The fertilized egg drops deeper into the colony away from the surface and develops a hard, spiny outer coat. This covering, resistant to adverse conditions, is responsible for the survival of the species, for it enables the egg to survive the winter or the drying up of a pond. Once these resistant fertilized eggs or oöspores are formed, the weather may do what it wishes. The colony will soon die, but these little strongboxes will settle down in the mud to wait for better conditions. When spring and the first warmth comes,



INVERSION OF DAUGHTER COLONY proceeds while it is still attached to the wall of the mother colony. Through various stages the daughter colony pushes through opening at top to turn itself inside out. In this way cells are arranged so that cilia that propel organism develop on outside of colony.

the oöspores split open and their contents emerge. After a period of enlargement and internal changes the egg peels off still another jacket and finally emerges as a naked, biflagellate cell.

Soon this cell settles down and begins to divide. In a short time it produces a sphere of cells, all sticking together. It is a juvenile form, containing fewer cells than one would expect of Volvox, but it is Volvox, sitting free and alone. This ball, true to form, turns inside out and becomes a miniature, spinning version of the organism. The next generation, which is asexual, produces larger colonies, and by the third generation the organism reaches its normal adult size.

THE aspect of Volvox that catches the imagination is that we have a group of what appear to be simple cells, and that these cells have in some way cooperated with one another to form an organized colony. How does it come about that such single cells can produce an obviously communal effort? One might argue that the cells are not really "single," since they are joined by fine protoplasmic connections that might enable them to communicate with one another readily. But this is no explanation, nor is it actually true, for some forms lack these connections during a good part of their life cycle.

The fact remains that these single cells show considerable division of labor: there is an upper and a lower end to the colony, each with cells slightly different in appearance, and only in the lower portion do cells arise that can reproduce asexually or produce sperm or eggs. Then there are the coordinated swimming movements of the colony and the wonderfully coordinated process of inversion. The pattern of growth itself—the invariable production of a colonial sphere—also shows some degree of organization.

We can only marvel at how these simple flagellated cells can be so clever. It is my conviction that if we could solve this mystery and discover the mechanisms whereby coordination is achieved in such low forms as Volvox, we would be a long way toward understanding how complex integration occurred in the evolution of higher forms.

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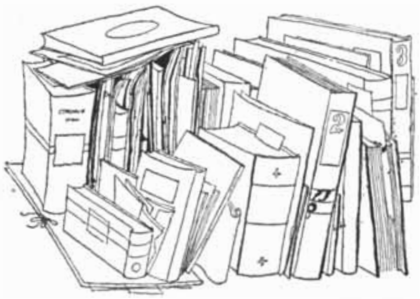


BOOKS

A remarkable book about Einstein, written by the subject and his colleagues in physics

by Sir Edmund Whittaker

ALBERT EINSTEIN: PHILOSOPHER-SCIENTIST, edited by Paul Arthur Schilpp. The Library of Living Philosophers, Inc. ($8.50).

THE publication of this book is an event of major importance for philosophy and science. It will not escape notice that of the seven eminent men who have been the subjects of volumes in *The Library of Living Philosophers,* no fewer than three (Whitehead, Russell, Einstein) began life not as philosophers but as mathematicians. Indeed, the work of Einstein as a mathematical physicist so far surpasses in importance any contributions he has made to philosophy that his selection for inclusion in the series may perhaps cause a moment of surprise. But the editor has made a wise choice: this work will be of the highest interest and value even to the professional philosopher, for it is not an account of Einstein's researches such as might have been written by a purely scientific disciple, but a penetrating discernment of their source. It shows how his discoveries sprang from a conception of the universe that was derived ultimately from his religious and philosophical outlook.

Albert Einstein was born at Ulm in Germany on March 14, 1879. His parents were Jewish, but nonobservant of their religion. From a deeply interesting autobiographical fragment we learn that at a very early age the boy's religious nature became dissatisfied with the spiritual emptiness of his surroundings; seeking for something deeper, he attached himself ardently to the faith of his people. But the character of his education changed this feeling. In his early years his education was very irregular, owing chiefly to changes in domicile brought about by the circumstances of his father's business: the family moved between Germany, Switzerland and Italy, and each successive move involved an awkward discontinuity in the school curriculum. Thrown very much on himself, he took to reading popular books of science and general knowledge, and from some of these he acquired the opinion that fact cannot easily be separated from legend in the framework of Jewish history. As a result what he later referred to as "the religious paradise of youth" was lost to him. He retained an affectionate loyalty to Judaism and accepted its ethical teachings, but he conceived of it no longer as a transcendental religion but as a moral attitude to life.

Transcendental belief came to him from another source. His imagination was stirred by the picture of nature existing independently of human beings and presenting for solution an eternal riddle, which yet was rational and therefore in principle soluble. This now became the center of his religion. "I believe," he declared, "in Spinoza's God, who reveals himself in the harmony of all being, not in a God who concerns himself with the fate and actions of men."

The conception of a God who is the author of the reign of law in the universe, but who takes no interest in the human race, has had a long history: it goes back beyond Spinoza to Aristotle, in whose system the Prime Mover caused the rotation of the outermost heavenly sphere, and so of all that lay within it, but was indifferent to the affairs of humanity. That this view should be adopted in the 20th century by a man of Einstein's intellectual distinction is profoundly significant. It induced in him what he calls a "cosmic religious feeling," that is, a belief in the possibility of interpreting nature in terms of a mathematical system of great beauty and simplicity. This is the spiritual background of his mature intellectual achievements.

It was in 1905, when Einstein was 26, that the world of science first became aware of his genius. In that year he wrote three papers, all printed in the same volume of the *Annalen der Physik,* any one of which would have sufficed to place him in the front rank of theoretical physicists. The first paper, on the action of ultraviolet light in ejecting electrons from a negatively-charged metallic plate, occupies in the history of quantum theory a place second only to Planck's original discovery of the quantum of action. The second, which explained the irregular thermal motion of microscopic particles suspended in a liquid, provided a striking verification of the kinetic theory of matter, and actually convinced doubters such as Mach and Ostwald. The third was the famous paper that created the Special Theory of Relativity. For the next 12 years a continuous succession of discoveries poured forth. It is possible to trace with some degree of assurance the way in which, under the inspiration of his "cosmic religious feeling," Einstein developed the theory of knowledge which issued ultimately in his most characteristic and best-known creation, the General Theory of Relativity.

How do concepts such as those that constitute natural philosophy originate? The narrower school of British empiricists might say that they are all derived from experience, by the methods of abstraction and induction. But Hume himself saw that they cannot be obtained from the data of experience by any strictly logical procedure, and Kant went much further. Impressed by the belief (universal in his day) that Euclidean geometry was perfectly correct and that the axioms on which it was founded were self-evident antecedently to all experience, Kant thought that there are certain truths—such as those of geometry—which we derive from reason alone, and which have an absolute validity. Einstein recognizes that this Kantian doctrine was overthrown by the discovery of non-Euclidean geometry, but as against some of the British empiricists he maintains that the concepts and categories, by the aid of which we construct science out of the data of experience, are themselves not derived by abstracting from experience but are the free creations of human thought.

He believes, then, that there is a spontaneous activity of the mind, altogether apart from experience, which can make contributions of the utmost value to natural philosophy. The method by which this is most effectively accomplished is to find systems of mathematical equations that satisfy certain conditions. One such condition is that the meaning of the equations shall not be affected by any arbitrary change in the choice of coordinates. Another condition is simplicity: he has (as Kepler had) a half-mystical belief that the simplest equations are the most likely to be true. Still another condition is that in special limiting cases the new equations should reduce to equations already known to be valid in those cases; for example, the equations proposed for any new theory of gravitation must yield the equations of the Newtonian theory as a limiting case.

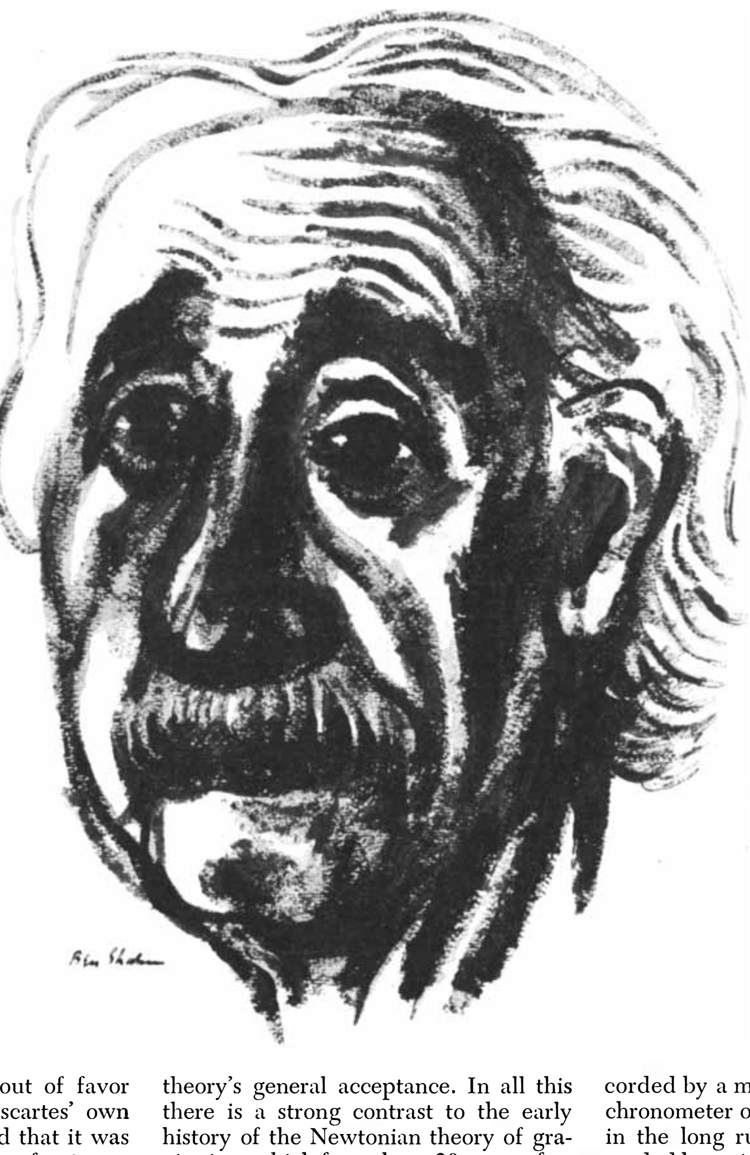
It might be expected *a priori* that conditions such as these would be insufficient to determine completely a new theory of nature. Thus the theory actually created by Einstein, the General

Theory of Relativity, was an unexpected and marvelous achievement. Such a theory must, of course, be tested by comparing its predictions with experience, but the point is that the whole of a creative work of this kind has to be done in the region of mathematical thought, and that the confrontation with observational facts is a subsequent operation, which may even have to be postponed owing to the lack of the required data.

It will be seen that Einstein's philosophy of scientific research bears a strong resemblance to Cartesianism. Descartes' predecessors—Tycho Brahe, Kepler, Galileo—had all taught that true knowledge can be acquired only piecemeal, by the patient interrogation of nature. Descartes, on the other hand, put forward an all-embracing theory of the universe without waiting to study its processes in detail; he laid down certain general principles, such as that bodies can act on each other only when they are contiguous, and trusted that the clarity of his explanations would secure their acceptance, leaving the question of their agreement with observation to be settled by his successors. Einstein likewise presented his theory as a somewhat speculative deduction from general principles, not as an induction from experience. He pointed out, however, that it led to some consequences that were not involved in the Newtonian theory, and he invited the practical astronomers to test them.

Einstein was well aware that the Cartesian procedure had been out of favor ever since the ruin of Descartes' own cosmology, and he admitted that it was unsuited to the early days of science, when very few facts had as yet accumulated. But he claimed that, when the aggregate of detailed knowledge had become very great, the mathematical imagination could take its rightful place and construct an all-embracing system which was unattainable by mere induction and which perhaps even possessed only scanty, difficult and remote contacts with observational data.

When the General Theory of Relativity was first published and expounded in the years 1915-1920, there was very little opposition to it. Probably most mature physicists reacted unfavorably, but they knew that they could not hope to understand it without serving a tedious apprenticeship to tensor calculus, so they remained silent. Almost the only man of eminence who expressed himself adversely was Heaviside, who (referring to the curvature of space-time) denied that anything could come out of "Einstein's distorted nothingness." The advocacy of Eddington, then already in the front rank, helped greatly to secure the theory's general acceptance. In all this there is a strong contrast to the early history of the Newtonian theory of gravitation, which for at least 20 years after its publication was rejected by practically every natural philosopher on the European Continent, and was not even taught officially in Newton's own University of Cambridge.



During the past 20 years the prestige of the General Theory of Relativity has perhaps declined somewhat, for several reasons. In the first place, it has become clear that General Relativity does not stand alone but is a member of a family of theories that have many features in common. In this family the most serious rival to Einstein's theory is E. A. Milne's theory of Kinematic Relativity. It is set forth by Milne himself in an article, "Gravitation Without General Relativity," in the volume under review.

Milne's and Einstein's theories are both in the tradition of Descartes rather than that of Galileo. There are, however, notable differences between them. The point at which they diverge is that whereas in the General Theory of Relativity *all* observers are equivalent, in Kinematic Relativity only those observers are assumed to be equivalent who are similarly related to the large-scale distribution of matter and motion in the universe. Now it appears from observation that the matter of the universe is concentrated into galaxies, which are approximately homogeneously distributed and which are apparently receding from one another with velocities proportional to the distances separating them. Observers situated at the nuclei of galaxies therefore would all be similarly related to the large-scale distribution of matter and motion in the universe, and in Milne's theory only such observers are equivalent.

In developing these ideas Milne builds up a complete theoretical physics from first principles. He does not assume the Lorentz formulae or any properties of light as Einstein does. In fact, he gives to all the laws of nature the character of theorems *deduced* from the defining axioms. Many of these theorems are startling. Thus it is found that the time (τ) recorded by a molar timekeeper such as a chronometer or the rotating earth differs in the long run from the time (t) recorded by a timekeeper based on atomic processes, such as a radioactive clock. The first, τ, is the time of Newtonian dynamics; that is, in terms of τ a particle moving under no forces has a constant velocity, and the Newtonian constant of gravitation remains permanently constant in time. In τ-time the age and volume of the universe are both infinite; in t-time, on the other hand, the universe is finite in volume, is expanding, and is aged only about 2×10^9 years. In both systems of time the galaxies would show a red shift in their spectra, but for totally different reasons. In all this it must be remembered that the description in τ-time and the description in t-time are simply two different descriptions of the same physical entity.

Thus in Milne's theory there is a particular instant of t-time which has a preferential character, namely the instant of what we may call the Creation. In Einstein's theory there is no such preferential instant. Milne's work, like Einstein's, is a wonderful intellectual feat; one may doubt whether the world has ever seen more brilliant displays of mathematical power. After reading Milne's article, one naturally turns to Einstein's "Remarks to the Essays Appearing in this Collective Volume" to see what Einstein has to say about it. The one great disappointment of the whole book is that Einstein says nothing beyond five lines of rejection.

We have now to consider whether in the case of either General Relativity or Kinematic Relativity the link with observed fact is strong enough to compel acceptance.

As to General Relativity, it must be said that some of the observational confirmations do not now appear to be so secure as they were thought to be a few years ago. One of the most important of them was the bending of light rays when they pass near a large gravitating body such as the sun. This phenomenon was observed at the eclipses of May, 1919, and September, 1922, with results which were considered to verify Einstein's predictions. But at the eclipse of May, 1929, the agreement was not satisfactory, and a re-examination of the 1922 measurements has raised further doubt. It is to be hoped that the eclipses of 1954 and 1955 will decide the matter. Another effect predicted by Einstein was that when rays of light are emitted by a source situated in a strong gravitational field, they should be displaced toward the red end of the spectrum. This was believed to be established by certain solar observations. But some recent work on the sun, *e.g.*, that by M. G. Adam of Oxford, has not been confirmatory.

If the position of General Relativity as regards observational verification is somewhat unsatisfactory, that of Kinematic Relativity is still more so. It is not even known whether Kinematic Relativity can account for the anomalous motion of the perihelion of the planet Mercury, which is explained in an unquestionably satisfactory way by Einstein's theory.

It must be said that even if the phenomena predicted by General or by Kinematic Relativity were found to occur, we should still not be able to regard the theories as logically demonstrated, for it is possible that other theories could give the same predictions. Indeed it is conceivable that General Relativity and Kinematic Relativity will be found to make identical assertions with regard to the very few observable effects that can be deduced from them.

The appeal of General Relativity (and of Kinematic Relativity also) has been further weakened by the growing doubt as to whether continuous differential equations in four-dimensional space-time can possibly provide a solution of some of the problems of quantum theory, such as those relating to the time of decay of a radium atom. This is a point of capital importance, which has been the subject of many papers published in recent years. Einstein takes one side, holding that the world can be completely described by a field theory of the type of General Relativity, which is rigidly deterministic. Most other theoretical physicists, particularly Max Born, Niels Bohr and Wolfgang Pauli, maintain on the contrary that in microphysics strict causality must be abandoned.

There is a lot about the controversy in the volume under review. Born, in a particularly well-written article, describes Einstein's discoveries in quantum theory with warm appreciation but adds: "Yet later, when out of his own work a synthesis of statistical and quantum principles emerged, which seemed to be acceptable to almost all physicists, he kept himself aloof and sceptical. Many of us regard this as a tragedy—for him, as he gropes his way in loneliness, and for us who miss our leader and standard-bearer." The article following this, by Walter Heitler on "The Departure from Classical Thought in Modern Physics," is a carefully reasoned exposition of some of the principles that Einstein rejects. After this comes an interesting recital by Bohr of his personal contacts with Einstein and of the discussions that culminated in the present situation. There are further thoughtful discussions of the problems involved in Einstein's outlook on this and other questions by many of the best American and European theoretical physicists and philosophers. The essay by H. P. Robertson on "Geometry As a Branch of Physics" is in a somewhat different category, being a masterly treatment of the physical doctrine of the curvature of space, to which Robertson himself has made outstanding contributions.

Ilse Schneider discusses Einstein's attitude toward the question as to whether the numerical constants of nature (such as the ratio of the gravitational to the electric force between two electrons, or the ratios of the masses of the elementary particles) can be derived in a purely epistemological way, without dependence on observation and experiment. Eddington believed that they could, and in fact devoted the later years of his life to their actual calculation. Einstein expresses his own position thus: "I would like to state a theorem which at present cannot be based upon anything more than upon a faith in the simplicity, *i.e.*, intelligibility, of nature: there are no *arbitrary* [dimensionless] constants; that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur [not constants, therefore, whose numerical values could be changed without destroying the theory]."

The most valuable contribution in the whole book is unquestionably Einstein's autobiography, which occupies the first 95 pages. It is a natural and fascinating description of the growth of his ideas, and makes clear many points that have hitherto been obscure. For instance, Einstein tells us that by 1908 he had already discovered the fundamental ideas on which the General Theory of Relativity is based: (1) the strict equality of inertial and gravitational mass, and (2) the principle that the laws of physics must be covariant with respect to *non-linear* transformations of the coordinates in the four-dimensional continuum. Why, then, did it take him seven years more to construct the General Theory? The main reason seems to be that it took all that time to free himself from the idea that coordinates must have an immediate metrical meaning.

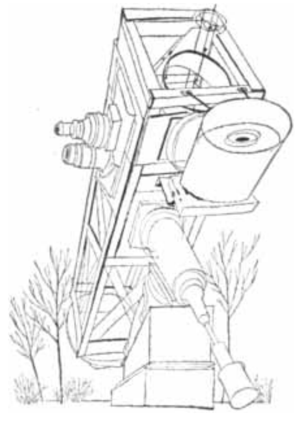
During the last 30 years he has never relaxed in his purpose of generalizing and completing the General Theory of Relativity by bringing electromagnetic phenomena within its scope. Quite recently he has discovered what he believes to be the right way to do this, and has himself explained, in the April issue of SCIENTIFIC AMERICAN, the principles on which it is based. May we express the hope that he may be spared to bring this latest creation of his genius to a happy and perfect completion.

Sir Edmund Whittaker is professor of mathematics at Edinburgh University.

BACKGROUNDS OF POWER, by Roger Burlingame. Charles Scribner's Sons ($5.00). This book puts on an air of examining the sociological and philosophical implications of the use of mass-production methods. In actuality it is an informal and interesting, if somewhat overlong, history of certain aspects of the development of mass-production and assembly-line techniques. Its most notable addition to this history is its description of some of the lesser-known contributions. Thus it points out that Cyrus McCormick's idea of installment selling was almost as important in the history of economic development as his invention of the reaper. As Burlingame trenchantly remarks, one of the factors that vitiated Karl Marx's prediction that the laboring class would be steadily impoverished is the ability of mass-production workers to buy the things they produce, notably demonstrated in the U. S. Another major advance was Andrew Carnegie's continuous strip mill, which in one unbroken series of processes under a single roof performs the complete operation of transforming raw material into finished product. For the rest, the book rescues from obscurity many an inventor and engineer who by advancing machine technology had more effect on history than much better-known soldiers or statesmen. Among these were the English toolmaker Maudslay, who first made uniform screws and bolts, and the American Oliver Evans, who originated what might be called the first fully automatic factory (a flour mill). The book reminds us how far back the idea of the assembly line goes (apparently to 1438) and how many individuals participated in the development of that complex and marvelously efficient method of production, of which the first wholly integrated and great exemplar was Henry Ford's River Rouge plant. Burlingame's book ends on the hopeful note that the abandonment of the Model T and the recent development of flexibility in mass-production methods portend a break away from the uniformity—and conformity—which characterized not only the things made by these methods but the people who bought them.

ONE HALF THE PEOPLE, by Charles Morrow Wilson. William Sloane Associates ($4.00). The theme of this book is as important as any could be: the shocking state of the world's health. ("One and a half to two billion people out of a total of two and three quarters billions are sick.") By means of vivid anecdotes and lively thumbnail sketches of native African or Amerindian doctors, Wilson tellingly brings home his point that in every part of the world, and particularly in the tropics, adequate medical care is conspicuous by its absence. Nor does he neglect his own country, listing our deficiencies, particularly in rural areas, and hitting at the enormous waste resulting from the fact that 70 per cent of U. S. expenditures on medicines go for proprietaries, not to mention the questionable value of the hundreds of millions spent annually on packaged vitamins. On health insurance Wilson takes no stand, being content to state the pros and cons. His criticism of our present health organization would have been even more telling if he had called attention to the limitations on entry into medical schools, as a result of which we have fewer medical students in proportion to our population today than we had 20 years ago. This book is distinctly intended to be "popular," making no attempt to be scientific or complete, yet there is no need for a popular book to be so poorly organized. T. N.

THE AMATEUR



Conducted by Albert G. Ingalls

ABOUT a year ago a number of 16-inch Pyrex glass blanks were offered to the readers of this magazine at a fraction of the market price. Within a short time the last of more than 400 blanks had been sold, two thirds of them to amateur telescope makers throughout the nation. One might assume that each purchaser at once started grinding a mirror, and that perhaps 250 16-inch telescopes emerged at the same time. A few of those who bought the blanks indeed began to work soon after receiving them, but it takes a long time to complete a 16-inch telescope. A majority are holding the blanks until they gain experience with smaller mirrors.

Some of those who own the 16-inch blanks have asked for suggestions about working them. Four methods will be discussed: face down against equal-diameter tools, (1) by hand and (2) with the Hindle machine; and face up against subdiameter tools, (3) by machine and (4) by hand.

Since a 16-inch blank weighs about 50 pounds, the first method would prove strenuous. The glass tool should be channeled as described by Fred Ferson in *Amateur Telescope Making—Advanced* (printings since mid-1944) to eliminate the risk of sticking and for other advantages, or else a similarly "broken" tool of glass or tile blocks pitched to metal may be used.

For the second method a large and rugged Hindle machine capable of throwing around a 50-pound blank would be needed. One such machine that John H. Hindle of England built, all metal and wire-rope driven by a heavy motor, was illustrated in SCIENTIFIC AMERICAN in March, 1943.

For the third method there are several sound types of machines. One that is seldom built by amateurs, perhaps because it requires two cranks geared together, is the triangular type shown in *Amateur Telescope Making* at *A* on page 163.

The arc-stroke machine shown at *B* on the same page enjoys a good record. In highly disguised but mechanically identical form it is widely used commercially. If the lengthwise arm of the machine were discarded and the arc arm forcibly oscillated we would have the "Arsenal sidewinder" used in the Frankford Arsenal and illustrated on page 83 in *Amateur Telescope Making—Advanced* (printings since mid-1944). As a commercial product the latter costs several hundred dollars. A. H. Johns of Larchmont, N. Y., embodied the same sidewinder principle, together with his caster buffers, in a machine known, because of various resemblances, as the "Johns banjo."

There remains in the subdiameter tool, mirror-face-up category, the Draper type of machine. During the war Dave Broadhead of Wellsville, N. Y., designed the machine shown on the opposite page directly from the original 1864 drawing by Draper as reproduced in *Amateur Telescope Making*, page 165. For several days I watched this machine at work in Broadhead's cellar shop. It was designed so well and worked so efficiently that it is offered with confidence as suitable for making 16-inch mirrors.

"Nearly all machines used in precision optics," Broadhead states, "are basically related to the Draper, with the following adjustments:

"1) A turntable rotating at a rate that balances accomplishment against heat.

"2) A reciprocating arm to drive the tool over the work (*'stroke' in the drawing on page 63*) at a rate perhaps five times that of the turntable, and means to vary its length.

"3) Means for varying the 'offset' (*see drawing*).

"4) Means for 'decentering' the driving pin so that the stroke takes place a fraction of an inch more on one side of the center of the work, in order to soften and spread a zone.

"5) Variable driving speed to permit the same linear speed in polishing work of different diameters."

As the machine shown was designed for 12-inch maximum work diameter, a few inches should be added to its length for 16-inch mirrors. The height should be changed to suit the worker's own height and that of his high stool. Vertical legs may be substituted for the A-frame legs, but if this is done the worker will no longer be able to stand close to his work. (In the drawing he would stand behind the machine, facing the reader.)

On 12-inch work the 1/6-horsepower motor has proved more than sufficient. A 1/3-horsepower motor was ample when the arm was temporarily extended to a separate spindle for making two 36-inch mirrors.

The motor's long V-belt with its sag on top improves the smoothness of the

ASTRONOMER

drive. The gear reduction may be obtained from the Chicago Gear Works or from the Boston Gear Works. Broadhead's was an old one, salvaged as per amateur tradition. The Ford transmission can be obtained from Sears, Roebuck and Company, but the one used cost $7 at a junk yard. Greasing suffices to lubricate it, no oil bath being needed. The gears shift readily without stopping the motor.

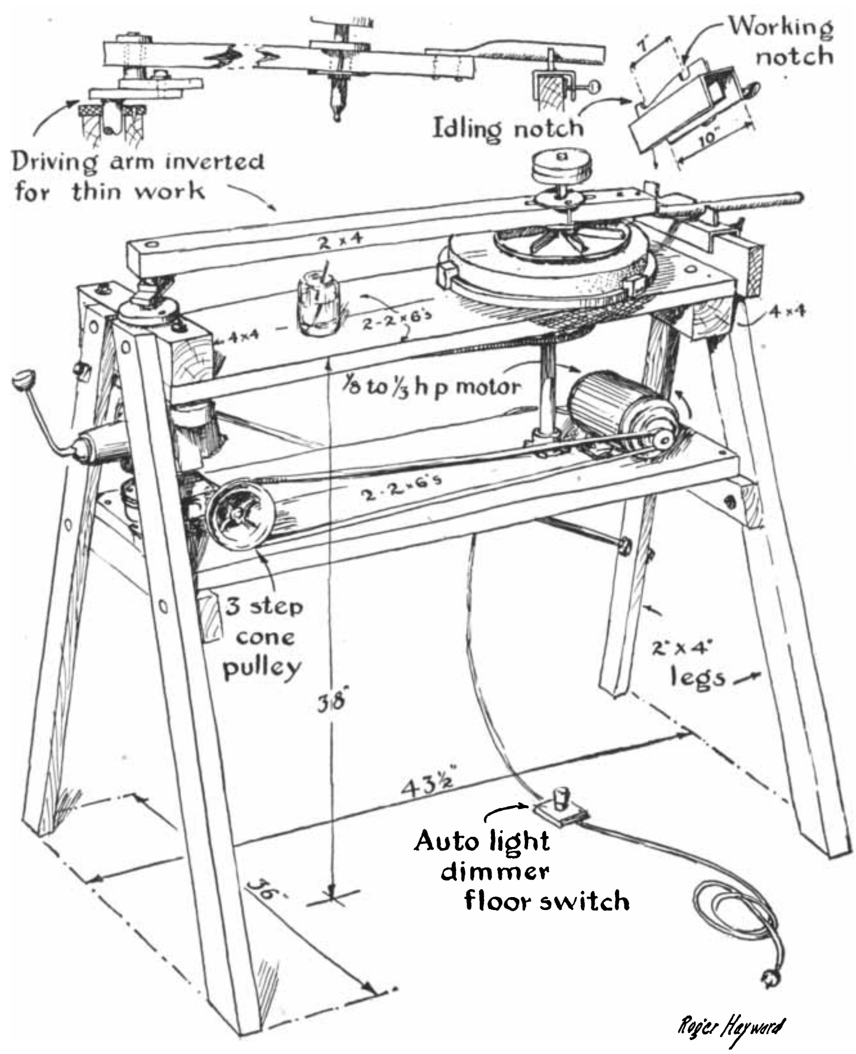
Pulleys of 3 inches and 15 inches diameter, or sprockets and chain, would improve this machine, Broadhead states, by giving a smoother drive to the turntable.

The reciprocating arm may be lifted entirely off the machine without first loosening anything. In his version of Draper's original, Broadhead embodied the illustrated provision for shifting the arm laterally to cancel zones without stopping the machine.

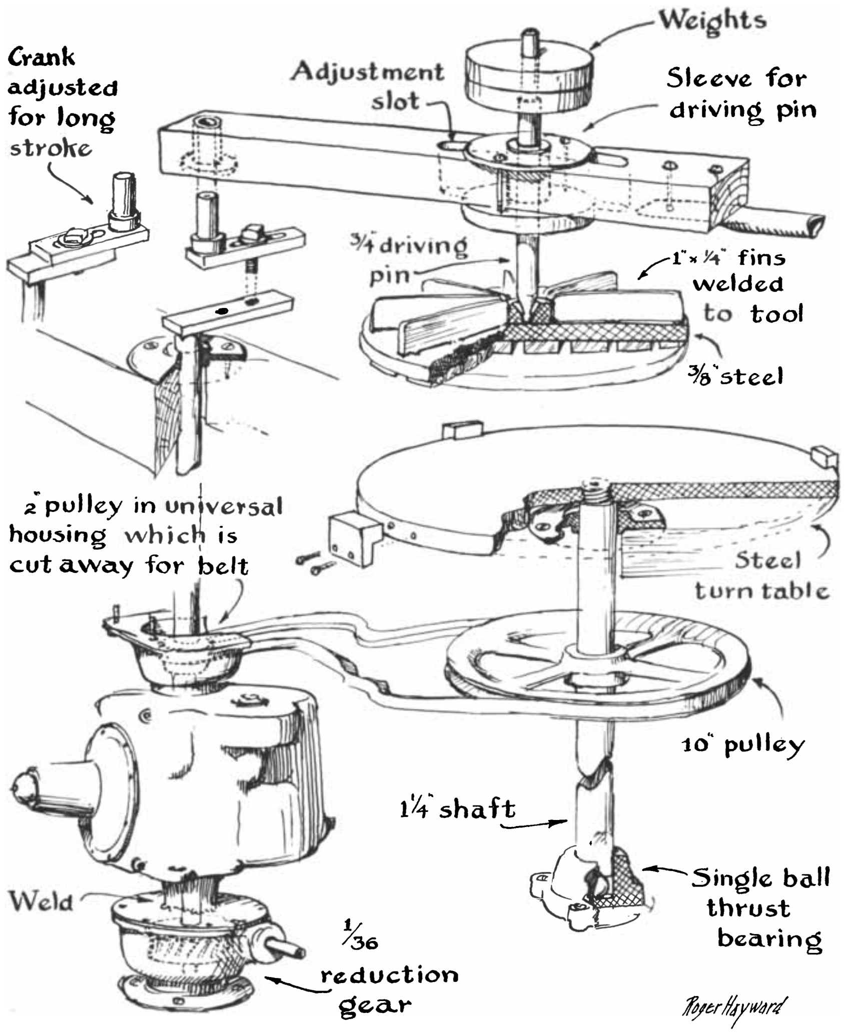
Since the driving pin is free to rise or fall within its oiled guide, the tool loading remains uniform and perfectly controlled; none of the weight of the arm rests on the tool.

The husky turntable shaft has a ⅞-14 SAE right-hand thread and a shoulder. This shaft should barely rise above its bearing.

On both vertical shafts the top lateral bearings are common floor flanges carefully bored out on the lathe. At the low speeds of these shafts relatively little power is lost in plain bearings. Power is lost, however, when shafts extend above their bearings, a grotesque fault of many machines, including Draper's. Fancy bearings will not recover this loss, which is due to cramping caused by flexure. The avoidance of this waste, together with the efficient transmission, largely explains why the midget motor has been adequate. The solidly bolted-in 4-by-4 puts the pipe-flange bearing high up, close to the "ears" of the crankshaft head. Thrusts up to 600 pounds are obtained in lowest gear. Nine speeds, from 1.2 revolutions per minute on the turntable and 6 strokes per minute on the arm up to 13.5 revolutions and 68 strokes, re-



Broadhead's version of Draper's original mirror-making machine



Details of the Broadhead grinding and polishing machine

spectively, are possible by shifting the motor belt on the step-pulleys in combination with the gear shift. Thus Broadhead can always obtain his favored slow eight-feet-per-minute for polishing, and slower speeds for figuring. For roughing out and for fine grinding much higher speeds can do no harm.

The movable dimmer switch on the floor serves not merely to control the motor; it assures quick stops in emergencies when the hands are otherwise occupied. It also frees the hands during halts.

One way to learn to operate such a machine is to try tools of various sizes with varied strokes until, after perhaps 100 years, the art is learned empirically. There is, however, a science to it that others have recorded. In his book entitled *Optical Workshop Principles* (Jarrell-Ash Co., Boston, 1943) Charles Dévé of France has set forth some of this science, though his book will call for hard study of geometrical principles.

Dévé shows geometrically why the method of equal-sized tools requires so much juggling to produce a sphere. The moment the edge of the upper disk extends beyond that of the lower, uniform abrasion ceases and, as Patrick A. Driscoll has pointed out in this department (October and November, 1945), we obtain first a hyperbola and then, due to the short strokes used in escaping from it, a turned edge. Thereafter, to balance off these two irregularities, we perform the juggling that makes the conquest of a mirror such a fine sport. The sport unfortunately loses its attraction on such a large mirror as a 16-inch.

Instead of going through this procedure with his Draper machine, Broadhead excavates with a two-thirds-diameter tool to full sagitta at the outset. He uses strokes that pass near the center of the mirror but do not extend the tool more than barely past the edge.

With the curve thus roughed out, a ⅝-diameter tool is used until figuring begins. As Driscoll has pointed out, a ⅝ tool has long been known in the optical industry as the best for holding the curve almost to the radius with which it starts. With this diameter of tool, correct setting of stroke and offset will suffice to increase the curvature, decrease it or hold it precisely. This "method of uniform wear," as it was called by Dévé, enhances the attractiveness of the subdiameter tool method. A drawback is the need to guard against grinding astigmatism into the mirror: the worker must start by grinding the blank flat, support it on Brussels carpet and turn it.

"So now," Broadhead writes, "we must discover experimentally the 'neutral position,' the precise combination of stroke and offset that will hold the curve at one radius. Do not change to the third abrasive until the neutral stroke has been found and can be held. Then grind and polish with this stroke."

Broadhead makes a combination roughing and grinding tool by cementing chamfered or sloping-sided blocks of glass to the steel backing out to ⅔ diameter, and surrounding these with a ring of thinner blocks extending to ⅚ diameter and of such thickness, ascertained perhaps by consulting a psychic medium, that the outer ring will come into contact just as the curve reaches the sagitta.

Now he adjusts the stroke to about .35 length of mirror diameter and .2 offset (trying .5 and .3, respectively, in case the medium was wrong), until the outer blocks reach contact. If the spherometer, preferably made with a dial indicator, shows that the curve is shallowing again, we may try .2 and .1.

In mirror polishing there are two common techniques: the wet-lap technique and the dry-lap technique. In the first, water is used very freely and heavy weights bring work and tool into something like contact. But, as Broadhead points out, gobs of water on one side of the work often lift it unevenly, and capillarity prevents the water from squeezing out. It is feared that too many amateurs follow this method, also using gobs of rouge. In the dry technique, observed in many commercial optical shops, the lap runs almost dry for lack of attention and squeals like an agonized pig, and this often causes sleeks.

When the worker can concentrate his full attention on one spindle he can use a third method—the moist technique. "In this I cold press," says Broadhead, "with no more water on the lap than might be deposited by breathing on it. To prevent sticking, I lay a damp cloth, not around the edge to produce a cold zone, but on the weight, which should be the same as the one to be used on the drive pin. On a 14-inch surface I use only three pounds. To maintain humidity, cover the work with a cake cover."

I watched Broadhead closely while he figured two mirrors. He put a spoonful of Barnesite in a glass of water and stirred it with a tiny artists' brush that had very few hairs. On the newly made lap he brushed a little of the pink liquid, washed the mirror and all but dried it with his hands. Accent throughout was strongly on little abrasive, little water.

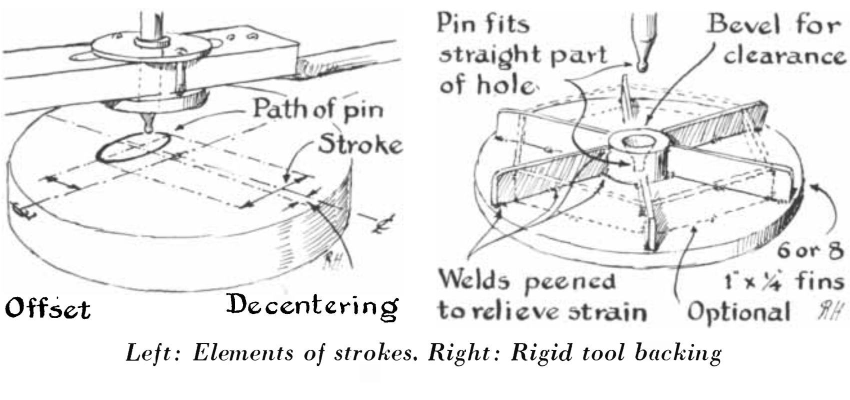
After a few minutes' work with the machine a hint of a squeal was heard. A tiny droplet—less than a drop of pink water—was dabbed on either side of the moving tool. This quieted the incipient squeal. Perhaps a quarter of a minute later, as the pig threatened to squeal again, two more stingy dabs were granted it, and so on throughout polishing, while the machine groaned from exertion. The aim is to maintain a strong and unvarying attraction, or "suction," due to extremely intimate contact during work. Into this the weights enter but little. At no time after the first stirring was the water in the glass stirred.

This moist technique, with its powerful adhesive forces, calls for a rigidly built machine and for tools having maximum rigidity and minimum weight.

Broadhead figured with agonizingly slow strokes, deliberately stretching the operation out to avoid heat caused by the low-moisture method and to maintain calm control. He used a star tool of .5 diameter. Such tools work fast and must be used very cautiously. He deliberately overcorrected a little, then cold-pressed the ⅚ lap on the mirror and ran it a few minutes at "neutral" stroke to smooth the figure.

"What you call my technique came largely," Broadhead protests, "from reading Driscoll's articles, talking with Ferson, and watching closely at Frankford Arsenal during a wartime visit."

The fourth method mentioned at the beginning of this article was by hand with subdiameter tools face up. Here the methods just described for machine use may be an improvement over those given in the chapter on subdiameter tools in *Amateur Telescope Making—Advanced.* Any reader who uses this method will in some measure be pioneering among amateurs and should report his findings.



Left: Elements of strokes. Right: Rigid tool backing

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