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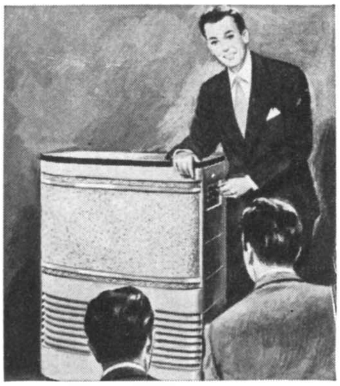

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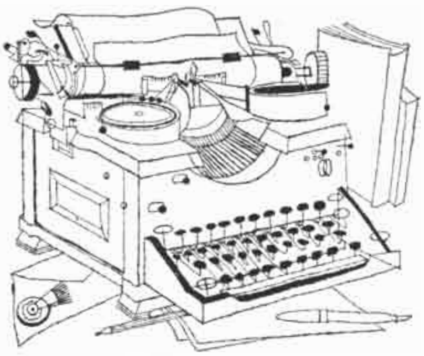

LETTERS

Sirs:

Our article on topology in the January issue brought responses which were interesting to us and which we thought might interest you.

The most gratifying responses were those showing that the article had stimulated scientific thought in fields outside mathematics. In a midwestern university a biologist who was working on the "lock and key" idea of protein molecule growth read the article and decided that he was faced with a topological problem. He had not realized before that there was such a branch of mathematics. He consulted his colleagues in the mathematics department, and moved a long way ahead in his investigation.

A chemist wrote that the article "strikes a chord with a problem I have in organic chemistry," and asked for technical references. In another letter an engineer in the Bonneville Power Administration said, "We are greatly interested in new uses of topology as applied to networks [and would be] grateful for references you could give us." We would like to refer other readers with a serious interest in the subject to the book *Introduction to Topology* by Solomon Lefschetz.

We are pleased with these responses and think they show the usefulness of interscience publication.

In our article we warned readers against trying to turn real inner tubes inside out. One reader, Mr. Bradford B. Underhill, an engineer in Collingswood, N. J., would not be deterred. He cut a three-inch diameter hole in an inner tube, turned it inside out, and sent it to us in the mail. The "grain" of the tube reversed its direction as we said it would, so experiment confirms theory. Mr. Underhill says that turning an inner tube inside out "is not at all difficult if one inserts his entire arm through the hole and grabs the far side and pulls. Be careful of your fingernails, however, for it is rather easy to bend them backward, with considerable pain." The inside-out inner tube is now in the mathematical museum of Fine Hall at Princeton.

We have received several requests for Klein bottles. The Klein bottle pictured on the January cover was made by Mr. Lee Harris, expert glass blower in Princeton's Palmer Physical Laboratory, and is itself a work of art.

We would also like to elucidate a point that was implied in the figures but not elaborated in the article. The four-color problem becomes a network problem when each state is given a capital and the capitals of two states with a common border are joined by a railroad that crosses that border only. Then one has to find a color scheme for the capitals so that capitals joined by a railroad have different colors. The railroads connecting the six capitals, etc., in the six-color map on page 23 also show how six points can be completely interconnected on a transparent Moebius band. Also, at the top center of page 24, "opposite" means "diametrically opposite" or "centrally symmetric."

HERBERT S. BAILEY, JR.
ALBERT W. TUCKER

Princeton University
Princeton, N. J.

Sirs:

Claude E. Shannon's "A Chess-Playing Machine" in your February number may seem a little out of focus to those who are fair-to-middling chess players but poor mathematicians.

Perhaps the catch lies in Shannon's phrase, "Assuming that a suitable method of position evaluation has been decided upon . . . " Now if a single method of position evaluation could be agreed

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upon by all chess masters, the difference between the modes of "thinking" of a human player and of a machine would probably be slight.

Suppose we look at the problem from the point of view of pitting two machines against each other. If each of the machines were given the same method of position evaluation, what would decide the outcome of a match between them? Chance? Then if two opposing groups of mathematicians were given unlimited facilities for attempting to improve the machines on a competitive basis, what would be the method of choice? Simply to make the machines more elaborate until they had enough sections working independently to run down the 10^{120} variations in the average game? Or would the mathematicians rather strive to improve the validity of the numbers used in position evaluation?

From the chess player's point of view it is the latter activity that is of interest. The fact that two grand masters, taken at random, have a good chance of disagreeing on the evaluation of a position is what makes chess an interesting game. If they generally agreed on the evaluation of positions, the game would then become a mere exercise in calculation.

Actually, of course, we should probably invent a new game at that point. The late Jose Raoul Capablanca, the nearest approach to a chess playing machine in the flesh yet seen, suggested in the 1920s, after he had gone undefeated for a number of years, that chess was worked out and should be modified or replaced. Capablanca's partisans in the chess world held that he would have gone undefeated forever if extraneous factors had not interfered with the working of his "flawless" mind. But others held that he fell from the championship because methods of evaluating positions that were an improvement over his own were developed.

It may be suggested that there is an optimum range for a game of perception and calculation somewhere between ticktacktoe, which most of us probably remember having proved to be always drawn with best play, and games which are so complicated that no satisfactory method of evaluating plays can be suggested. Checkers has less appeal than chess simply because it is too near the mere calculation side of this scale, and calls for too much memory work. Poker with too many wild cards is too far on the random variation side of the scale and so is less attractive than a straight game.

If the machine designers really want a challenge, why don't they design a machine that will exhaust "Go," the oriental game played on the intersections of 19 lines with about 150 pieces on each side?

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50 AND 100 YEARS AGO

APRIL 1900. "The great meteorite which Lieut. Peary brought back from his last expedition still remains on the Cob Dock of the Brooklyn Navy Yard. It is the largest in the world, and Lieut. Peary has been trying to dispose of it to some museum. The meteorite weighs 200,000 pounds, and it is said that Lieut. Peary wishes to obtain $75,000 for it."

"A French inventor, M. Mercadier, states that he has solved the problem of sending a number of dispatches simultaneously on a single wire. Messages have been transmitted between Paris and Pau. Twelve independent message currents were sent on the circuit at once in either direction, making a total of twenty-four telegrams."

"The wonderful progress which we have made in the last few years in the increase and extension of our export trade, has naturally resulted in the desire of our legislators to foster our commerce by all possible means. The proposal to establish a new executive department to be known as the 'Department of Commerce and Industries,' the head of which shall hold a seat in the President's Cabinet, seems a wise one."

"One of the notable circumstances connected with the present war in South Africa has been the wide and varied application of the results of modern science in regard to it. We now perform a considerable portion of our scouting by balloons. By means of wireless telegraphy, communications have been successfully established between various stations occupied by the British troops. Infective wound diseases have been practically banished from them by universal and scrupulous attention to cleanliness and by the rigid use of antiseptic dressings in wounds and injuries, and by the performance of all operations while patients were under the influence of anesthetics. The use of the Roentgen rays has enabled the surgeons to detect the presence and exact site of any missile or foreign body."

"The steamer 'Southern Cross,' with C. E. Borchgrevink and the survivors of the South Polar expedition, which was fitted out in 1898 by Sir George Newnes, has arrived at Wellington, New Zealand. Herr Borchgrevink reports that the magnetic pole has been located. 'The key to the future knowledge of terrestrial magnetism lies in the determination of the exact position of the southern magnetic pole,' remarked Sir Joseph Hooker, several years ago. If the expedition has done nothing more than discover the south magnetic pole, it has many times paid for itself from a scientific point of view."

"A year ago Prof. Dewar liquefied hydrogen; he has now gone a step further and produced hydrogen as a solid. He surrounded the tube containing it with liquid air to prevent the increase of heat and then applying a powerful air pump to the liquid hydrogen he transformed it into a white opaque solid. Its transformation is interesting because it is the elementary body of the lowest atomic weight. One of its uses was in the solidification of oxygen, and it could also be used in the separation of mixed gases."

"The spring meeting of the National Academy of Sciences was held at Columbian University in Washington on April 17-19. Perhaps the most important feature of the meeting is the election of new members. This year, those who were selected included James E. Keeler, Henry F. Osborn, the Da Costa Professor of Biology in Columbia University; Franz Boas, who is professor of anthropology in Columbia University and an assistant curator in the American Museum of Natural History, New York, and whose ethnological studies among the Indians of the Northwest have gained for him much reputation; and Samuel L. Penfield, professor of mineralogy in Sheffield Scientific School of Yale University. An award of the Barnard medal was made to William Conrad Roentgen for his discovery of the X-rays."

"An automobile recently covered the distance from Coventry to London, 92 miles, in four hours, this being an average of 23 miles an hour."

APRIL 1850. "There were 127,000 more bales of cotton made in the United States in 1849 than in France. We shall soon be the *cotton cloth making* as well as the *cotton growing nation*."

"Capt. Robert Brown, of New London, Conn., has invented a most important improvement for shooting and capturing whales. At best the harpooning and lancing of whales is a very dangerous and difficult business, and sometimes, on account of the sea, an impossible thing. The idea of firing the harpoon out of a gun has been often advanced. But the construction of the harpoon and the way in which it was attached to the line to be fired off, rendered all former attempts void for want of accuracy. Capt. Brown has obviated all former difficulties, and his harpoon, with the line attached, can be fired as accurately as a musket ball."

"Dr. Alexandre, from Paris, has lately brought out a sub-marine boat, in which a company of persons can go down to the bottom, have communication with the land, performing any sort of work by digging or otherwise, and return to the surface at will."

"Mr. O'Reilly is now on his way West, for the purpose of immediately commencing a section of the Mississippi and Pacific telegraph. Preparations have been made to run up the line at once as far as Fort Leavenworth, on the Western border of Missouri. This will connect the East with the farthest bounds of civilization West. Mr. O'Reilly hopes to reach California by July of next year."

"The English government will give twenty thousand pounds sterling to any party or parties, of any country, who shall render efficient assistance to the crews of the discovery ships under the command of Sir John Franklin."

"Professor Agassiz, at the meeting in Charleston, S. C., of the American Association for the Advancement of Science, avowed his disbelief in the unity of the human race! He declared his readiness to maintain, in opposition to the authority of Scripture, that all the nations of the earth were not made of one blood, but that the different races of men descended from different stocks!"

"All organic matter consists of carbon, hydrogen, oxygen, and nitrogen; and in combinations of these elements we have all the necessities for the support of life and the means of its sudden destruction. The loaf bread and the beef steak contain the elements of Prussic Acid, Morphia, and Strichnia."

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THE COVER

The painting on the cover shows a scene in the laboratory of Harvard University zoologist Carroll M. Williams (*see page 24*). In the center of the painting a male Cecropia moth crawls out of a cylindrical cardboard container. The larva of the Cecropia moth, better known as the silkworm, lends itself to some fascinating experiments with the mechanism by which insects are transformed from egg to larva to pupa to adult. The abdomen of the green silkworm at the right has been tied off from its thorax. The thorax has metamorphosed into the pupa, indicating that the substance controlling metamorphosis originates in the thorax. In the left foreground is another experimental preparation in which a Cecropia pupa has been cut in half and joined by a plastic tube. In the center of the painting is the white rim of a porcelain funnel sunk in the top of the table. Here the insects are anesthetized with carbon dioxide. Resting on the edge of the funnel is a pair of microscissors used in insect surgery. Beside it are a beaker of Ringer's solution and a blue box containing plastic parts. In the right background is an alcohol lamp.

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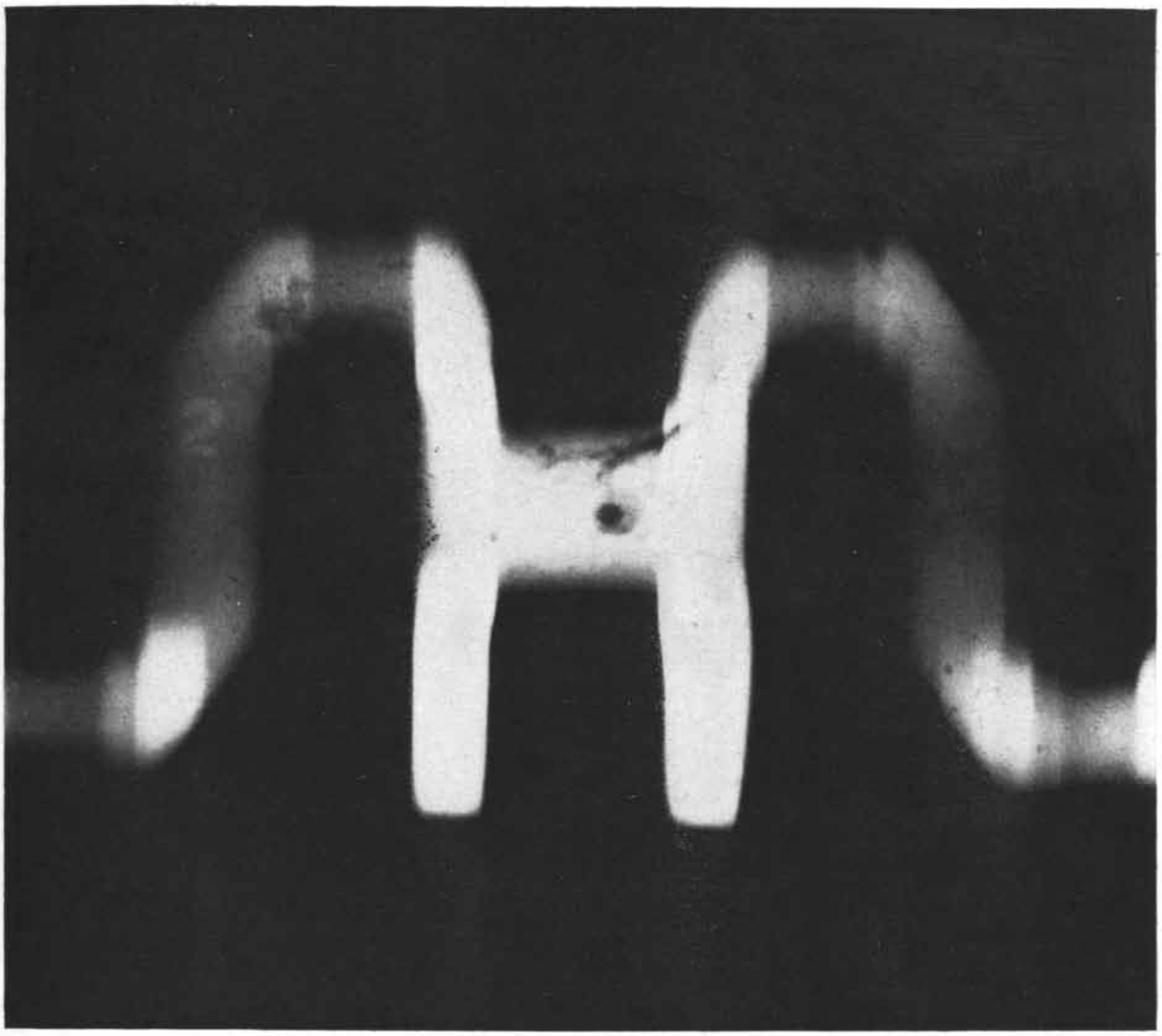

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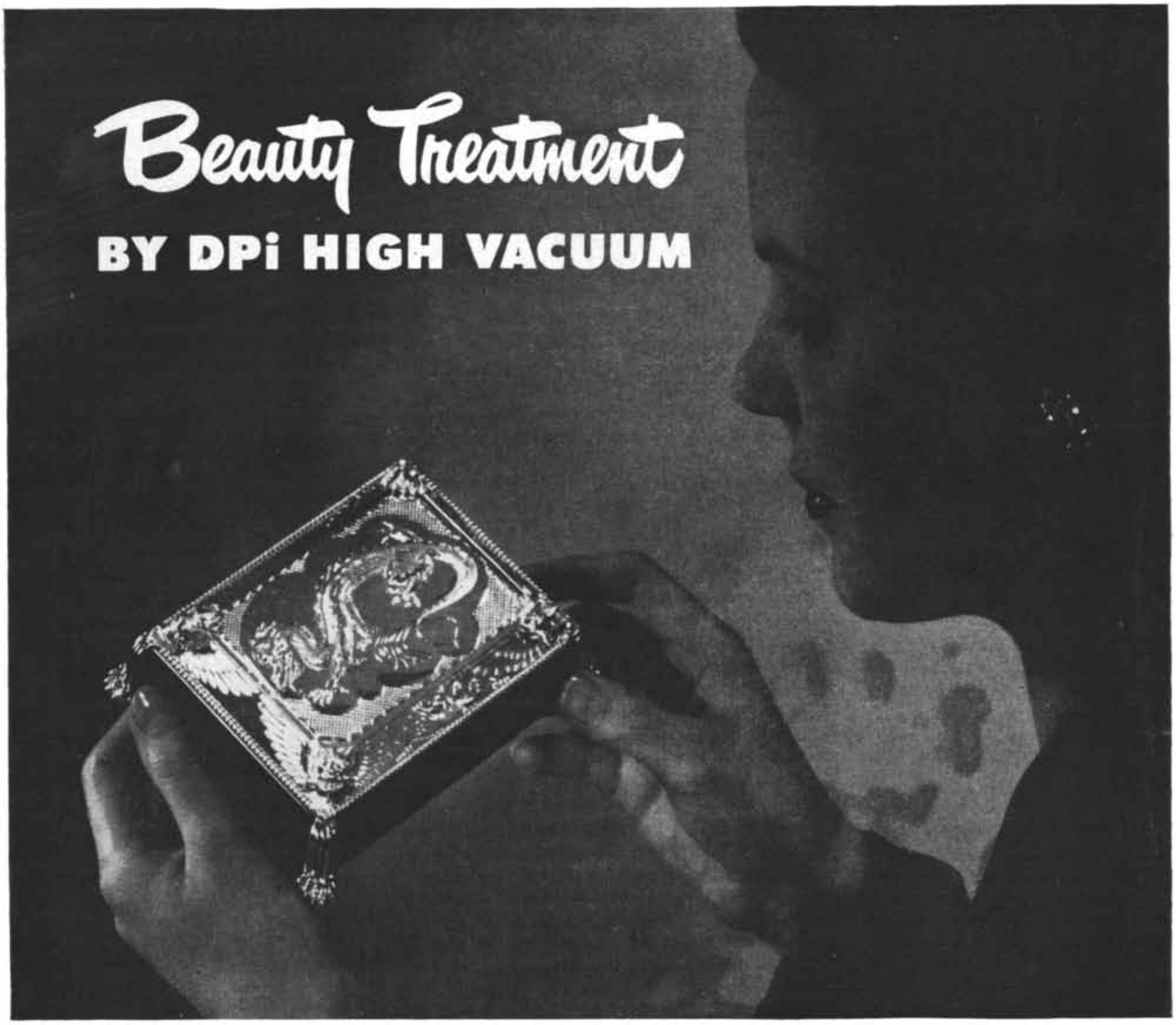

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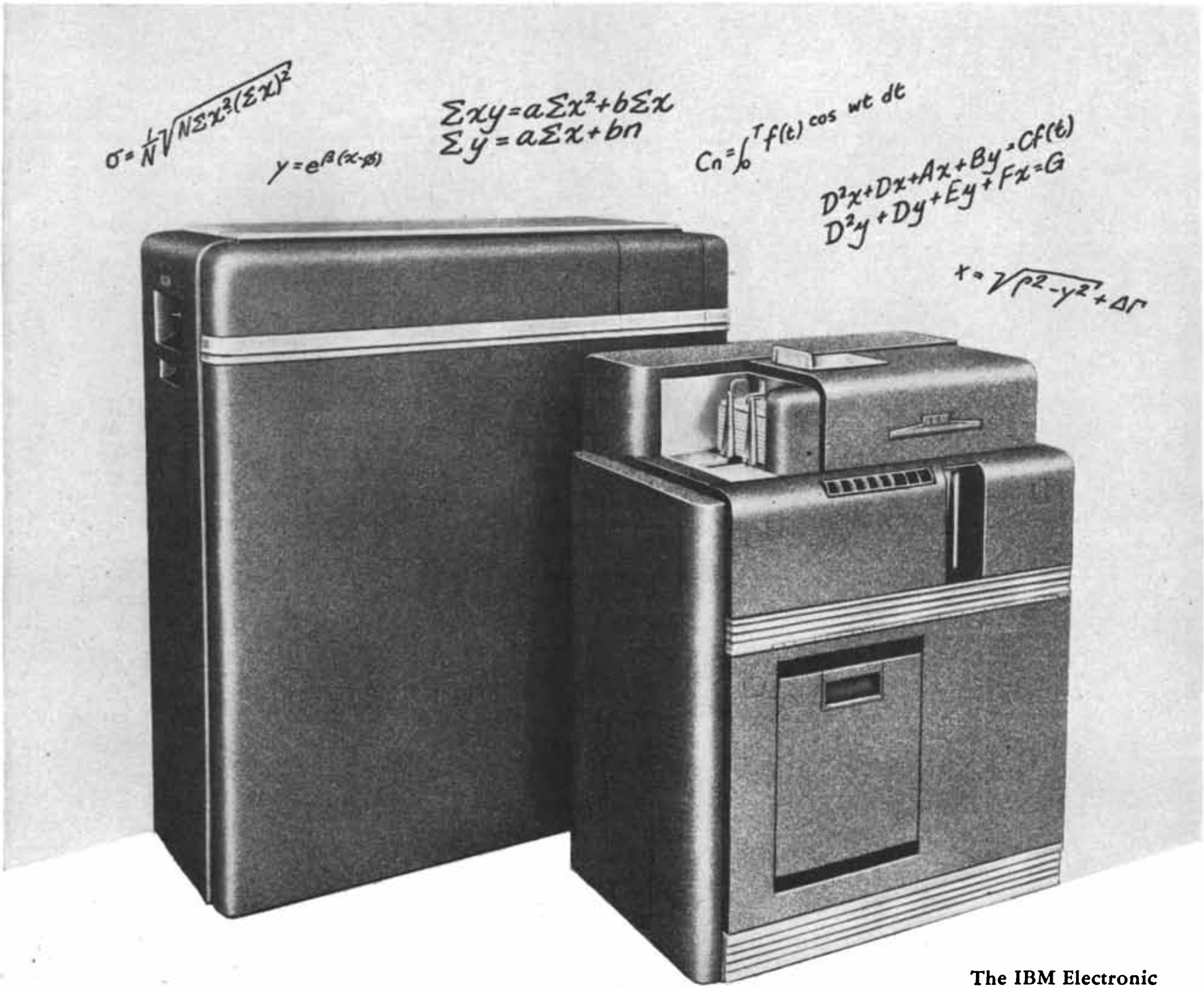

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APRIL 1950 SCIENTIFIC AMERICAN VOL. 182, NO. 4

On the Generalized Theory of Gravitation

An account of the newly published extension of the general theory of relativity against its historical and philosophical background

by Albert Einstein

THE editors of SCIENTIFIC AMERICAN have asked me to write about my recent work which has just been published. It is a mathematical investigation concerning the foundations of field physics.

Some readers may be puzzled: Didn't we learn all about the foundations of physics when we were still at school? The answer is "yes" or "no," depending on the interpretation. We have become acquainted with concepts and general relations that enable us to comprehend an immense range of experiences and make them accessible to mathematical treatment. In a certain sense these concepts and relations are probably even final. This is true, for example, of the laws of light refraction, of the relations of classical thermodynamics as far as it is based on the concepts of pressure, volume, temperature, heat and work, and of the hypothesis of the non-existence of a perpetual motion machine.

What, then, impels us to devise theory after theory? Why do we devise theories at all? The answer to the latter question is simply: Because we enjoy "comprehending," *i.e.*, reducing phenomena by the process of logic to something already known or (apparently) evident. New theories are first of all necessary when we encounter new facts which cannot be "explained" by existing theories. But this motivation for setting up new theories is, so to speak, trivial, imposed from without. There is another, more subtle motive of no less importance. This is the striving toward unification and simplification of the premises of the theory as a whole (*i.e.*, Mach's principle of economy, interpreted as a logical principle).

There exists a passion for comprehension, just as there exists a passion for music. That passion is rather common in children, but gets lost in most people later on. Without this passion, there would be neither mathematics nor natural science. Time and again the passion for understanding has led to the illusion that man is able to comprehend the objective world rationally, by pure thought, without any empirical foundations—in short, by metaphysics. I believe that every true theorist is a kind of tamed metaphysicist, no matter how pure a "positivist" he may fancy himself. The metaphysicist believes that the logically simple is also the real. The tamed metaphysicist believes that not all that is logically simple is embodied in experienced reality, but that the totality of all sensory experience can be "comprehended" on the basis of a conceptual system built on premises of great simplicity. The skeptic will say that this is a "miracle creed." Admittedly so, but it is a miracle creed which has been borne out to an amazing extent by the development of science.

The rise of atomism is a good example. How may Leucippus have conceived this bold idea? When water freezes and becomes ice—apparently something entirely different from water—why is it that the thawing of the ice forms something which seems indistinguishable from the original water? Leucippus is puzzled and looks for an "explanation." He is driven to the conclusion that in these transitions the "essence" of the thing has not changed at all. Maybe the thing consists of immutable particles and the change is only a change in their spatial arrangement. Could it not be that the same is true of all material objects which emerge again and again with nearly identical qualities?

This idea is not entirely lost during the long hibernation of occidental thought. Two thousand years after Leucippus, Bernoulli wonders why gas exerts pressure on the walls of a container. Should this be "explained" by mutual repulsion of the parts of the gas, in the sense of Newtonian mechanics? This hypothesis appears absurd, for the gas pressure depends on the temperature, all other things being equal. To assume that the Newtonian forces of interaction depend on temperature is contrary to the spirit of Newtonian mechanics. Since Bernoulli is aware of the concept of atomism, he is bound to conclude that the atoms (or molecules) collide with the walls of the container and in doing so exert pressure. After all, one has to assume that atoms are in motion; how else can one account for the varying temperature of gases?

A simple mechanical consideration shows that this pressure depends only on the kinetic energy of the particles and on their density in space. This should have led the physicists of that age to the conclusion that heat consists in random motion of the atoms. Had they taken this consideration as seriously as it deserved to be taken, the development of the theory of heat—in particular the discovery of the equivalence of heat and mechanical energy—would have been considerably facilitated.

This example is meant to illustrate two things. The theoretical idea (atomism in this case) does not arise apart from and independent of experience; nor can it be derived from experience by a purely logical procedure. It is produced by a creative act. Once a theoretical idea has been acquired, one does well to hold fast to it until it leads to an untenable conclusion.

AS FOR my latest theoretical work, I do not feel justified in giving a detailed account of it before a wide group of readers interested in science. That should be done only with theories which have been adequately confirmed by experience. So far it is primarily the simplicity of its premises and its intimate connection with what is already known (*viz.*, the laws of the pure gravitational field) that speak in favor of the theory to be discussed here. It may, however, be of interest to a wide group of readers to become acquainted with the train of thought which can lead to endeavors of such an extremely speculative nature. Moreover, it will be shown what kinds of difficulties are encountered and in what sense they have been overcome.

In Newtonian physics the elementary theoretical concept on which the theoretical description of material bodies is based is the material point, or particle. Thus matter is considered *a priori* to be discontinuous. This makes it necessary to consider the action of material points on one another as "action at a distance." Since the latter concept seems quite contrary to everyday experience, it is only natural that the contemporaries of Newton—and indeed Newton himself—found it difficult to accept. Owing to the almost miraculous success of the Newtonian system, however, the succeeding generations of physicists became used to the idea of action at a distance. Any doubt was buried for a long time to come.

But when, in the second half of the 19th century, the laws of electrodynamics became known, it turned out that these laws could not be satisfactorily incorporated into the Newtonian system. It is fascinating to muse: Would Faraday have discovered the law of electromagnetic induction if he had received a regular college education? Unencumbered by the traditional way of thinking, he felt that the introduction of the "field" as an independent element of reality helped him to coordinate the experimental facts. It was Maxwell who fully comprehended the significance of the field concept; he made the fundamental discovery that the laws of electrodynamics found their natural expression in the differential equations for the electric and magnetic fields. These equations implied the existence of waves, whose properties corresponded to those of light as far as they were known at that time.

This incorporation of optics into the theory of electromagnetism represents one of the greatest triumphs in the striving toward unification of the foundations of physics; Maxwell achieved this unification by purely theoretical arguments, long before it was corroborated by Hertz' experimental work. The new insight made it possible to dispense with the hypothesis of action at a distance, at least in the realm of electromagnetic phenomena; the intermediary field now appeared as the only carrier of electromagnetic interaction between bodies, and the field's behavior was completely determined by contiguous processes, expressed by differential equations.

Now a question arose: Since the field exists even in a vacuum, should one conceive of the field as a state of a "carrier," or should it rather be endowed with an independent existence not reducible to anything else? In other words, is there an "ether" which carries the field; the ether being considered in the undulatory state, for example, when it carries light waves?

The question has a natural answer: Because one cannot dispense with the field concept, it is preferable not to introduce in addition a carrier with hypothetical properties. However, the pathfinders who first recognized the indispensability of the field concept were still too strongly imbued with the mechanistic tradition of thought to accept unhesitatingly this simple point of view. But in the course of the following decades this view imperceptibly took hold.

The introduction of the field as an elementary concept gave rise to an inconsistency of the theory as a whole. Maxwell's theory, although adequately describing the behavior of electrically charged particles in their interaction with one another, does not explain the behavior of electrical densities, *i.e.*, it does not provide a theory of the particles themselves. They must therefore be treated as mass points on the basis of the old theory. The combination of the idea of a continuous field with that of material points discontinuous in space appears inconsistent. A consistent field theory requires continuity of all elements of the theory, not only in time but also in space, and in all points of space. Hence the material particle has no place as a fundamental concept in a field theory. Thus even apart from the fact that gravitation is not included, Maxwell's electrodynamics cannot be considered a complete theory.

Maxwell's equations for empty space remain unchanged if the spatial coordinates and the time are subjected to a particular kind of linear transformations—the Lorentz transformations ("covariance" with respect to Lorentz transformations). Covariance also holds, of course, for a transformation which is composed of two or more such transformations; this is called the "group" property of Lorentz transformations.

Maxwell's equations imply the "Lorentz group," but the Lorentz group does not imply Maxwell's equations. The Lorentz group may indeed be defined independently of Maxwell's equations as a group of linear transformations which leave a particular value of the velocity—the velocity of light—invariant. These transformations hold for the transition from one "inertial system" to another which is in uniform motion relative to the first. The most conspicuous novel property of this transformation group is that it does away with the absolute character of the concept of simultaneity of events distant from each other in space. On this account it is to be expected that all equations of physics are covariant with respect to Lorentz transformations (special theory of relativity). Thus it came about that Maxwell's equations led to a heuristic principle valid far beyond the range of the applicability or even validity of the equations themselves.

Special relativity has this in common with Newtonian mechanics: The laws of both theories are supposed to hold only with respect to certain coordinate systems: those known as "inertial systems." An inertial system is a system in a state of motion such that "force-free" material points within it are not accelerated with respect to the coordinate system. However, this definition is empty if there is no independent means for recognizing the absence of forces. But such a means of recognition does not exist if gravitation is considered as a "field."

Let A be a system uniformly accelerated with respect to an "inertial system" I. Material points, not accelerated with respect to I, are accelerated with respect to A, the acceleration of all the points being equal in magnitude and direction. They behave as if a gravitational field exists with respect to A, for it is a characteristic property of the gravitational field that the acceleration is independent of the particular nature of the body. There is no reason to exclude the possibility of interpreting this behavior as the effect of a "true" gravitational field (*principle of equivalence*). This interpretation implies that A is an "inertial system," even though it is accelerated with respect to another inertial system. (It is essential for this argument that the introduction of independent gravitational fields is considered justified even though no masses generating the field are defined. Therefore, to Newton such an argument would not have appeared convincing.) Thus the concepts of inertial system, the law of inertia and the law of motion are deprived of their concrete meaning—not only in classical mechanics but also in special relativity. Moreover, following up this train of thought, it turns out that with respect to A time cannot be measured by identical clocks; indeed, even the immediate physical significance of coordinate differences is generally lost In view of all these difficulties, should one not try, after all, to hold on to the concept of the inertial system, relinquishing the attempt to explain the fundamental character of the gravitational phenomena which manifest themselves in the Newtonian system as the equivalence of inert and gravitational mass? Those who trust in the comprehensibility of nature must answer: No.

THIS is the gist of the principle of equivalence: In order to account for the equality of inert and gravitational mass within the theory it is necessary to admit non-linear transformations of the four coordinates. That is, the group of Lorentz transformations and hence the set of the "permissible" coordinate systems has to be extended.

What group of coordinate transformations can then be substituted for the group of Lorentz transformations? Mathematics suggests an answer which is based on the fundamental investigations of Gauss and Riemann: namely, that the appropriate substitute is the group of all continuous (analytical) transformations of the coordinates. Under these transformations the only thing that remains invariant is the fact that neighboring points have nearly the same coordinates; the coordinate system expresses only the topological order of the points in space (including its four-dimensional character). The equations expressing the laws of nature must be covariant with respect to all continuous transformations of the coordinates. This is the principle of general relativity.

The procedure just described overcomes a deficiency in the foundations of mechanics which had already been noticed by Newton and was criticized by Leibnitz and, two centuries later, by Mach: Inertia resists acceleration, but acceleration relative to what? Within the frame of classical mechanics the only answer is: Inertia resists acceleration *relative to space*. This is a physical property of space—space acts on objects, but objects do not act on space. Such is probably the deeper meaning of Newton's assertion *spatium est absolutum* (space is absolute). But the idea disturbed some, in particular Leibnitz, who did not ascribe an independent existence to space but considered it merely a property of "things" (contiguity of physical objects). Had his justified doubts won out at that time, it hardly would have been a boon to physics, for the empirical and theoretical foundations necessary to follow up his idea were not available in the 17th century.

According to general relativity, the concept of space detached from any physical content does not exist. The physical reality of space is represented by a field whose components are continuous functions of four independent variables —the coordinates of space and time. It is just this particular kind of dependence that expresses the spatial character of physical reality

Since the theory of general relativity implies the representation of physical reality by a *continuous* field, the concept of particles or material points cannot play a fundamental part, nor can the concept of motion. The particle can only appear as a limited region in space in which the field strength or the energy density are particularly high.

A relativistic theory has to answer two questions: 1) What is the mathematical character of the field? 2) What equations hold for this field?

Concerning the first question: From the mathematical point of view the field is essentially characterized by the way its components transform if a coordinate transformation is applied. Concerning the second question: The equations must determine the field *to a sufficient extent* while satisfying the postulates of general relativity. Whether or not this requirement can be satisfied depends on the choice of the field-type.

The attempt to comprehend the correlations among the empirical data on the basis of such a highly abstract program may at first appear almost hopeless. The procedure amounts, in fact, to putting the question: What most simple property can be required from what most simple object (field) while preserving the principle of general relativity? Viewed from the standpoint of formal logic, the dual character of the question appears calamitous, quite apart from the vagueness of the concept "simple." Moreover, from the standpoint of physics there is nothing to warrant the assumption that a theory which is "logically simple" should also be "true."

Yet every theory is speculative. When the basic concepts of a theory are comparatively "close to experience" (*e.g.*, the concepts of force, pressure, mass), its speculative character is not so easily discernible. If, however, a theory is such as to require the application of complicated logical processes in order to reach conclusions from the premises that can be confronted with observation, everybody becomes conscious of the speculative nature of the theory. In such a case an almost irresistible feeling of aversion arises in people who are inexperienced in epistemological analysis and who are unaware of the precarious nature of theoretical thinking in those fields with which they are familiar.

On the other hand, it must be conceded that a theory has an important advantage if its basic concepts and fundamental hypotheses are "close to experience," and greater confidence in such a theory is certainly justified. There is less danger of going completely astray, particularly since it takes so much less time and effort to disprove such theories by experience. Yet more and more, as the depth of our knowledge increases, we must give up this advantage in our quest for logical simplicity and uniformity in the foundations of physical theory. It has to be admitted that general relativity has gone further than previous physical theories in relinquishing "closeness to experience" of fundamental concepts in order to attain logical simplicity. This holds already for the theory of gravitation, and it is even more true of the new generalization, which is an attempt to comprise the properties of the total field. In the generalized theory the procedure of deriving from the premises of the theory conclusions that can be confronted with empirical data is so difficult that so far no such result has been obtained. In favor of this theory are, at this point, its logical simplicity and its "rigidity." Rigidity means here that the theory is either true or false, but not modifiable.

THE greatest inner difficulty impeding the development of the theory of relativity is the dual nature of the problem, indicated by the two questions we have asked. This duality is the reason why the development of the theory has taken place in two steps so widely separated in time. The first of these steps, the theory of gravitation, is based on the principle of equivalence discussed above and rests on the following consideration: According to the theory of special relativity, light has a constant velocity of propagation. If a light ray in a vacuum starts from a point, designated by the coordinates x_1, x_2 and x_3 in a three dimensional coordinate system, at the time x_4, it spreads as a spherical wave and reaches a neighboring point $(x_1+dx_1, x_2+dx_2, x_3+dx_3)$ at the time x_4+dx_4. Introducing the velocity of light, c, we write the expression:

$$\sqrt{dx_1^2+dx_2^2+dx_3^2}=c\,dx_4$$

This can also be written in the form:

$$dx_1^2+dx_2^2+dx_3^2-c^2\,dx_4^2=0$$

This expression represents an objective relation between neighboring space-time points in four dimensions, and it holds for all inertial systems, provided the coordinate transformations are restricted to those of special relativity. The relation loses this form, however, if arbitrary continuous transformations of the coordinates are admitted in accordance with the principle of general relativity. The relation then assumes the more general form:

$$\sum_{ik} g_{ik}\,dx_i\,dx_k=0$$

The g_{ik} are certain functions of the coordinates which transform in a definite way if a continuous coordinate transformation is applied. According to the principle of equivalence, these g_{ik} functions describe a particular kind of gravitational field: a field which can be obtained by transformation of "field-free" space. The g_{ik} satisfy a particular law of transformation. Mathematically speaking, they are the components of a "tensor" with a property of symmetry which is preserved in all transformations; the symmetrical property is expressed as follows:

$$g_{ik}=g_{ki}$$

The idea suggests itself: May we not ascribe objective meaning to such a symmetrical tensor, even though the field *cannot* be obtained from the empty space of special relativity by a mere coordinate transformation? Although we cannot expect that such a symmetrical tensor will describe the most general field, it may well describe the particular case of the "pure gravitational field." Thus it is evident what kind of field, at least for a special case, general relativity has to postulate: a symmetrical tensor field.

Hence only the second question is left: What kind of general covariant field law can be postulated for a symmetrical tensor field?

This question has not been difficult to answer in our time, since the necessary mathematical conceptions were already at hand in the form of the metric theory of surfaces, created a century ago by Gauss and extended by Riemann to manifolds of an arbitrary number of dimensions. The result of this purely formal investigation has been amazing in many respects. The differential equations which can be postulated as field law for g_{ik} cannot be of lower than second order, *i.e.*, they must at least contain the second derivatives of the g_{ik} with respect to the coordinates. Assuming that no higher than second derivatives appear in the field law, *it is mathematically determined by the principle of general relativity*. The system of equations can be written in the form:

$$R_{ik}=0$$

The R_{ik} transform in the same manner as the g_{ik}, *i.e.*, they too form a symmetrical tensor.

These differential equations completely replace the Newtonian theory of the motion of celestial bodies provided the masses are represented as singularities of the field. In other words, they contain the law of force as well as the law of motion while eliminating "inertial systems."

The fact that the masses appear as singularities indicates that these masses themselves cannot be explained by symmetrical g_{ik} fields, or "gravitational fields." Not even the fact that only *positive* gravitating masses exist can be deduced from this theory. Evidently a complete relativistic field theory must be based on a field of more complex nature, that is, a generalization of the symmetrical tensor field.

BEFORE considering such a generalization, two remarks pertaining to gravitational theory are essential for the explanation to follow.

The first observation is that the principle of general relativity imposes exceedingly strong restrictions on the theoretical possibilities. Without this restrictive principle it would be practically impossible for anybody to hit on the gravitational equations, not even by using the principle of special relativity, even though one knows that the field has to be described by a symmetrical tensor. No amount of collection of facts could lead to these equations unless the principle of general relativity were used. This is the reason why all attempts to obtain a deeper knowledge of the foundations of physics seem doomed to me unless the basic concepts are in accordance with general relativity from the beginning. This situation makes it difficult to use our empirical knowledge, however comprehensive, in looking for the fundamental concepts and relations of physics, and it forces us to apply free speculation to a much greater extent than is presently assumed by most physicists. I do not see any reason to assume that the heuristic significance of the principle of general relativity is restricted to gravitation and that the rest of physics can be dealt with separately on the basis of special relativity, with the hope that later on the whole may be fitted consistently into a general relativistic scheme. I do not think that such an attitude, although historically understandable, can be objectively justified. The comparative smallness of what we know today as gravitational effects is not a conclusive reason for ignoring the principle of general relativity in theoretical investigations of a fundamental character. In other words, I do not believe that it is justifiable to ask: What would physics look like without gravitation?

The second point we must note is that the equations of gravitation are 10 differential equations for the 10 components of the symmetrical tensor g_{ik}. In the case of a non-general relativistic theory, a system is ordinarily not overdetermined if the number of equations is equal to the number of unknown functions. The manifold of solutions is such that within the general solution a certain number of functions of three variables can be chosen arbitrarily. For a general relativistic theory this cannot be expected as a matter of course. Free choice with respect to the coordinate system implies that out of the 10 functions of a solution, or components of the field, four can be made to assume prescribed values by a suitable choice of the coordinate system. In other words, the principle of general relativity implies that the number of functions to be determined by differential equations is not 10 but $10-4=6$. For these six functions only six independent differential equations may be postulated. Only six out of the 10 differential equations of the gravitational field ought to be independent of each other, while the remaining four must be connected to those six by means of four relations (identities). And indeed there exist among the left-hand sides, R_{ik}, of the 10 gravitational equations four identities—"Bianchi's identities"—which assure their "compatibility."

In a case like this—when the number of field variables is equal to the number of differential equations—compatibility is always assured if the equations can be obtained from a variational principle. This is indeed the case for the gravitational equations.

However, the 10 differential equations cannot be entirely replaced by six. The system of equations is indeed "overdetermined," but due to the existence of the identities it is overdetermined in such a way that its compatibility is not lost, *i.e.*, the manifold of solutions is not critically restricted. The fact that the equations of gravitation imply the law of motion for the masses is intimately connected with this (permissible) overdetermination.

After this preparation it is now easy to understand the nature of the present investigation without entering into the details of its mathematics. The problem is to set up a relativistic theory for the total field. The most important clue to its solution is that there exists already the solution for the special case of the pure gravitational field. The theory we are looking for must therefore be a generalization of the theory of the gravitational field. The first question is: What is the natural generalization of the symmetrical tensor field?

This question cannot be answered by itself, but only in connection with the other question: What generalization of the field is going to provide the most natural theoretical system? The answer on which the theory under discussion is based is that the symmetrical tensor field must be replaced by a non-symmetrical one. This means that the condition $g_{ik}=g_{ki}$ for the field components must be dropped. In that case the field has 16 instead of 10 independent components.

There remains the task of setting up the relativistic differential equations for a non-symmetrical tensor field. In the attempt to solve this problem one meets with a difficulty which does not arise in the case of the symmetrical field. The principle of general relativity does not suffice to determine completely the field equations, mainly because the transformation law of the symmetrical part of the field alone does not involve the components of the antisymmetrical part or *vice versa*. Probably this is the reason why this kind of generalization of the field has hardly ever been tried before. The combination of the two parts of the field can only be shown to be a natural procedure if in the formalism of the theory only the total field plays a role, and not the symmetrical and antisymmetrical parts separately.

It turned out that this requirement can indeed be satisfied in a natural way. But even this requirement, together with the principle of general relativity, is still not sufficient to determine uniquely the field equations. Let us remember that the system of equations must satisfy a further condition: the equations must be compatible. It has been mentioned above that this condition is satisfied if the equations can be derived from a variational principle.

This has indeed been achieved, although not in so natural a way as in the case of the symmetrical field. It has been disturbing to find that it can be achieved in two different ways. These variational principles furnished two systems of equations—let us denote them by E_1 and E_2—which were different from each other (although only slightly so), each of them exhibiting specific imperfections. Consequently even the condition of compatibility was insufficient to determine the system of equations uniquely.

It was, in fact, the formal defects of the systems E_1 and E_2 that indicated a possible way out. There exists a third system of equations, E_3, which is free of the formal defects of the systems E_1 and E_2 and represents a combination of them in the sense that every solution of E_3 is a solution of E_1 as well as of E_2. This suggests that E_3 may be the system we have been looking for. Why not postulate E_3, then, as the system of equations? Such a procedure is not justified without further analysis, since the compatibility of E_1 and that of E_2 do not imply compatibility of the stronger system E_3, where the number of equations exceeds the number of field components by four.

An independent consideration shows that irrespective of the question of compatibility the stronger system, E_3, is the only really natural generalization of the equations of gravitation.

But E_3 is not a compatible system in the same sense as are the systems E_1 and E_2, whose compatibility is assured by a sufficient number of identities, which means that every field that satisfies the equations for a definite value of the time has a continuous extension representing a solution in four-dimensional space. The system E_3, however, is not extensible in the same way. Using the language of classical mechanics we might say: In the case of the system E_3 the "initial condition" cannot be freely chosen. What really matters is the answer to the question: Is the manifold of solutions for the system E_3 as extensive as must be required for a physical theory? This purely mathematical problem is as yet unsolved.

The skeptic will say: "It may well be true that this system of equations is reasonable from a logical standpoint. But this does not prove that it corresponds to nature." You are right, dear skeptic. Experience alone can decide on truth. Yet we have achieved something if we have succeeded in formulating a meaningful and precise question. Affirmation or refutation will not be easy, in spite of an abundance of known empirical facts. The derivation, from the equations, of conclusions which can be confronted with experience will require painstaking efforts and probably new mathematical methods.

The Hydrogen Bomb: II

In which the technical and strategic discussion of last issue is continued, and a proposal is made for a first step toward the international control of atomic weapons

by Hans A. Bethe

LAST month Louis N. Ridenour published an article on the hydrogen bomb in this magazine. The discussion is continued in this second article because of the tremendous importance of the issue. Ridenour described the essential parts of the theory of the nuclear reactions in the hydrogen bomb, and also discussed the likely effects of the bomb on our military security. I agree entirely with his view that the creation of the H-bomb makes our country more vulnerable rather than more secure. It remains for me to discuss two things: On the technical side, I shall try to clarify the many misconceptions that have crept into the discussions of the H-bomb in the daily press. On the political side, I wish to take up the moral issue and the meaning of the bomb in the general framework of our foreign relations.

Everybody who talks about atomic energy knows Albert Einstein's equation $E=Mc^2$: *viz.*, the energy release in a nuclear reaction can be calculated from the decrease in mass. In the fission of the uranium nucleus, one tenth of one per cent of the mass is converted into energy; in the fusion of four hydrogen nuclei to form helium, seven tenths of one per cent is so converted. When these statements are made in newspaper reports, it is usually implied that there ought to be some way in which all the mass of a nucleus could be converted into energy, and that we are merely waiting for technical developments to make this practical. Needless to say, this is wrong. Physics is sufficiently far developed to state that there will never be a way to make a proton or a neutron or any other nucleus simply disappear and convert its entire mass into energy. It is true that there are processes by which various smaller particles—positive and negative electrons and mesons—are annihilated, but all these phenomena involve at least one particle which does not normally occur in nature and therefore must first be created, and this creation process consumes as much energy as is afterwards liberated.

All the nuclear processes from which energy can be obtained involve the rearrangement of protons and neutrons in nuclei, the protons and neutrons themselves remaining intact. Hundreds of experimental investigations through the last 30 years have taught us how much energy can be liberated in each transformation, whether by the fission of heavy nuclei or the fusion of light ones. In the case of fusion, only the combination of the very lightest nuclei can release very large amounts of energy. When four hydrogen nuclei fuse to form helium, .7 per cent of the mass is transformed into energy. But if four helium nuclei were fused into oxygen, the mass would decrease by only .1 per cent; and the fusion of two silicon atoms, if it ever could occur, would release less than .02 per cent of the mass. Thus there is no prospect of using elements of medium atomic weight for the release of nuclear energy, even in theory.

> **EDITOR'S NOTE**
>
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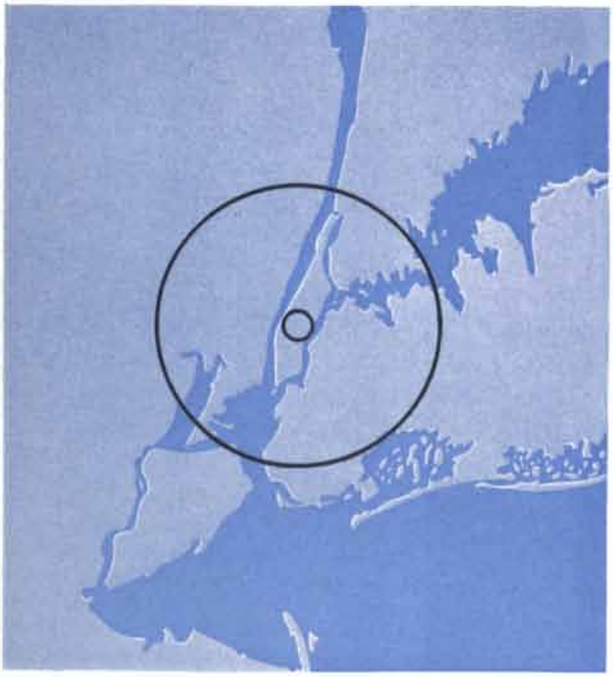
THE main problem in the release of nuclear energy in those cases that we can consider seriously is not the amount of energy released—this is always large enough—but whether there is a mechanism by which the release can take place at a sufficient rate. This consideration is almost invariably ignored by science reporters, who seem to be incurably fascinated by $E=Mc^2$. In fusion the rate of reaction is governed by entirely different factors from those in fission. Fission takes place when a nucleus of uranium or plutonium captures a neutron. Because the neutron has no electric charge and is not repelled by the nucleus, temperature has no important influence on the fission reaction; no matter how slow the neutron, it can enter a uranium nucleus and cause fission. In fusion reactions, on the other hand, two nuclei, both with positive electric charges, must come into contact. To overcome their strong mutual electrical repulsion, the nuclei must move at each other with great speed. Ridenour explained how this is achieved in the laboratory by giving very high velocities to a few nuclei. This method is very inefficient because it is highly unlikely that one of the fast projectiles will hit a target nucleus before it is slowed down by the many collisions with the electrons also present in the atoms of the target. Therefore the energy released by nuclear reactions in these laboratory experiments is always much less than the energy invested in accelerating the particles.

The only known way that energy can be extracted from light nuclei by fusion is by thermonuclear reactions, *i.e.*, those which proceed at exceedingly high temperatures. The prime example of such reactions occurs in the interior of stars, where temperatures are of the order of 20 million degrees Centigrade. At this temperature the average energy of an atom is still only 1,700 electron volts—much less than the energies given to nuclear particles in "atom smashers." But all the particles present—nuclei and electrons—have high kinetic energy, so they are not slowed down by colliding with one another. They will keep their high speeds. Nevertheless, in spite of the high temperature, the nuclear reactions in stars proceed at an extremely slow rate; only one per cent of the hydrogen in the sun is transformed into helium in a billion years. Indeed, it would be catastrophic for the star if the reaction went much faster.

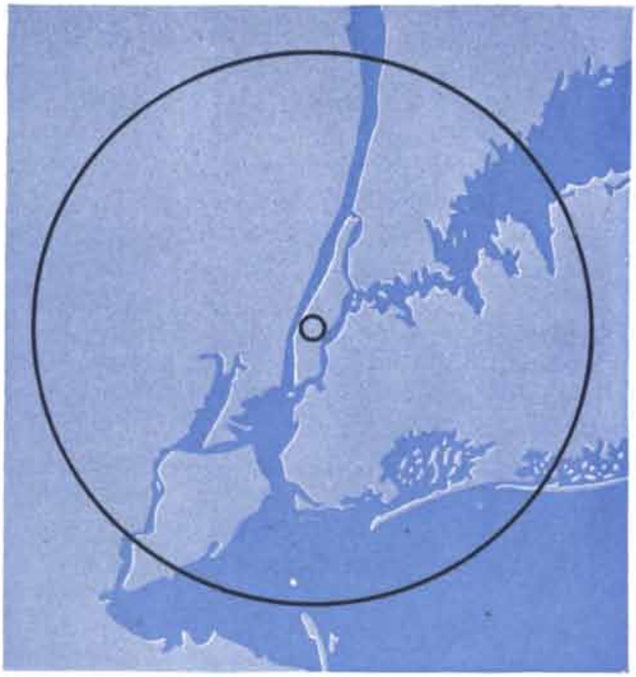
The temperature at the center of a star is kept high and very nearly constant by an interplay of a number of physical forces. The radiation produced by nuclear reactions in the interior can escape from the star only with great difficulty. It proceeds to the surface not in a straight line but by a complicated, zigzag route, since it is constantly absorbed by atoms and re-emitted in new directions. It is this slow escape of radiation that maintains the high interior temperature, which in turn maintains the thermonuclear reactions. Only a star large enough to hold its radiations for a long time can produce significant amounts of energy. The sun's radiation, for example, takes about 10,000 years to escape. A star weighing one tenth as much as the sun would produce so little energy that it would not be visible, and the largest planet, Jupiter, is already so small that it could not maintain nuclear reactions at all. This rules out the possibility that the earth's atmosphere, or the ocean, or the earth's crust, could be set "on fire" by a hydrogen superbomb and the earth thus be converted into a star. Because of the small mass of the bomb, it would heat only a small volume of the earth or its atmosphere, and even if nuclear reactions were started, radiation would carry away the nuclear energy much faster than it developed, and the temperature would drop rapidly so that the nuclear reaction would soon stop.

If thermonuclear reactions are to be initiated on earth, one must take into consideration that any nuclear energy released will be carried away rapidly by radiation, so that it will not be possible to keep the temperature high for a long time. Therefore, if the reaction is to proceed at all, it must proceed very quickly. Reaction times of billions of years, like those in the sun, would never lead to an appreciable energy release; we must think rather in terms of millionths of a second. On the other hand, on earth we have a choice of materials: whereas the stellar reactions can use only the elements that happen to be abundant in stars, notably ordinary hydrogen, we can choose any elements we like for our thermonuclear reactions. We shall obviously choose those with the highest reaction rates.

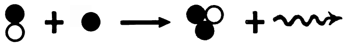
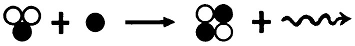
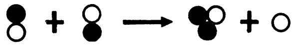
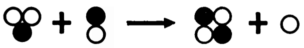
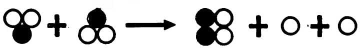
The reaction rate depends first of all, and extremely sensitively, on the product of the charges of the reacting nuclei; the smaller this product, the higher the reaction rate. The highest rates will therefore be obtainable from a reaction between two hydrogen nuclei, because hydrogen has the smallest possible charge—one unit. (The principal reactions in



BLAST EFFECT of present and proposed atomic weapons is projected on a map of New York City and the surrounding area. A uranium bomb set off above the SCIENTIFIC AMERICAN office in midtown would cause severe destruction within a radius of a mile (*small circle*); a hydrogen bomb 1,000 times more powerful would cause severe destruction within 10 miles (*large circle*).



FLASH EFFECT of a hydrogen bomb 1,000 times more powerful than present bombs would be relatively greater than its blast effect. The Hiroshima bomb caused fatal burns at distances up to 4,000 to 5,000 feet (*small circle*). A hydrogen bomb would cause fatal burns at distances of 20 miles or more (*large circle*). The inhabitants of Chicago and its suburbs could thus be wiped out.

$H^1 + H^1 \longrightarrow H^2 + e^+$ 	1.4 mev	100,000,000,000 years
$H^2 + H^1 \longrightarrow He^3 + h\nu$ 	5 mev	.5 second
$H^3 + H^1 \longrightarrow He^4 + h\nu$ 	20 mev	.05 second
$H^2 + H^2 \longrightarrow He^3 + n$ 	3.2 mev	.00003 second
$H^2 + H^2 \longrightarrow H^3 + H^1$ 	4 mev	.00003 second
$H^3 + H^2 \longrightarrow He^4 + n$ 	17 mev	.0000012 second
$H^3 + H^3 \longrightarrow He^4 + n + n$ 	11 mev	?

THE NUCLEAR REACTIONS involving the three isotopes of hydrogen, H^1, H^2 (deuterium) and H^3 (tritium) illustrate a fundamental consideration in making a hydrogen bomb. The reactions are at left, the energy released by each is in center, the time required for each is at right. The reactions involving the heavier isotopes of hydrogen proceed at a much faster rate.

stars are between carbon, of charge six, and hydrogen.) We can choose any of the three hydrogen isotopes, of atomic weight one (proton), two (deuteron) or three (triton). These isotopes undergo different types of nuclear reactions, and the reactions occur at different rates.

The fusion of two protons is called the proton-proton reaction. It has long been known that this reaction is exceedingly slow. As Robert E. Marshak stated in his article, "The Energy of Stars," in the January issue of this magazine, the proton-proton reaction takes 100 billion years to occur at the center of the sun. Ridenour pointed out that the situation is quite different for the reactions using only the heavy isotopes of hydrogen: the deuteron and triton. A number of reported measurements by nuclear physicists have shown that the reaction rates for this type of fusion are high.

A further variable governing the rate of the reaction is the density of the material. The more atoms there are per unit volume, the higher the probability for nuclear collisions.

It is also well known, as Ridenour noted, that the reactions would require enormous temperatures. Whether the temperature necessary to heat heavy hydrogen sufficiently to start a thermonuclear reaction can be achieved on the earth is a major problem in the development of the H-bomb. To find a practical way of initiating H-bombs will require much research and considerable time.

WHAT would be the effects of a hydrogen bomb? Ridenour pointed out that its power would be limited only by the amount of heavy hydrogen that could be carried in the bomb. A bomb carried by a submarine, for instance, could be much more powerful than one carried by a plane. Let us assume an H-bomb releasing 1,000 times as much energy as the Hiroshima bomb. The radius of destruction by blast from a bomb increases as the cube root of the increase in the bomb's power. At Hiroshima the radius of severe destruction was one mile. So an H-bomb would cause almost complete destruction of buildings up to a radius of 10 miles. By the blast effect alone a single bomb could obliterate almost all of Greater New York or Moscow or London or any of the largest cities of the world. But this is not all; we must also consider the heat effects. About 30 per cent of the casualties in Hiroshima were caused by flash burns due to the intense burst of heat radiation from the bomb. Fatal burns were frequent up to distances of 4,000 to 5,000 feet. The radius of heat radiation increases with power at a higher rate than that of blast, namely by the square root of the power instead of the cube root. Thus the H-bomb would widen the range of fatal heat by a factor of 30; it would burn people to death over a radius of up to 20 miles or more. It is too easy to put down or read numbers without understanding them; one must visualize what it would mean if, for instance, Chicago with all its suburbs and most of their inhabitants were wiped out in a single flash.

In addition to blast and heat radiation there are nuclear radiations. Some of these are instantaneous; they are emitted by the exploding bomb itself and may be absorbed by the bodies of persons in the bombed area. Others are delayed; these come from the radioactive nuclei formed as a consequence of the nuclear explosion, and they may be confined to the explosion area or widely dispersed. The bombs, both A and H, emit gamma rays and neutrons while they explode. Either of these radiations can enter the body and cause death or radiation sickness. It is likely, however, that most of the people who would get a lethal dose of radiation from the H-bomb would be killed in any case by flash burn or by collapsing or burning buildings.

There would also be persistent radioactivity. This is of two kinds: the fission products formed in the bomb itself, and the radioactive atoms formed in the environment by the neutrons emitted from the bomb. Since the H-bomb must be triggered by an A-bomb, it will produce at least as many fission products as an A-bomb alone. The neutrons produced by the fusion reactions may greatly increase the radioactive effect. They would be absorbed by the bomb case, by rocks and other material on the ground, and by the air. The bomb case could be so designed that it would become highly radioactive when disintegrated by the explosion. These radioactive atoms would then be carried by the wind over a large area of the bombed country. The radioactive nuclei formed on the ground would contaminate the center of the bombed area for some time, but probably not for very long because the constituents of soil and buildings do not form many long-lived radioactive nuclei by neutron capture.

Neutrons released in the air are finally captured by nitrogen nuclei, which are thereby transformed into radioactive carbon 14. This isotope, however, has a long half-life—5,000 years—and therefore its radioactivity is relatively weak. Consequently even if many bombs were exploded, it is not likely that the carbon 14 would become dangerous.

THE decision to proceed with the development of hydrogen bombs has been made. I believe that this decision settles only one question and raises a hundred in its place. What will the bomb do to our strategic position? Will it restore to us the superiority in armament that we possessed before the Russians obtained the A-bomb? Will it improve our chances of winning the next war if one should come? Will it diminish the likelihood that we should see our cities destroyed in that war? Will it serve to avert or postpone war itself? How will the world look after a war fought with hydrogen bombs?

I believe the most important question is the moral one: Can we who have always insisted on morality and human decency between nations as well as inside our own country, introduce this weapon of total annihilation into the world? The usual argument, heard in the frantic week before the President's decision and frequently since, is that we are fighting against a country which denies all the human values we cherish, and that any weapon, however terrible, must be used to prevent that country and its creed from dominating the world. It is argued that it would be better for us to lose our lives than our liberty, and with this view I personally agree. But I believe this is not the choice facing us here; I believe that in a war fought with hydrogen bombs we would lose not only many lives but all our liberties and human values as well.

Whoever wishes to use the hydrogen bomb in our conflict with the U.S.S.R., either as a threat or in actual warfare, is adhering to the old fallacy that the ends justify the means. The fallacy is the more obvious because our conflict with the U.S.S.R. is mainly about means. It is the means that the U.S.S.R. is using, both in dealing with her own citizens and with other nations, that we abhor; we have little quarrel with the professed aim of providing a decent standard of living for all. We would invalidate our cause if we were to use in our fight means that can only be termed mass slaughter.

We believe in personal liberty and human dignity, the value and importance of the individual, sincerity and openness in the dealings between men and between nations, prosperity for all and peace based on mutual trust. All this is in great contrast to the methods which the Soviet Government uses in pursuing its aims and which it believes necessary in the "beginning phase" of Communism—which by now has lasted 33 years. Regimentation of the private lives of all citizens, systematic education in spying upon one's friends, ruthless shifting of populations regardless of their personal ties and preferences, inhuman treatment of prisoners in labor camps, suppression of free speech, falsification of history in dealing both with their own citizens and with other nations, violation of promises and treaties and the distorted interpretations offered in excuse of these violations—these are some of the methods of the U.S.S.R. which are hateful to the people of the Western World. But if we wish to fight against these methods, *our* methods must be clean.

We believe in peace based on mutual trust. Shall we achieve it by using hydrogen bombs? Shall we convince the Russians of the value of the individual by killing millions of them? If we fight a war and win it with H-bombs, what history will remember is not the ideals we were fighting for but the methods we used to accomplish them. These methods will be compared to the warfare of Genghis Khan, who ruthlessly killed every last inhabitant of Persia.

WHAT would an all-out war fought with hydrogen bombs mean? It would mean the obliteration of all large cities and probably of many smaller ones, and the killing of most of their inhabitants. After such a war, nothing that resembled present civilization would remain. The fight for mere survival would dominate everything. The destruction of the cities might set technology back a hundred years or more. In a generation even the knowledge of technology and science might disappear, because there would be no opportunity to practice them. Indeed it is likely that technology and science, having brought such utter misery upon man, would be suspected as works of the devil, and that a new Dark Age would begin on earth.

We know what physical destruction does to the moral values of a people. We have seen how many Germans, already demoralized by the Nazis, lost all sense of morality when during and after the war the bare necessities of life, food, clothing and shelter were lacking. Democracy and human decency were empty words; there was no reserve strength left for such luxuries. If we have learned any lesson from the aftermath of World War II, it is that physical destruction brings moral destruction.

We have also learned that prosperity is the best shield against communism and dictatorship, and in this knowledge we have poured billions into Western Europe to restore her economy. This generosity has won us more friends than anything else we have done. But after the next war, if it were fought with atomic and hydrogen bombs, our own country would be as grievously destroyed as Europe and the U.S.S.R., and we could no longer afford such generosity. It would be everyone for himself, and everyone against the other.

It is ironical that the U. S. of all countries should lead in developing such methods of warfare. The military methods adopted by this nation at the outset of the Second World War had the aim of conserving lives as much as possible. Determined not to repeat the slaughter of the First World War, during which hundreds of thousands of soldiers were sacrificed in fruitless frontal attacks, the U. S. high command substituted war by machines for war by unprotected men. But the hydrogen bomb carries mechanical warfare to ultimate absurdity in defeating its own aim. Instead of saving lives, it takes many more lives; in place of one soldier who would die in battle, it kills a hundred noncombatant civilians. Surely it is time for us to reconsider what our real intentions are.

One may well ask: Why advance such arguments with reference to the H-bomb and not atomic bombs in general? Is an atomic bomb moral and a hydrogen bomb immoral, and if so, where is the dividing line? I believe there was a deep feeling in this country right after the war that the use of atomic bombs in Japan had been a mistake, and that these bombs should be eliminated from national armaments. This feeling, indeed, was one of the prime reasons for President Truman's offer of international control in 1945. We know that the negotiations for control have not led to success as yet. But our inability to eliminate atomic bombs is no reason to introduce a bomb which is a thousand times worse.

When atomic bombs were first introduced, there was a general feeling that they represented something new, that the thousandfold increase of destructive power from blockbuster to atom bomb required and made possible a new approach. The step from atomic to hydrogen bombs is just as great again, so we have again an equally strong reason to seek a new approach. We have to think how we can save humanity from this ultimate disaster. And we must break the habit, which seems to have taken hold of this nation, of considering every weapon as just another piece of machinery and a fair means to win our struggle with the U.S.S.R.

I HAVE reviewed the moral issues that should deter us from using hydrogen bombs even if we were sure that we alone would have them, and that they would contribute to our victory. As Ridenour explained, the situation is rather the opposite. We can hardly expect to have a monopoly on hydrogen bombs. If we ever had any illusions about this, the events of the past few months should have destroyed them. The U.S.S.R. has the atomic bomb. She was undoubtedly helped in her efforts by the secret information she received from Klaus Fuchs, which presumably included many of the vital "secrets" of our project. But knowing how a group of scientists put the bomb together would not by itself enable a nation to make one. If Fuchs had given his information to Spain, for instance, it would hardly have been understood; it would presumably not have been used, and even if used it would almost certainly not have led to success. The prime requirements for the job still are a group of highly capable scientists, a country determined to make the weapon and a great industrial effort. We know now, if we ever doubted it, that the U.S.S.R. has all of these. For the Soviet scientists the information must simply have resolved many doubts as to which steps to take next and saved a number of costly and futile parallel developments.

Their obvious competence will presumably again bring success to the Russians when they try to develop the H-bomb. Yet their decisions and their successes are not independent of our own. Our decision to make the H-bomb, which showed that we considered the project feasible, may well have prompted them to take the same decision. For this reason I think that our decision, if taken at all, should have been taken in secret. This became impossible, however, when the advocates of the H-bomb used public statements as a means of exerting pressure on the President. If the Russians were already working on the H-bomb before our decision, they will now have increased their effort.

It is impossible to predict whether we or the Russians will have the hydrogen bomb first. We like to assume that we shall. If so, I refuse to believe that the U. S. would start a preventive war. That would violate all the fundamental beliefs of this nation, and that these beliefs are still strong is shown by the history of the past four years: although we had a monopoly of the atomic bomb we did not start a war. Clearly, then, the time will come when both the U.S.S.R. and this country will have H-bombs. Then this country will be much more vulnerable than the U.S.S.R.: as Ridenour explained, we have many more large cities that would be inviting targets, and many of these lie near the coast so that they could be reached by submarine and perhaps a relatively short-range rocket. I think it is therefore correct to say that the existence of the hydrogen bomb will give us military weakness rather than strength.

BUT, say the advocates of the bomb, what if the Russians obtain the H-bomb first? If the Russians have the bomb, Harold Urey argued in a speech just before the President's decision, they may confront us with an ultimatum to surrender. I do not believe we would accept such an ultimatum even if we did not have the H-bomb, or that we would need to. I doubt that the hydrogen bomb, dreadful as it would be, could win a war in one stroke. Though it might devastate our cities and cripple our ability to conduct a long war with all modern weapons, it would not seriously affect our power for immediate retaliation. Our atomic bombs, whether "old style" or hydrogen, and our planes would presumably be so distributed that they could not all be wiped out at the same time; they would still be ready to take off and reduce the country of the aggressor to at least the same state as our own. Thus the large bomb would bring untold destruction but no decision. I believe that "old-fashioned" A-bombs would be sufficient to even the score in case of an initial Soviet attack with H-bombs on this country. In fact, because of the greater number available, A-bombs may well be more effective in destroying legitimate military targets, including production centers. H-bombs, after all, would be useful only against the largest targets, of which there are very few in the U.S.S.R.

So we come finally to one reason, and only one, that can justify our building the H-bomb: namely, to deter the Russians from using it against us, if only for fear of our retaliation. Our possession of the bomb might possibly put us in a better position if the U.S.S.R. should present us with an ultimatum based on their possession of it. In other words, the one purpose of our development of the bomb would be to prevent its use, not to use it.

If this is our reason, we can contribute much to the peace of the world by stating this reason openly. This could be done in a declaration, either by Congress or by the President, that the U. S. will never be the first to use the hydrogen bomb, that we would employ the weapon only if it were used against us or one of our allies. A pledge of this kind was proposed in a press statement by 12 physicists, including myself, on February 4. It still appears to me as a practical step toward relief of the international tension, and toward freedom from fear for the world. The pledge would indicate our desire to avoid needless destruction; it would reduce the likelihood of the use of the hydrogen bomb in the case of war, and it would largely eliminate the danger that fear of the H-bomb itself would precipitate a war.

If we do not make this pledge, the hydrogen bomb would almost surely be used. Once war broke out, our military leaders would be blamed, in the absence of a pledge, if they did not immediately initiate a full-scale hydrogen-bomb attack. But if such a pledge existed, they would be blamed if they did use the bomb first. To be sure, the pledge might not be relied on by our adversaries, but at least it would create a doubt in their minds and they might decide to wait and see. Perhaps they would not wish to provoke the certain use of the bomb by dropping the first one. Moreover, if they started a war, they would probably hope to capture our country and to exploit its wealth rather than to conquer a heap of rubble.

We have proposed unilateral action rather than an international treaty on this pledge. We have done this because negotiations with the U.S.S.R. are known to be long and frustrating. A unilateral pledge involving only this country could be made quickly, and it could not again lead to the disappointment of a break-down of negotiations. On the other hand, we certainly would not want to exclude a pact with the U.S.S.R. on this subject. This might be the first point on which the two countries could agree, and this in itself would be important.

Obviously the pledge can only be a first step. What we really want is a workable agreement on atomic energy, as part of our efforts toward a lasting peace. Much has been said in the last few weeks about new negotiations on atomic control. Opinions vary from that of Senator Brien McMahon, who proposed to spend $50 billion for rehabilitation of war-devastated countries including the U.S.S.R. in exchange for an atomic settlement, to that of Senator Millard Tydings, who declared that an atomic settlement would not be acceptable to this country unless it was coupled with general disarmament, which he has advocated for a long time. Both of these viewpoints, and those of many other Senators, show the desire of this country for some agreement. At the same time there are persistent reports, clearly indicated in recent dispatches from the New York *Times* correspondent in Moscow, that the Russians might like to negotiate. It seems to me that too much is at stake to miss any such opportunity.

ON the other hand, President Truman voiced the fears of many of us when he stated recently that there is no security in agreements with the Russians because they break them at will. He referred to the agreements of Yalta and Potsdam in 1945. Since then we have learned much about Soviet methods, and the Russians have found that we do not retreat as easily as they apparently imagined in 1945. This more realistic mutual appraisal makes it much more likely that we could now come to arrangements which neither side would regret afterward. Obviously in any negotiation each side must be willing to make concessions and to consider primarily proposals directed to mutual advantage rather than superiority over the other.

The situation in atomic energy has changed, both because of the Soviet development of the A-bomb and because of our decision on the H-bomb. To leave atomic weapons uncontrolled would be against the best interests of both countries. If we can negotiate seriously with the U.S.S.R., the scope of the negotiations should probably be as broad as possible. But the situation would be greatly eased even if we could agree only to eliminate the greatest menace to civilization, the hydrogen bomb.

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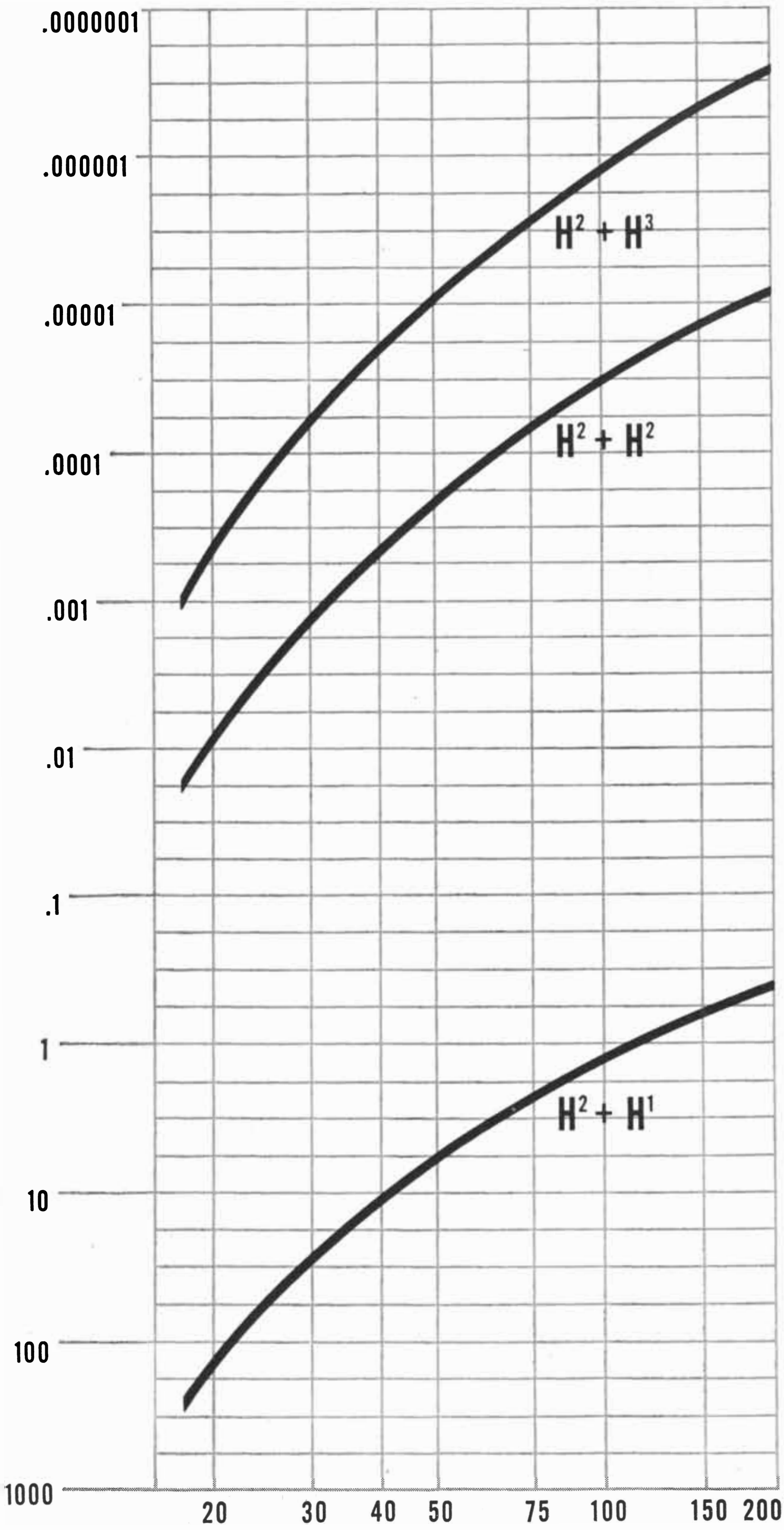


THE TIME REQUIRED for the nuclear reactions between deuterons (H^2 nuclei) and each of the three hydrogen isotopes is plotted against temperature. The vertical coordinate is in seconds; the horizontal coordinate in millions of degrees Centigrade. Deuteron-triton reaction proceeds fastest. Sun's temperature is 6,000 degrees at surface, 20 million degrees at center.

The Metamorphosis of Insects

The phenomenon has long fascinated naturalists; now it sheds light on the forces that regulate growth and direct the specialization of cells

by Carroll M. Williams

THE human infant at birth contains about 10 trillion cells—the progeny of a single pair of cells derived from its parents. During the embryonic period of 10 lunar months, many of these cells possess the capacity for unlimited and disorderly growth. From experiments on animals we know that such cells, removed from the early embryo and cultured in a flask of nutrient solution, may grow aimlessly and without apparent restraint. Yet as long as they remain part of the embryo, their behavior is marvelously coordinated. As if in conformity to some master blueprint, sooner or later each cell becomes committed to a precise and humble role in the final organism. During the embryonic period each cell also comes under influences that restrict its growth and multiplication; if it did not, the final result would be not an infant but a monster. The original fertilized egg divides into two cells, the two into four, the four into eight, and so on through an average of 43 divisions to produce the 10 trillion cells of the human infant. The process must stop right there. If the cells of the growing embryo underwent 63 divisions, say, instead of 43, the infant at birth would be larger than a sulfur-bottom whale.

So the forces at work in the embryo must do two things: regulate the growth of the cells in the enlarging community and assign to each cell a specific role in the total organism. These forces obviously are not the exclusive property of the higher and more pretentious animals. Even in plants and animals too small to be seen with the naked eye, it is easy to show that the individual parts are held servant to a predictable and hereditary design of the organism as a whole. Evidently the perfection of mechanisms for controlling growth and differentiation was among the earliest accomplishments in the evolution of life.

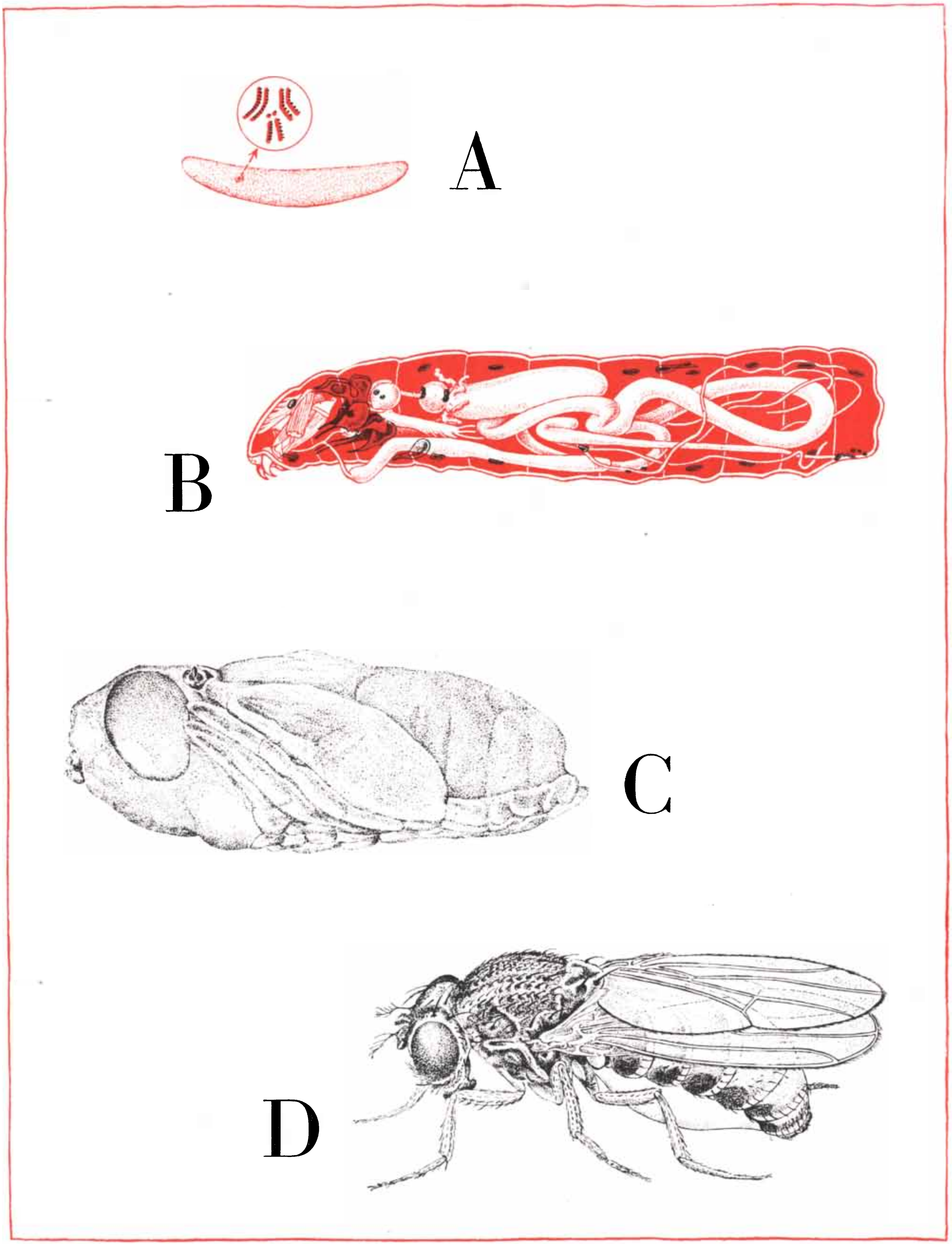
This being so, biologists have been able to study these mechanisms, so important to the human species, in a varied assortment of "beasts, fowl and creeping things." Indeed, it is fair to say that studies of the human species itself have made scant contribution to our present understanding of the matter; the bulk of our knowledge is based on studies of less intricate organisms ranging from oat seedlings to tadpoles. Particularly illuminating is the investigation of the metamorphosis of insects. Insects that metamorphose are especially interesting subjects for our study because in them the formative processes are prolonged throughout the life span, instead of being restricted to the period of embryonic development, as in most other animals. Insect metamorphosis is an old story to biologists and students of natural history; it has recently been reopened with the fresh purpose of learning what it has to tell us about the basic problems of growth and differentiation.

CONSIDER, for example, an extreme type of metamorphosis, such as that of the fruit fly. The animal's life is partitioned into four distinct stages—egg, larva, pupa and adult. The pertinent events in its metamorphosis actually begin within the unhatched egg. At this stage the eggshell encloses a yolk-filled space of no apparent structure. Under the microscope, however, the yolk particles are found enmeshed in a network of living protoplasm which surrounds a single centrally placed nucleus. It is this nucleus (more precisely, the genes on the chromosomes within the nucleus) that represents the hereditary blueprint of the future organism. In fact there is a double set of blueprints, since the nucleus contains two complete sets of chromosomes and genes, one contributed by the paternal fly and the other by the maternal fly. What we shall witness is the orderly construction of an organism according to a detailed hereditary formula.

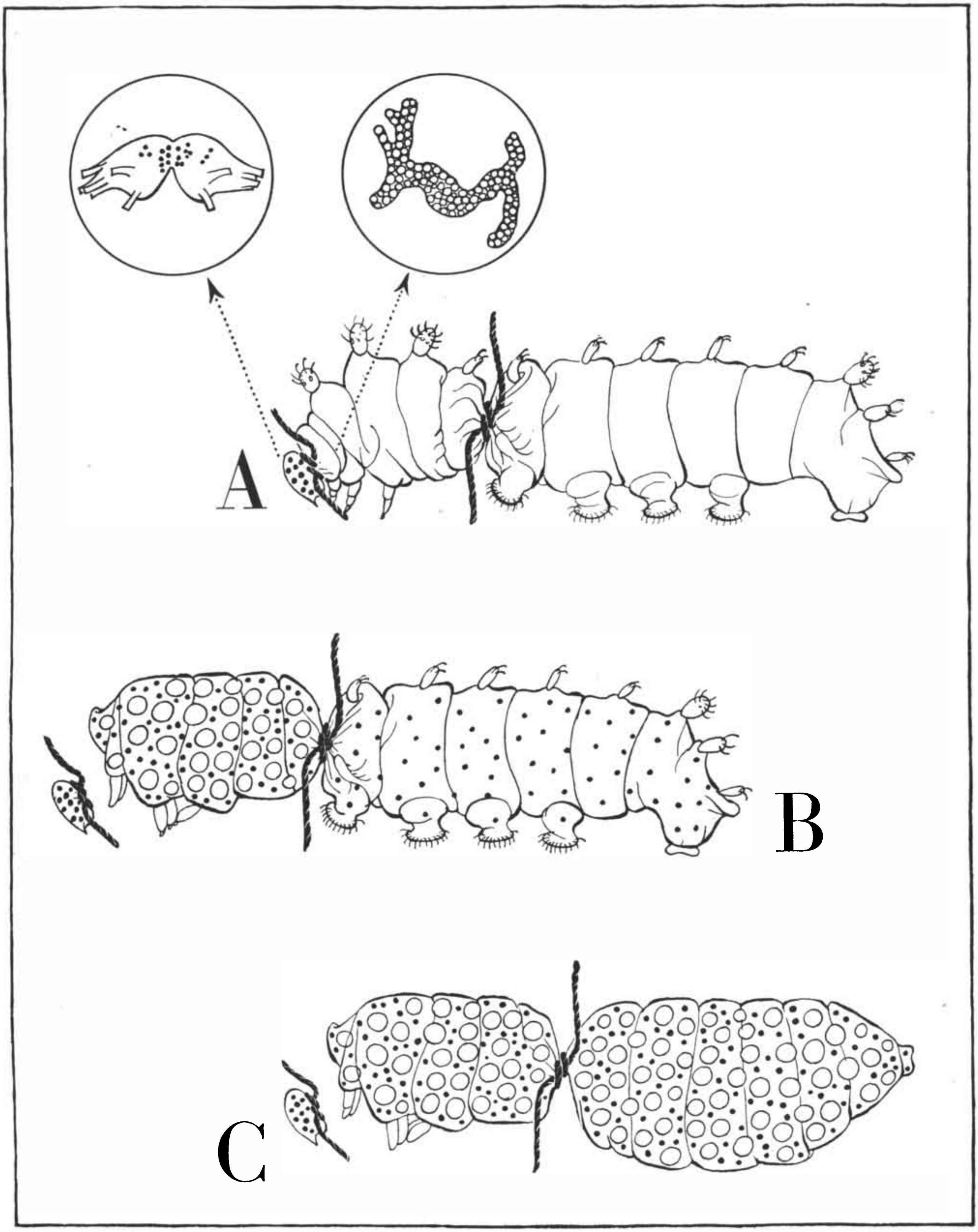
The first thing that happens after the egg has been fertilized is a subdivision of the single nucleus into two separate nuclei, followed by a further series of nuclear divisions. There is convincing evidence that each of these divisions is preceded by a duplication of each pair of genes. In consequence the multiplication of nuclei does not dilute the genetic material, although each nucleus is equipped with a full set of genes. The egg at this stage consists of a single yolk-rich cell containing several hundred nuclei. As the latter continue to divide, they seem to be attracted toward the outermost region of the egg. Then for the first time cell boundaries are laid down around the nuclei and the single multinucleated egg is transformed into a hollow, yolk-filled ball of cells.

Only those nuclei that are fortunate enough to land along the axis of the belly of the egg will contribute to the formation of the embryo itself. The vast majority come to rest elsewhere, and are destined to form embryonic membranes that are ultimately discarded. As the English biologist V. B. Wigglesworth has remarked, "the cells are but bricks; whether they play a noble or a humble part in the final building is decided by the chance of where they fall."

Few phenomena in biology are as baffling as the events that now take place:



LIFE OF THE FRUIT FLY begins with the fertilized egg (A), which grows into the larva (B). The organism then metamorphoses into the pupa (C) and finally the adult fly (D). The single nucleus of the fertilized egg (*inset*) contains eight chromosomes, four from each parent. Indicated within the chromosomes are the genes, the hereditary blueprints of the organism. Indicated in black within the larva are the imaginal disks, which develop into the pupa and the adult fly. The larval tissues indicated in red break down in metamorphosis.



METAMORPHOSIS OF THE SILKWORM (*i.e.,* the larva of the Cecropia moth) to the pupa is examined by experiment. Silkworm tissues require for metamorphosis a hormone secreted by the prothoracic gland (*right inset*). This gland must in turn be stimulated by a hormone secreted in the brain (*left inset*). Here three silkworms have been tied off into three compartments at three ages. Silkworm A is tied off before the brain hormone (*dots*) is secreted; the silkworm fails to pupate. Silkworm B is tied off after the brain hormone has circulated throughout its body, but before it has set off the prothoracic gland. The prothoracic hormone (*circles*) is restricted to the thorax, and only the thorax pupates. Silkworm C, tied off still later, pupates completely.

From a region of the ovum that will form the future thorax, there arises an influence of unknown nature that spreads like a wave over the embryo. As it traverses the hollow ball of cells it casts the majority of the cells for the specific parts they will play in the future larval insect. A few hours later the same thoracic center generates a second wave of determination that commits other cells to the formation of specific parts in the pupal and adult insect. Now, though the embryo still consists only of a hollow, yolk-filled ball of cells, the plans of two future organisms, the larval and pupal-adult insects, have already been roughed out. Two living systems exist side by side—one destined to form the larva, the other the pupal and adult fly.

UP to this point any cell in the embryo could have contributed to any part of the final insect, for each cell is equipped with a complete set of genes, and these are the blueprints of the total organism. With one swift stroke the influence of the thoracic center has altered the cells' potentialities. Each cell continues to possess a full set of genes, but these genes now direct the cell toward a specific fate and function. Thus the cell accepts a specialized role in the organism by surrendering its other latent potentialities.

Now the cells committed to the formation of the larva rapidly execute their various developmental tasks. Within a few hours a tiny fly larva crawls from the egg. During the four days that follow, the headless, footless, wingless larva grows rapidly, twice molting its skin. Curiously this growth of the fly larva occurs not by multiplication but solely by enlargement of the cells. When the larva matures it has no more larval cells than were present when it hatched from the egg.

Meanwhile the embryonic cells that were committed to the formation of the pupa and adult also are present, but take no part in the larva's domestic affairs. They are found scattered throughout the larva in the form of little nests of cells called "imaginal disks." These disks are held under biochemical restraint by a hormone circulating in the blood which prevents them from differentiating into the pupal and adult organs. Though the disks grow at approximately the same rate as the larva itself, their growth takes place by cellular division, not by enlargement. In other words, the growing fly larva is a kind of double individual, one within the other and each growing by a totally different method.

When the larva is full-grown, its skin hardens and darkens, and the animal rounds into an oval mass. The larva is now motionless and seemingly dead, yet extraordinary events are occurring inside. The larval cells are indeed dying, but simultaneously the imaginal disks throughout the body spurt in growth and differentiate into the organs of the pupal insect. In this process the growing cells utilize the dead larval tissues as a kind of elegant culture medium. The net result is that the larval tissues are replaced by pupal tissues derived from the imaginal disks. Soon afterward the pupal organs are transformed into the complicated structures of the adult fly.

What can be learned from such a peculiar sequence of events? For one thing we see that the fly larva is a rather different organism from the pupa and adult. The imaginal disks, the precursors of the mature animal, live a kind of parasitic existence within the host larva and in the process of pupation appropriate the larval corpse to nourish their growth. Thus the assets of the larva are finally liquidated and reinvested in what may be regarded as a new organism.

From such a life history a further implication is self-evident. There must be some over-all mechanism of control whereby the death of one developmental system, the larva, is synchronized with the birth of a second developmental system, the pupa and adult. This mechanism fortunately has proved more accessible to experimental analysis than the earlier and more perplexing events occurring in the egg. Indeed, some illuminating experiments can be performed with no more equipment than a few dozen insects and a piece of string.

BECAUSE of their small size, fly larvae are not as suitable for such experiments as certain larger larvae; for example, the Cecropia silkworm. The experiments consist in tying string around the insect's body in such a way as to divide the animal into two or more horizontal compartments. The most interesting results are obtained when one ligature is placed transversely behind the head and another just behind the thorax, thereby dividing the larva into three compartments—head, thorax and abdomen.

The isolated head promptly dies, but the behavior of the thorax and abdomen depends on the stage of maturity of the silkworm at the time of ligation. If a mature Cecropia silkworm is subdivided before the cocoon is spun, its metamorphosis is completely arrested. Both the thoracic and abdominal compartments continue to live for several months, but neither can transform to the pupal state. This fact suggests that the pupation of the thorax and abdomen requires some factor derived from the head of the caterpillar. And this indeed is found to be the case, for if the same treatment is applied two days later, after the larva has finished spinning its cocoon, the thoracic compartment now undergoes pupation. Evidently during the period of the spinning of the cocoon the head releases the required factor. Further experiments show that the pertinent factor is a hormone which is secreted by about two dozen nerve cells within the brain.

This brain hormone seems to have a limited function. Its principal role is to trigger the secretion of a second hormone by a pair of endocrine organs located in the thorax, the "prothoracic glands." The second hormone in turn acts on the imaginal disks to provoke the transformation of the larva into a pupa. The prothoracic glands secrete this "growth and differentiation hormone" during a period of three days after being acted upon by the brain hormone. If ligatures are placed on the silkworm less than three days after the completion of the cocoon, the thoracic compartment undergoes pupation, but the abdominal compartment does not. Only after the three-day period does the abdomen acquire the necessary concentration of growth and differentiation hormone.

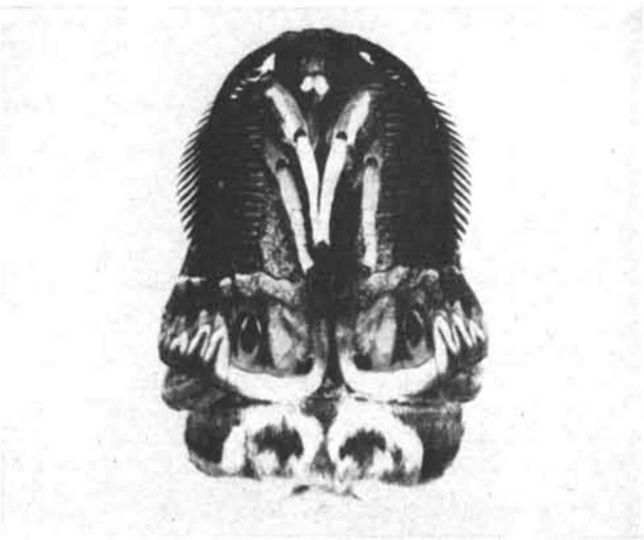
These simple experiments demonstrate that the insect brain is an unusual organ, serving as the highest center in both the nervous and the endocrine systems. A further strange finding is that the growth and differentiation hormone from the prothoracic glands seems to act back on the brain to shut off the secretion of the brain hormone. Thus the endocrinological system of the insect is a kind of self-balancing mechanism, using a biological application of the "negative feedback" principle to regulate the flow of hormone.

The brain and the prothoracic glands control not only the formation of the pupa but the development of the adult moth from the pupa. After the pupation of the Cecropia silkworm, the brain ceases to secrete its hormone for many months. This accounts for the state of dormancy in which the pupa spends the winter. The months of exposure to winter's low temperatures serve to build up the brain's activity again. In the spring the brain releases its hormone and terminates dormancy. Thus does the secretory activity of the brain synchronize the life history of the animal with the seasons.

ALTHOUGH our information is still incomplete, it seems probable that the growth and recurrent molting of insects in the larval stage also require this very same growth and differentiation hormone. There is one important difference, however. During the period of larval life the tissues are exposed to a third hormone secreted by a tiny pair of glands located just behind the brain—the "corpora allata." If these glands are surgically removed when the caterpillars are young and immature, the animals undergo precocious pupation at the very next molt and ultimately develop into midget-sized adult moths.

It appears that this "juvenile hor-

ANTERIOR HALF of a Cecropia pupa is cut off from the posterior half (*below*) and its brain removed. The fragment remains alive, but it cannot metamorphose.



ANTERIOR HALF METAMORPHOSES when a living brain is implanted in it. The brain hormone causes prothoracic gland to liberate metamorphic hormone.

POSTERIOR HALF of the pupa also remains alive after it is cut off from anterior. It lacks both brain and prothoracic gland, however, and cannot metamorphose.

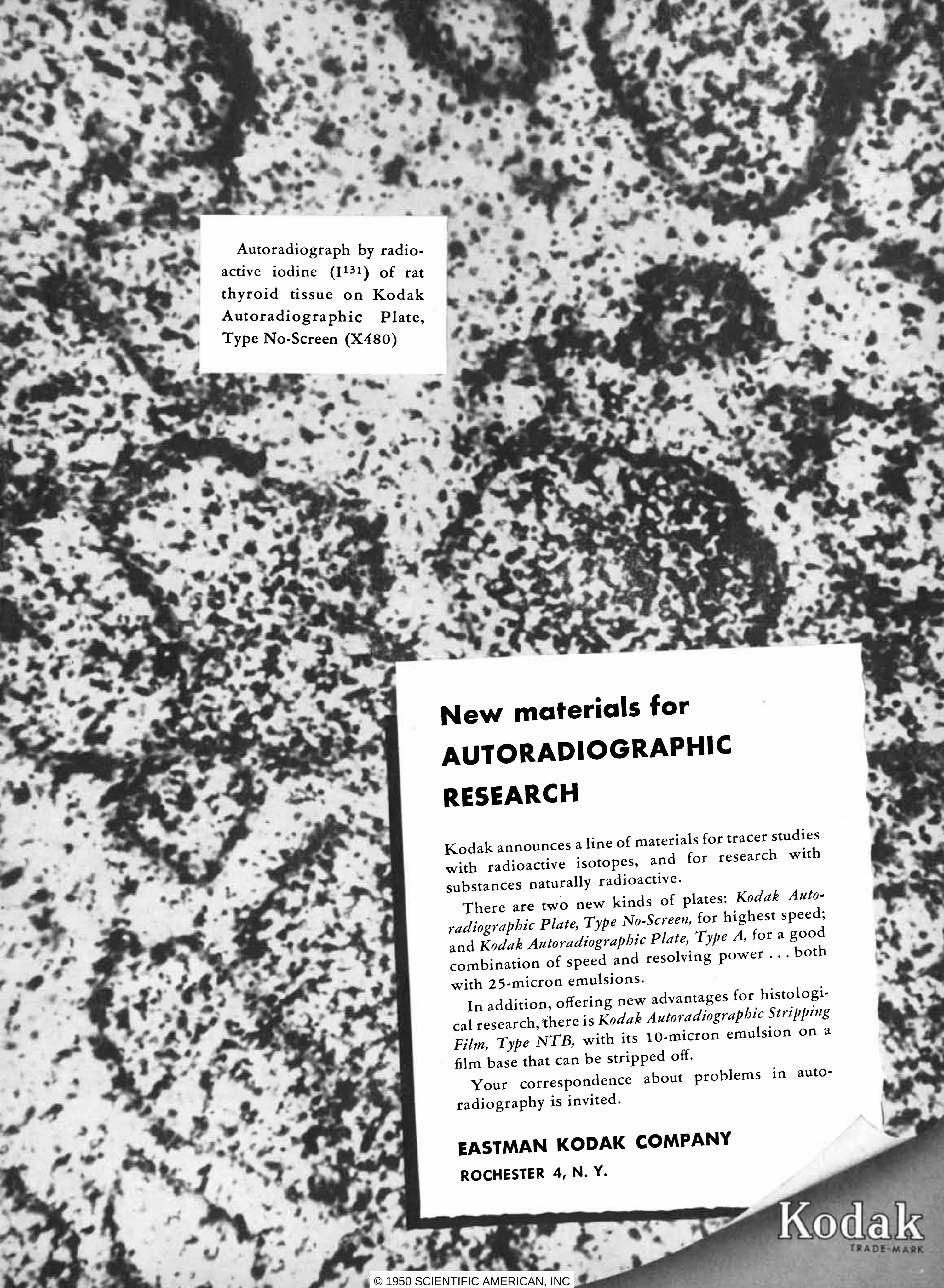
POSTERIOR HALF METAMORPHOSES when brain and prothoracic gland are implanted in it. The brain hormone again calls forth the prothoracic hormone.

mone" secreted by the corpora allata acts as a stabilizing factor during the larval life of the insect. It does not interfere with the growth of the imaginal disks or of the larva; it merely prevents them from proceeding further in their differentiation. Late in larval life the corpora allata apparently are shut off by some unknown mechanism and discontinue the secretion of juvenile hormone. The imaginal disks, released from this biochemical restraint, immediately respond to the growth and differentiation hormone by differentiating into the pupal parts. And for the larval tissues the same transition signals biological death. In short, the stirring events that culminate in the fabrication of the pupa and the simultaneous death of the larval tissues are set in motion by the production of one hormone and the withdrawal of another.

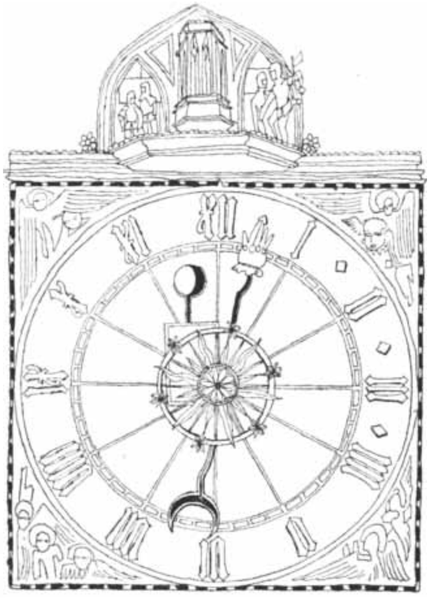
Surveying our present knowledge of metamorphosis, it is difficult to avoid the conclusion that the post-embryonic development of an insect is the acting out of a sequence of roles which has been assigned the individual cells according to a genetic formula during early embryonic development. Presumably as a result of the mysterious "waves of determination" that sweep over the embryo at that time, each cell is endowed with a detailed program of differentiation, to the execution of which certain specialized tissues such as the brain, prothoracic glands and corpora allata provide specific biochemical cues. Though much has been learned about the latter processes, we cannot yet pretend to understand the earlier mechanisms whereby the cells are made servant to the distant goals of the organism as a whole. For though each cell, as we have seen, is equipped with a blueprint of the total organism, its fate is decided by influences that are the common property of the entire growing system.

Between the gene and the final organism as a unified going concern there is obviously room enough for the labors of a whole generation of biologists. Meanwhile we have cause to rejoice in the proof that the living organism knows what it is doing—and does it effectively.

Carroll M. Williams is associate professor of zoology at Harvard University.



Autoradiograph by radioactive iodine (I^{131}) of rat thyroid tissue on Kodak Autoradiographic Plate, Type No-Screen (X480)



National Science Foundation

THE bill to establish a National Science Foundation, which had been held in the House of Representatives for nearly two years, began to show signs of emerging last month, but in a form that threatened to result in a stillbirth. The House passed and sent to the Senate a revised version of the bill to which many scientists objected.

One of the major changes in the bill was an amendment, sponsored by Representative Howard A. Smith and unanimously accepted by the House on a voice vote, which would require approval by the Federal Bureau of Investigation of everyone connected with the proposed Foundation. The amendment said: "No person shall be employed by the Foundation and no scholarship shall be awarded to any person by the Foundation unless and until the FBI shall have investigated such person and reported to the Foundation that such person is loyal to the U. S., believes in our system of government, and is not and has not been at any time a member of any organization declared subversive by the Attorney General or any organization that teaches or advocates the overthrow of the government of the U. S. by force and violence." Another amendment, evidently prompted by the Fuchs case, would require FBI clearance of any foreign citizen associated with the Foundation "in any way whatsoever."

Another change in the bill that greatly disturbed its proponents was a sharp cut in the proposed funds for the Foundation. The bill would limit the Foundation to $500,000 in its first year and to a maximum of $15 million a year thereafter, instead of the $20 million allowed in the bill previously passed by the Senate. Still other revisions forbid the Foundation to support any research in the broad field of atomic energy without the consent of the Atomic Energy Commission, and direct the Foundation to conduct classified military research.

The Federation of American Scientists asserted that Rep. Smith's FBI amendment "strikes at the heart of scientific support of the legislation." It added:

"There seems little doubt, considering that the amendment goes far beyond anything previously enacted for a Federal agency, that its intent is more to kill the bill than to protect security. H. R. 4846, as it emerged from the House, has been so altered that many scientists undoubtedly will want to reconsider the support they have long given to the legislation. . . . The Foundation is severely limited by budgetary and other restrictions—so severely as to raise serious doubts that it can make a significant contribution to the national science effort. In addition, the Foundation is open to distortion by military interest. Under H. R. 4846 as amended, we have not realized the hope of freeing basic research from security limitations by segregating such research in an exclusive agency. Finally, the bill contains provisions profoundly repugnant to the traditions and aspirations of scientists."

The Council of the National Academy of Sciences also expressed to Congress its strong objection to the Smith amendment. The Council said: "We are convinced that this provision, if made into law, would so distort the purpose of the original bill as to work serious damage to the development of science in the U. S."

Having passed the House, the bill went to a House-Senate conference committee for resolution of its differences with the Senate bill, which scientists favor. As this issue went to press, the Washington representatives of scientific organizations were seeking to persuade the conference committee to drop the objectionable amendments, particularly the one requiring FBI investigations. If they failed, it seemed likely that they would urge defeat of the bill.

Atomic Spy

THE celebrated case of Klaus Fuchs, atomic spy, came to a swift end last month. Fuchs, a German Communist who went to England in 1933, became a wartime participant in the atomic bomb project and most recently was head of the theoretical physics division at the British atomic energy research center at Harwell, pleaded guilty to having transmitted atomic secrets to agents of the U.S.S.R. He confessed to four specific contacts with these agents: in Birmingham, England, in 1943; in New York City in 1944; in Boston in February, 1945, and in Berkshire, England, in 1947. His trial in a British court did not disclose what information he had given, but it was stated to be considerable. Convicted of violation of the British Official Secrets Act of 1911, Fuchs received the maximum sentence of 14 years in prison.

A strange feature of the case was that the U.S.S.R. repudiated Fuchs' confession. Tass, the Soviet news agency, said that "Fuchs is unknown to the Soviet Government and no 'agents' of the Soviet Union had any connection with Fuchs."

The case deeply disturbed atomic scientists in Britain and the U. S., both because a scientist had betrayed his trust and because the affair promised to result in still further restrictions on scientific work in both countries. Yet they felt that if the Fuchs case had any lesson to offer, it was the essential futility of the great and growing structure of secrecy in the field of atomic energy. The fact that, in spite of the security precautions, atomic secrets had "leaked" was a proof of what many scientists had contended: that it is altogether impractical to expect to maintain the secrecy of a project that has employed hundreds of thousands of persons.

As a result of the Fuchs case, the negotiations among the U. S., Canada and Great Britain, looking toward an agreement for increased exchange of information and cooperation in atomic energy research among the three countries, were broken off.

Increase

SINCE 1900 the population of the U. S. has doubled; in a half-century it has grown as much as in the previous 300 years. This is the most striking fact in a mid-century review of vital statistics by the Metropolitan Life Insurance Company, which reports that the U. S. population is now well over 150 million. During the 50-year period the population of California, the fastest-growing state, increased by 600 per cent, and that of the Far West as a whole by 400 per cent. Florida, Michigan, Oklahoma and Texas also had large gains. Among the cities Washington, D. C., had the most spectacular growth; its population trebled. The lowest rates of increase, as is to be expected, were shown by northern New England and farm areas of the Midwest and South.

In 1949 a new low in the U. S. death rate and a new high in life expectancy were recorded, according to statisticians of Metropolitan and the Federal Security Agency. Sharp decreases were reported in deaths from influenza, pneumonia, tuberculosis, childhood diseases, childbirth hazards, syphilis, appendicitis, rheumatic fever, typhoid fever, diarrhea and enteritis. "External hazards" have also been reduced: between 1911 and 1949 accidental deaths among Metropolitan's policyholders fell 51 per cent, homicides 60 per cent and suicides 47 per cent. These successes make the diseases of middle and old age, particularly chronic heart disease and cancer, the main causes of death now.

The average life expectancy in the U. S. in 1949 was 67.8. Mortality in every age period has decreased, but most sharply in childhood and early adulthood. However, these cheerful statistics do not apply uniformly to all groups in the U. S. population. For example, the death rate among infants less than one year old in 1949 was only 32.2 per 1,000 for white babies, but almost twice that—56.5 per 1,000—for "nonwhites."

Oak Blight

THERE seems to be some danger that the lordly oak may go the way of the spreading chestnut tree. The oak trees of the U. S. face extinction by a microscopic fungus which is already well entrenched in the upper Mississippi Valley and is spreading east and south at the rate of about 50 miles a year. The organism, *Chalara quercina,* a relative of the fungus that causes Dutch elm disease, was first observed and named in 1944. It was a fungus that virtually wiped out the American chestnut.

Chalara quercina is known to attack at least 28 different species of oak. It kills the tree by clogging the channels through which water passes from the roots to the leaves. On red oaks its effects appear first in the upper crown. The leaves turn a dull light green, curl upward, then turn yellow or brown. An infected tree may lose all its leaves within a month.

Oak is one of the chief American woods, most commonly used for floors, railroad ties, mine props, barrel staves and furniture. In large areas of the eastern U. S. oaks make up 50 to 75 per cent of the forest cover.

So far the fungus disease has spread to seven states, as far south as Paducah, Ky., and as far east as Gary, Ind. It has shown an ability to survive in a wide range of climates. In the hope of stopping its spread, research workers of the U. S. Department of Agriculture are trying to learn how it jumps from one locality to another.

An English Kinsey Report

SEXUAL behavior is just as common in Britain as in the U. S., according to a recent survey by Mass-Observation, a British opinion research organization. Britons refer to the study as "a sort of Gallup on a sort of Kinsey." Its results were reported in the *Public Opinion Quarterly* by L. R. England, director of Mass-Observation.

The survey consisted of street interviews of 2,000 men and women, answers to a more intimate written questionnaire by 11 per cent of the interviewees and by 400 members of Mass-Observation's National Panel of Voluntary Observers, and answers to brief attitude questionnaires by a number of "opinion leaders" among doctors, clergymen and school teachers.

In general the man (and woman) in the street differed rather widely from the opinion leaders in the attitude toward sexual behavior. Only 51 per cent of the street sample were unreservedly opposed to prostitution, as against 93 per cent of the clergy. Only 58 per cent of the street interviewees were unreservedly in favor of marriage, whereas 75 per cent of the doctors, 80 per cent of the teachers and 90 per cent of the clergy favored it.

"Most people feel that there is nothing innately wrong or unpleasant in sex in itself," Dr. England reports. He found that attitudes were somewhat correlated with the sex, social class and religious belief of the respondent, but that religious belief had more effect on the individual's attitude than on his or her behavior.

Premarital and extramarital sexual activity apparently are widely practiced among Britons as well as among Americans. The main divergence from the Kinsey findings was that only 12 per cent said they had had physical homosexual relationships.

The traditional British reticence did not prevent most of the interviewees from answering Dr. England's questions. One exception was a clergyman, who wrote in response to his questionnaire: "I count it infernal insolence on your part that you sent it to me."

The survey was intended only as a preliminary outline for a more comprehensive study. Dr. England already has one conclusion to offer: "In the field of sex, as in many others, modern man is confused."

Second Sound

WORKERS in the field of low-temperature physics have been divided between two theories about the nature of helium II, the so-called "fourth state of matter." Helium II, a strange fluid produced when liquid helium is cooled below 2.19 degrees above absolute zero, possesses a number of unique properties, among them the ability to conduct heat at extraordinarily high speeds—a phenomenon known as "second sound."

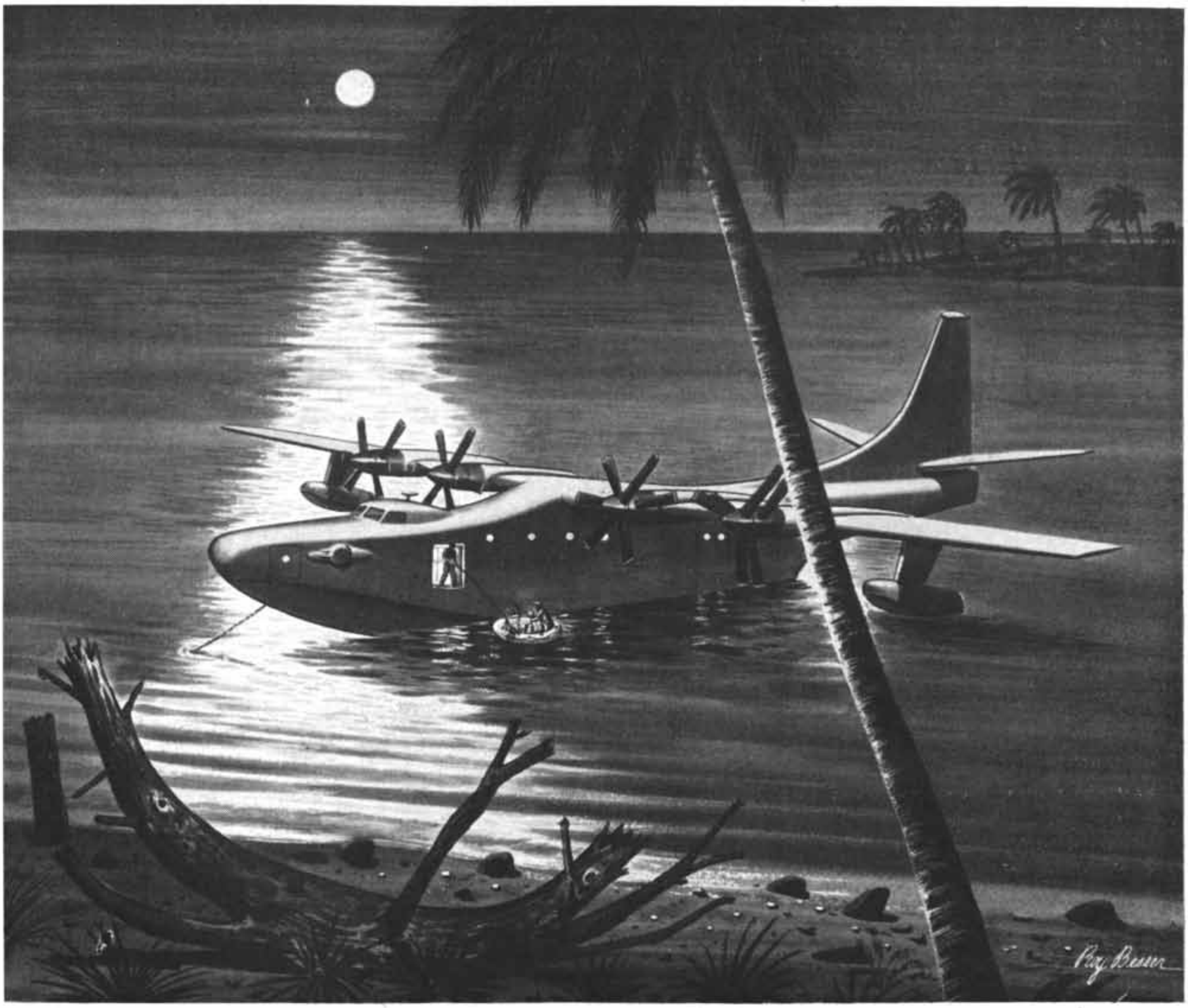
To explain the peculiarities of helium II, Laszlo Tisza of the Massachusetts Institute of Technology and Fritz London of Duke University postulated that helium II is a mixture of two fluids: 1) a "normal" liquid, and 2) a "superfluid" consisting of atoms with the smallest possible heat energy. According to another theory, proposed by the Soviet physicist Lion Landau, the superfluid atoms possess no heat energy at all. Both theories accounted successfully for all observed properties of helium II at temperatures above 1.3 absolute, and both predicted the discovery of second sound. But below one degree absolute they clashed. Here Landau predicted a sudden rise in the velocity of second sound, while the London-Tisza theory predicted a drop in velocity.

The question has now been settled by two workers at the National Bureau of Standards, J. R. Pellam and R. B. Scott. Using the adiabatic demagnetization technique to attain extremely low temperatures and new methods of detecting and timing second sound, they measured the speed of second sound at temperatures below one degree absolute for the first time. They found that, as Landau had predicted, the speed rose sharply. At 1.1 degrees absolute the speed of second sound was 60.4 feet per second; at a temperature between .5 and .7-degree absolute it increased to 111 feet per second. The report concluded: "Low-temperature scientists can now confidently employ Landau's postulates in their research."

This confirmation suggests the possibility of producing extremely low temperatures by new methods. When helium II is in contact with a surface with an opening less than .00001-inch in diameter, atoms of the superfluid pass through the opening and atoms of the normal fluid are left behind. Because the superfluid atoms, according to Landau's theory, take no heat energy with them through the opening, it should be possible to go to lower and lower temperatures by repeatedly passing helium II through small openings.

Phosphorus from Sewage

THE problem of salvaging useful material from sewage, one of the most conspicuous wastes of civilization, has long interested engineers, but it has been difficult to find economical ways of doing so. Now two engineers at the University of Wisconsin have developed a practical method of recovering phosphorus. William L. Lea and Gerard A. Rohlich have developed a process which uses alum as a coagulating agent. It produces a sludge from which phosphorus can be recovered in the form of calcium phosphate, useful as fertilizer. Nearly all the alum can be separated and used again. Lea and Rohlich estimate that a ton of fertilizer can be recovered daily from the 15 million gallons of sewage processed every day at the sewage plant in Madison, Wis. At this rate the sewage of the cities of the U. S. would yield over 400,000 tons of fertilizer a year.



Removal of phosphorus would not only produce fertilizer but would cut down one of the chief factors promoting nuisance growths of algae in lakes and rivers. The process could also be used to segregate dangerous radioactive phosphorus in the wastes of atomic research installations.

Brain Waves of Murderers

WHEN is a murderer responsible for his crime? According to the law, he is sane and subject to execution if he knows what he is doing and that it is "wrong." But psychiatrists would like to see a more scientific criterion for criminal insanity. An editorial in the *British Medical Journal* recently discussed some investigations of the brain waves of murderers that may suggest such a criterion.

D. Stafford-Clark and F. H. Taylor examined 64 prisoners, 58 men and six women, all charged with murder. They found that in 11 cases where the killing was in a sense unintentional, as in self-defense, only one of the prisoners gave an abnormal electroencephalogram. Of 16 persons who had a clear criminal motivation, such as robbery, four showed abnormal recordings. Of 15 who killed with no apparent adequate motive, 11 showed abnormalities. Among 14 murderers who were clinically insane 12, or 86 per cent, had abnormal brain waves.

The *Journal* remarks: "The cases of inadequately motivated murder appear to present a new medical problem calling for investigation, particularly since many of the prisoners in this group [appeared] normal."

Tuberculosis Test

A NEW blood test to detect active tuberculosis was announced last month by Sidney Rothbard of the Montefiore Hospital in New York. The test is based on studies of virulent and avirulent tubercle bacilli by René Dubos and Gardner Middlebrook of the Rockefeller Institute for Medical Research (SCIENTIFIC AMERICAN, October).

In Rothbard's test a sample of the patient's blood is mixed with red blood cells taken from tuberculous sheep. The mixture is heated. If the patient has active pulmonary tuberculosis, the red cells clump together, and the degree of activity of the disease can be measured by the extent of clumping. The result is known within 24 hours. Rothbard reported that the test had proved 92 per cent accurate in a sampling of 1,200 cases; in no case did it give a false negative result.

Since the standard tuberculin skin test does not show the state of activity of a tuberculous infection, and X-ray chest examinations often fail to distinguish lung lesions of tuberculosis from those of other diseases, the new test will aid greatly in diagnosis.

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THE SYNTHETIC ELEMENTS

There are nine of them, including the newly manufactured berkelium. Four have filled gaps in the periodic table of 92 elements and five have extended it beyond uranium

by I. Perlman and G. T. Seaborg

THE urge to take our material world apart and identify its ultimate units of construction is at least as old as the early Greek philosophers. We have come a long way from their conclusion that all substances are variations of an Olympian brew composed of only four ingredients—fire, water, earth and air—but the end of the quest is not yet in sight. At the moment the list of identified elements stands at 97. The physicists, of course, have broken these down into protons, neutrons and units which may be even more basic. In this article, however, we shall stop short of the subatomic world and confine ourselves to the elements, considering protons and neutrons only as they affect the elements' stability. From the strictly chemical point of view, the elements may be considered the blocks of which our universe is built.

Our particular concern in this article will be the so-called synthetic elements, which for all practical purposes are not found in nature but are created only by the alchemy of the modern laboratory. Let us make clear at the beginning what we mean when we say that the synthetic elements are missing in nature. Actually tiny amounts of some of them, such as plutonium, have been detected in the earth, and all of them doubtless existed in considerable amounts at the primordial creation of the elements. But without exception they are so unstable that the original atoms must have disappeared long ago; any such atoms now found in nature are created only rarely by spontaneous nuclear reactions due to cosmic-ray bombardment or natural radioactivity.

The idea that all matter could be reduced to a limited number of chemically indivisible elements began to take form in the 19th century. It developed principally from the discovery of certain periodic similarities among the known elements. When the elements were arranged in the sequence of their atomic weights, it was found that elements occurring at certain intervals on the list resembled one another in chemical properties. This resulted in the construction of a periodic table of the elements, which in turn disclosed some gaps. It was logical to assume that the missing chemical properties should be attributed to still undetected elements.

With the discovery of X-rays and of the atomic nucleus at the turn of the century, a more meaningful picture of the differences among elements began to emerge. We now know that the distinguishing mark of each element—what determines its chemical properties—is the number of electrons it possesses, and that this in turn is uniquely determined by the number of positive charges or protons in the nucleus. The electrons are attached to the nucleus in successive shells, and as we go up the periodic table from the lower to the higher elements we find that the electrons closest to the nucleus are attached more and more firmly to the atom. The dislodging of one of these inner electrons is immediately followed by an outer electron falling into the vacancy, and the energy released by this event appears as an X-ray. The wavelength of the X-ray is characteristic of the element. It was H. G. J. Moseley of England who discovered this relationship and thereby was able to arrange the elements according to atomic number and to tell precisely which elements were missing. Gradually most of the gaps between hydrogen (atomic number 1) and uranium (atomic number 92) were filled by the discovery of new elements. By 1925 only four elements remained to be found: those of atomic numbers 43, 61, 85 and 87.

As one might expect, a new element did not necessarily appear for the first time in pure form, nor did it assert its singularity. Some research workers may have handled substances in relatively pure form and failed to recognize them as new elements. More often new elements were reported which proved to be identical with previously known elements or mixtures. During the 1920s and 1930s a number of workers reported the discovery of elements 43, 61, 85 and 87. They gave these elements such names as masurium, illinium, florentium, alabamine, virginium and moldavium, and to this day these names appear in some tables of elements. It is fairly certain, however, that none of these elements can exist in nature in quantities detectable by the methods of investigation then employed. Actually the unambiguous identification of three of the four elements (the exception: element 87) had to await their preparation by artificial means, and even element 87 can be prepared more readily by transmutation than from natural sources.

Stable and Unstable Isotopes

To understand the transmutation of elements, we must turn to considerations of nuclear stability. An element, as we have noted, is uniquely characterized by the number of protons in the nucleus. But the number of neutrons associated with a given number of protons may vary. This results in the existence of various species of the same element, known as isotopes, which differ in weight and stability but not appreciably in chemical properties. Relatively few of the possible isotopes of any element are stable; in fact, of the 1,000 isotopes of the 97 elements known to date, only about 275 are stable. Several hundred unstable nuclei may yet be prepared, but probably few stable nuclei remain to be discovered. The paucity of stable nuclei is largely explained by the interconversion of protons and neutrons; a proton will change into a neutron or *vice versa* if there is a slight imbalance from a norm characteristic of each region of the periodic table. The nucleus is much more stable if it has an even number of neutrons or protons. As a result each element with an odd number of protons has only one or two stable isotopes.

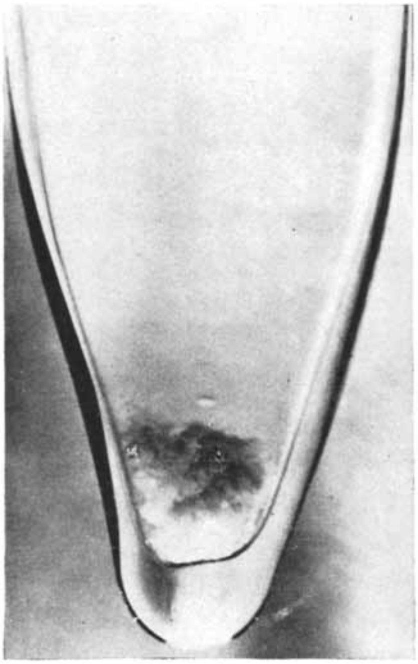
The margin by which an isotope may be stable or unstable is indeed small when compared with the total amount of energy involved in binding together the components of a nucleus. In moderately heavy nuclei the total binding energy is about 1,000 million electron volts, yet if one nucleus is bound more firmly by even .01 mev than another with one more proton and one less neutron, the second nucleus will decay into the first. Such small irregularities in nuclear binding may deprive some odd-numbered elements of the possibility of having even one stable isotope. Consequently such an element, barring some freakish factor that prevented its most nearly stable isotope from decaying, would not be found in nature.

It may be of interest to speculate how different our lives would be, if indeed we would be here at all, should certain elements be unstable. One element with only a single stable isotope, for example, is iodine. This element, as a constituent of thyroxine, the hormone of the thyroid gland, is vital as a regulator of growth and development and of the metabolic rate. It is difficult to visualize what form vertebrate animal life would have taken had this element been missing. Another element with but one stable isotope is gold. As well as we can measure it, this isotope, Au^{197}, is considerably less than one mev more stable than the artificial and highly unstable mercury isotope Hg^{197}. If this situation were reversed, Fort Knox might still be used to store something, but it would not be gold.

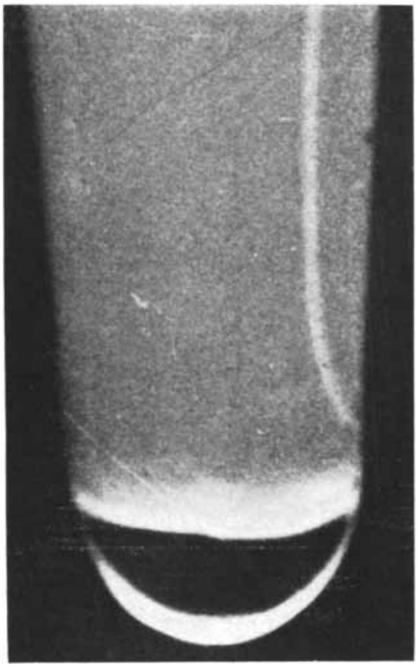
The Missing Elements

Below lead, element 82, only two elements are missing in nature. These are elements 43 (technetium) and 61 (promethium) which, as we shall see, may be prepared artificially in radioactive form just as one may prepare radioactive isotopes of all of the elements. The form of instability responsible for the absence of elements 43 and 61 involves neutron-proton interconversions. It is called beta-instability, meaning that the nucleus emits beta particles, *i.e.,* electrons, in attaining stability.

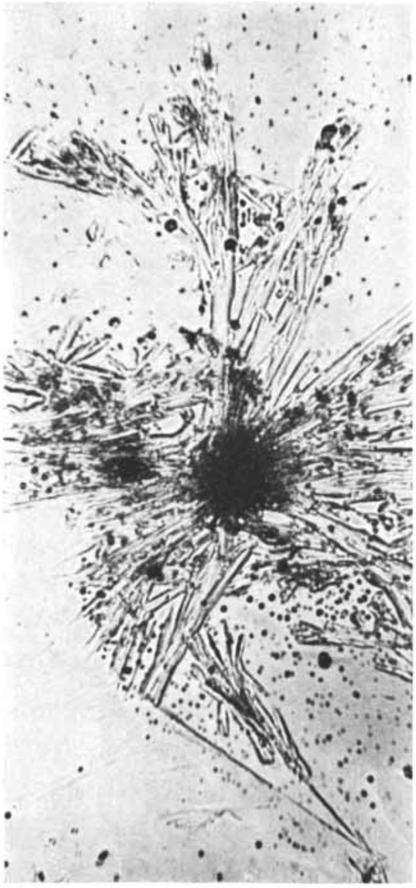
Among the heavier elements another type of instability sets in. This type is a consequence of what may loosely be considered an overstuffing of positive



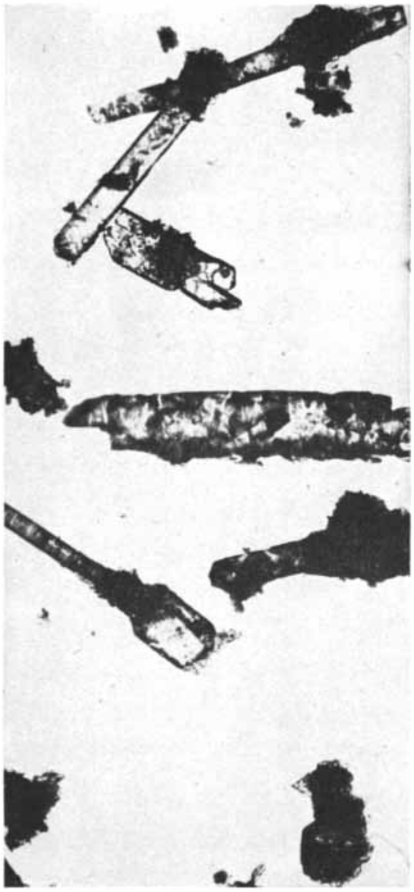
PLUTONIUM hydroxide is isolated in a few crystals at the bottom of a capillary tube. Sample was prepared at University of Chicago in 1942.



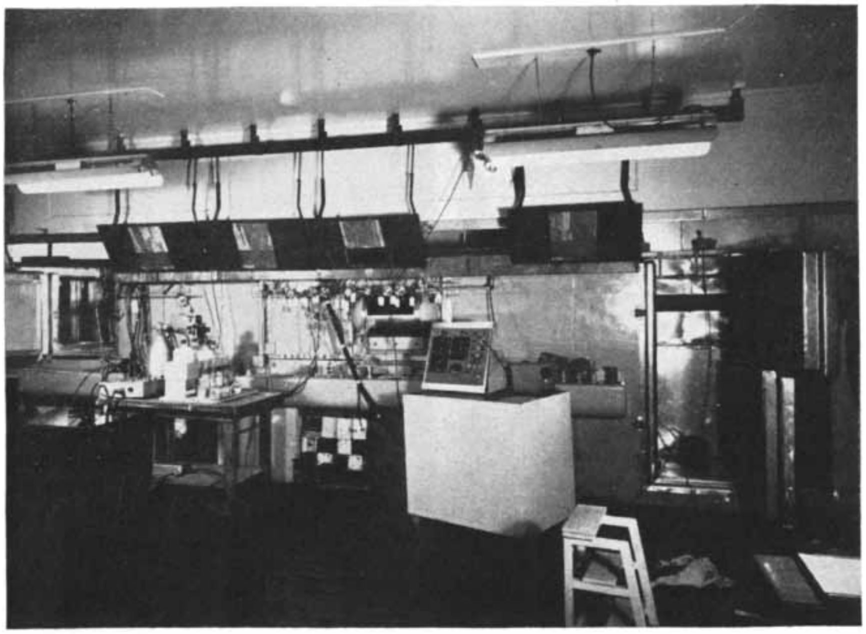
CURIUM is so intensely radioactive that it glows by its own light in a water solution. Curium was discovered at University of Chicago in 1944.



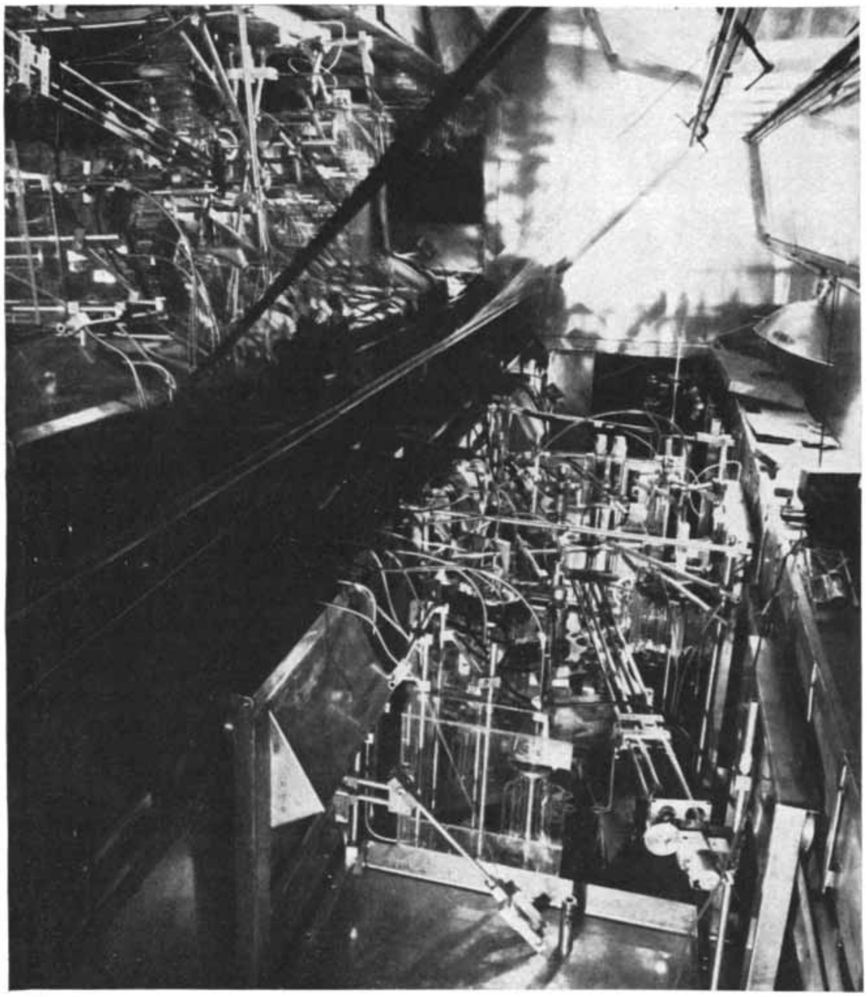
PROMETHIUM nitrate is isolated as clustered crystals. The crystals in the original photomicrograph have been enlarged by about 30 diameters.



TECHNETIUM is prepared in the compound ammonium pertechnetate. In original photomicrograph crystals were enlarged 16 diameters.



HOT LABORATORY at the University of California provides facilities for working with highly radioactive elements, synthetic and otherwise. Elements are chemically manipulated behind a lead wall by remote control (*below*).



BEHIND LEAD WALL is equipment for manipulating radioactive elements. At upper left is a mirror in which the manipulations may be observed. Some stages in the isolation of curium were carried out in this laboratory.

charge in the nucleus. The nucleus has an urge to get rid of protons. The mechanism for relieving its condition is the emission of alpha particles, or helium nuclei, composed of two protons and two neutrons. The reason this complex particle rather than a proton is emitted is simply that the helium nucleus is such a stable structure that it is more economical of energy to rid the nucleus of protons in this fashion than individually. By the time bismuth, element 83, is reached, alpha instability sets in as a general condition. (Some nuclei do not exhibit their alpha instability, however, because their beta-decay rate is much faster than their alpha-decay rate.) These alpha-emitters have vastly varying lifetimes: some as short as a microsecond, others comparable with the age of the earth. The point to be made here is that there are only three nuclei above bismuth sufficiently long-lived to have survived geological time—thorium 232, uranium 235 and uranium 238. These isotopes are responsible for the fact that the earth still has small amounts of the elements between 83 and 92, for the latter arise as products of the decay of uranium and thorium. Thus the existence of this small island of relative stability at thorium and uranium is the only factor preventing the termination of the periodic table at bismuth.

As these three nuclei decay, they maintain their various products in equilibrium with them, in amounts that depend on their relative stability or half-lives. For example, radium 226 is one of the decay products of U^{238}. Since the respective half-lives of these isotopes are 1,600 years and 4.5 billion years, the two are found together in the ratio of one part of radium to three million parts of uranium, or a third of a gram of radium to a ton of uranium. Two of the elements with extremely short half-lives, elements 85 and 87, are almost missed completely in the radioactive-decay series; element 87 occurs in uranium only in the fantastically low concentration of a few parts per billion billion. In the case of element 85, the amount that has been detected in nature is much smaller. Such small quantities, of course, cannot be isolated and are measurable only through their radioactivity.

It is only by the grace of an odd combination of unusual circumstances, by the way, that fissionable U^{235} still exists in the earth in sufficient quantity to provide us with nuclear chain reactors and atomic energy. U^{235} has a half-life of only .7 billion years, which means that more than 90 per cent has disappeared through radioactive decay during the three billion years of the earth's age. Thus only by the slenderest of margins does enough U^{235} remain in natural uranium to operate a nuclear reactor or to make its separation from U^{238} feasible. And this is only half the story. Recent studies of alpha radioactivity have shown that U^{235} falls into a category of nuclei whose half-lives are longer than would be predicted from their decay energy—the principal factor influencing the half-life. Even among this group in which alpha decay is "forbidden," U^{235} is something of a freak. For its particular decay energy it might be expected to decay about 10 times more rapidly than it does; while even if its decay were only twice as rapid as it actually is, it would essentially have disappeared from the earth by this time.

Above uranium, alpha-decay half-lives again become quite short, so the transuranium elements of primordial origin are no longer present although there is every reason to believe that such elements were formed at the same time as the more stable ones. The longest-lived transuranium isotope known to date, neptunium 239, has a half-life of only two million years, which is almost 100 times too short to have permitted the element to persist through geological time.

Radiochemistry

What about the chemical behavior of these unstable elements? Basically the chemistry of a radioactive substance is no different from that it would have if it were not radioactive. There is one practical difference in handling it, however, and this is that we can detect it even when it is present in vanishingly small concentrations. If it were not for this facility, most unstable nuclei would remain undiscovered, for they are found or can be prepared only in unweighable amounts.

Today the techniques of the new branch of study called radiochemistry make it possible to obtain a great deal of information about chemical properties and to carry through chemical separations with amounts of material far too small to handle by the usual methods of chemistry. By the mere analysis of a substance's radioactivity it is possible to obtain semiquantitative information about its solubility, its oxidation-reduction potentials, its formation of complex ions and many other properties.

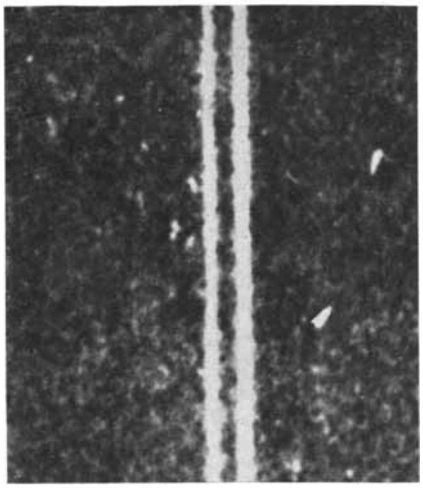
Once the element has been identified there is a great incentive for manufacturing it in visible amounts so that one can study its spectra, its crystal structure and many other properties that are inaccessible to radiochemical methods. With the advent of the nuclear reactor the synthesis of these radioactive elements is no longer difficult, provided the transmutations can be effected with neutrons. There are problems, however, in connection with the elements' great radioactivity. It is desirable to work with an isotope with a relatively long half-life, for if the half-life is short it may be difficult to produce the element at a faster rate than it decays. Also important is the hazard in handling these radioactive substances when they are made in visible amounts. A good example is the curium isotope Cm^{242}, the principal isotope of curium that has been used for experimentation up to this time. This isotope has a half-life of only five months, and if it were possible to make one milligram of it, its alpha radioactivity would be 3.5 curies. This would be a considerable amount of radioactivity to work with. If it were spread uniformly over the entire state of New York (we deliberately refrain from spreading it here in California), radioactivity could be detected on every square foot of ground.

Thus the experimenter has no alternative but to work with extremely small amounts of such isotopes. Ultramicrochemical methods have been developed, however, which permit almost any type of chemical and physical measurement to be made on only a few micrograms to a milligram of an element.

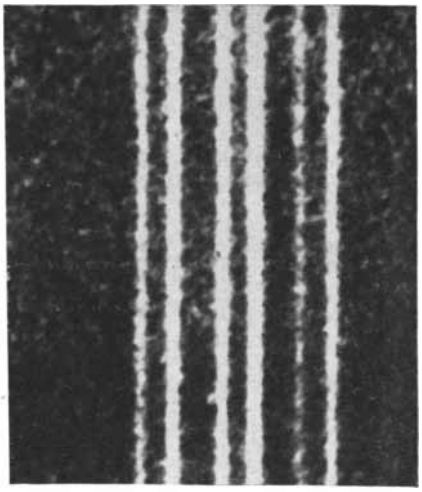
Element 43

The first synthetic element to be created was technetium, element 43, which filled the gap in the periodic table between molybdenum and ruthenium. Technetium was definitely identified for the first time by C. Perrier and E. Segrè of Italy in 1937. A sample of molybdenum that had been irradiated with deuterons in the University of California cyclotron was sent to them. From it they isolated a chemical fraction which, on the basis of its radioactive behavior, was distinct from all other known elements. Its chemistry conformed with what might have been expected from element 43, an element in the series known as Group VII. Such a group, as already indicated, is made up of elements in the periodic table that are chemically similar to one another because they have the same number of electrons in the outer shell. Further exploratory work showed that element 43 was somewhat closer in properties to rhenium, the next heaviest element in Group VII, than to manganese, the next lowest element in the group. Ten years later Segrè suggested that element 43 be named technetium (Tc), derived from the Greek *technikos*, signifying the element's artificial or "technical" origin.

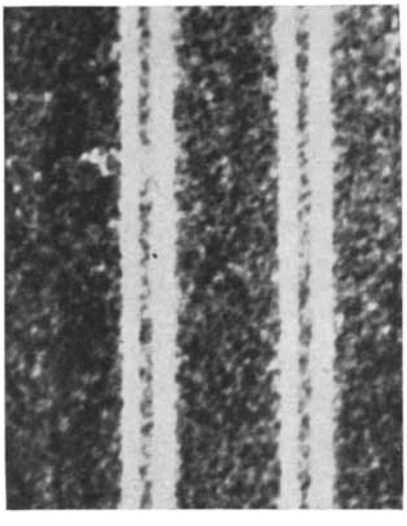
From the behavior of a certain isotope of technetium, Tc^{99}, with a half-life of six hours, it was deduced that this isotope must have another form, or nuclear isomer, with a long half-life. Thus one of the conditions for obtaining macroscopic amounts of the element was fulfilled, namely, that a long-lived isotope must exist. The other condition, a method of preparing the element in quantity, was realized when it was shown that the six-hour Tc^{99} is a fission product and therefore can be made in an atomic pile. The fission yield of technetium is high; Tc^{99}



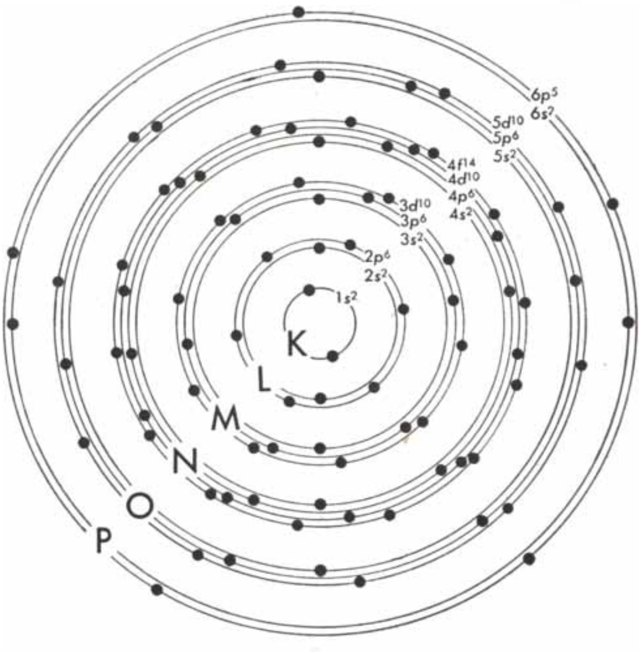
ONE ELEMENT, the synthetic rare earth promethium, has a characteristic X-ray spectrum with two lines.



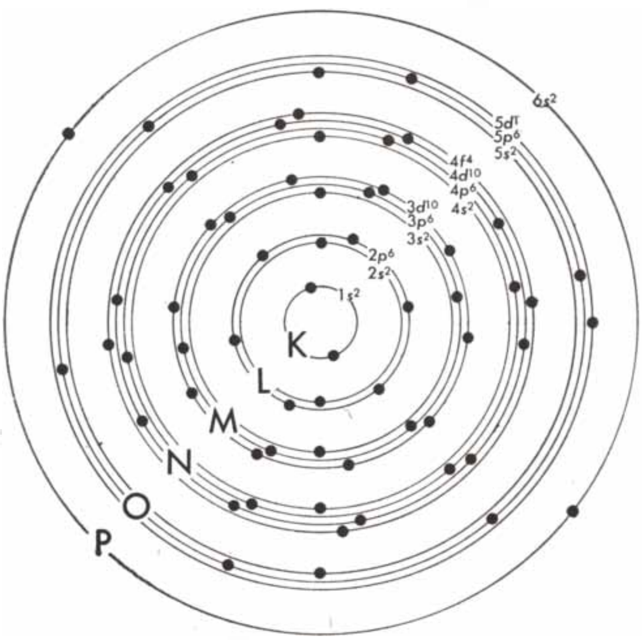
THREE ELEMENTS in succession, neodymium, promethium and samarium, have successive pairs of lines.



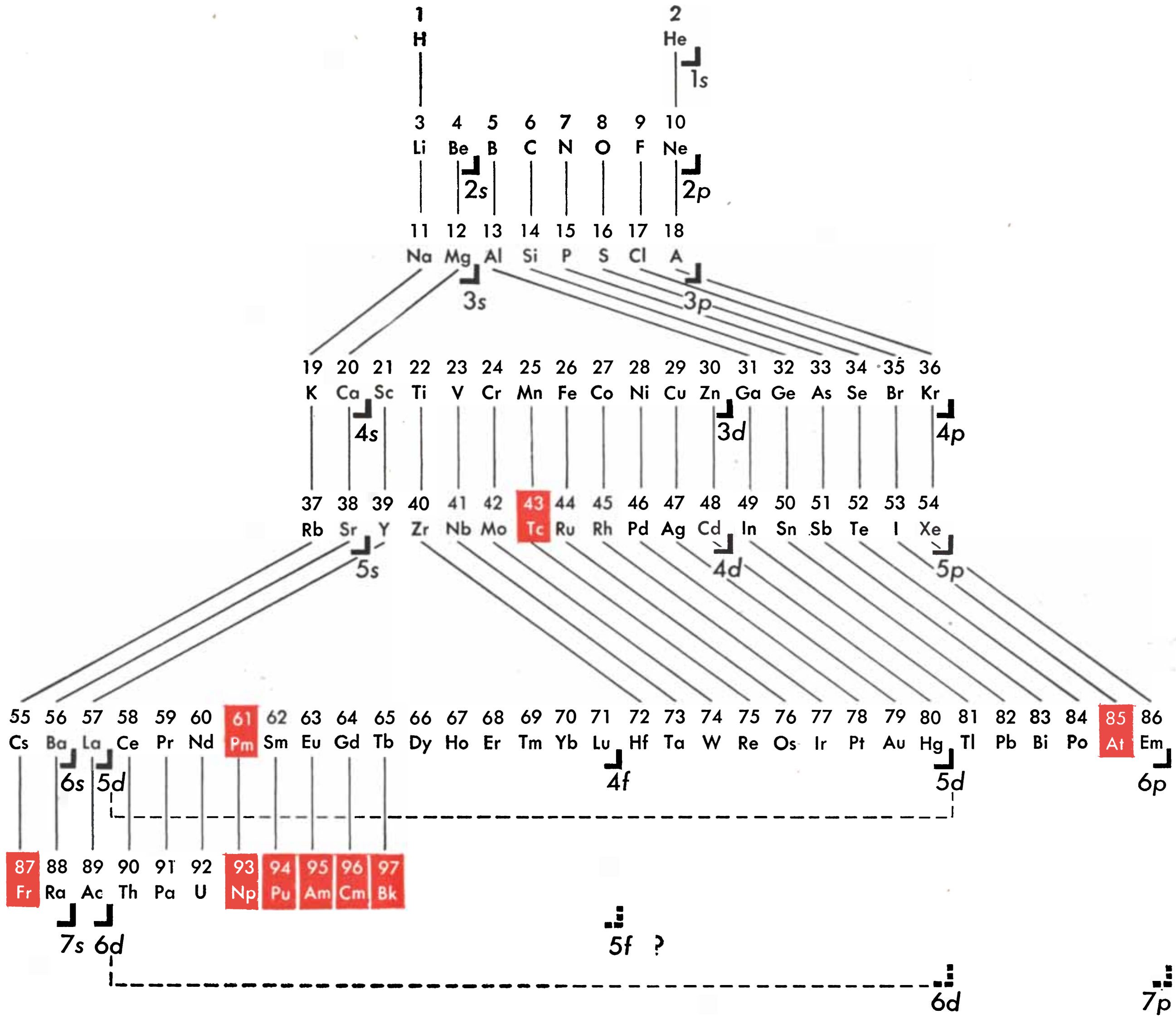
TWO ELEMENTS, neodymium and samarium, have X-ray lines with a gap between them for promethium.



ASTATINE



PROMETHIUM



constitutes 6.2 per cent of the eventual fission products in a pile, and it can be calculated that the fission of one gram of U^{235} produces 26 milligrams of Tc^{99}. The element can also be made by irradiating molybdenum with neutrons to form Mo^{99}, which decays to Tc^{99}; so two methods for production in quantity are available.

When it became possible to produce suitable amounts of long-lived Tc^{99}, it turned out to have a half-life of close to one million years. With this half-life the element becomes relatively easy to handle. A number of milligrams have now been isolated and many of its chemical properties have been investigated. Like the brilliant violet permanganates familiar to chemists, the corresponding pertechnetates are also brightly colored. Technetium has been prepared in the metallic state and combined in a number of compounds; its optical emission spectrum and X-ray spectrum have been recorded; its mass number has been proved to be 99 by means of the mass spectrograph.

It is almost certain that there can be no primordial technetium in nature, since all possible isotopes of the element seem to have half-lives which are far too short. The only processes that come to mind as possible sources for the continuing formation of technetium in nature are (1) the spontaneous fission of U^{238}, a very rare event, and (2) the action of stray neutrons on molybdenum and U^{235}. If we assume that the yield of Tc^{99} from the spontaneous fission of U^{238} is the same as that from the neutron-induced fission of U^{235}, and that the half-life of spontaneous fission is 10^{16} years, then each kilogram of uranium when dug from the ground would contain only a few millionths of one microgram of Tc^{99}. The other mechanisms for producing Tc^{99} would not yield much more.

Element 61

The next synthetic element we shall consider is the rare earth promethium. The rare-earth elements are a group from cerium to lutetium (atomic numbers 58-71 inclusive). They are closely allied in chemical properties to one another and to their prototype, lanthanum (element 57). The rare earths always occur together and have a marked predilection for remaining together under most chemical treatments. The classical method for separating them is repeated recrystallizations, a most laborious and material-consuming process.

When the rare earths were finally lined up according to atomic number, the space for element 61 remained unfilled. Obviously the place to look for element 61 was in rare-earth ores, but the difficulty of separating rare earths from one another was an obstacle. Although a number of claims to its discovery were made, the question of the existence or nonexistence of element 61 in nature was still unsettled when the possibility of preparing it artificially presented itself. Several groups of investigators irradiated neighboring rare earths and produced some new sources of radioactivity, some of which undoubtedly were isotopes of element 61. But which radioactivities belonged to element 61 and which to new isotopes of known rare earths? This question remained unanswered because the methods of fractionating rare earths were of insuperable difficulty and the radioactivities observed had short half-lives.

Two developments in the Manhattan Project during the war conspired to allow the unambiguous discovery of element 61. Foremost was the development of methods for separating the rare earths by means of synthetic ion-exchange resins. It was found that neighboring rare earths could be largely separated in one pass through a glass column filled with resin. Furthermore, the rare earths came off the column in a definite order, inversely as the atomic number, so that it was fairly safe to assume that element 61 would follow samarium, element 62. The second important discovery was that a relatively long-lived isotope of element 61 occurs as a result of uranium fission. The first positive identification of element 61 came in 1945 from the experiments of J. A. Marinsky and L. E. Glendenin at the Clinton (now Oak Ridge National) Laboratory. They suggested that the element be named promethium (Pm) to draw a parallel between mankind's newly acquired nuclear power and the acquisition of fire, which according to Greek mythology was stolen from the gods and given to man by Prometheus.

The longest-lived known isotope of promethium, Pm^{147}, has a half-life of 3.7 years; nevertheless it has been isolated in the pure state. At the Oak Ridge National Laboratory G. W. Parker and P. W. Lantz obtained promethium from a fission-product mixture, and B. H. Ketelle and G. E. Boyd isolated some from neutron-irradiated neodymium.

Element 85

Let us now consider the third of the four gaps in the periodic table, element 85. The synthesis of this element actually came second chronologically, before promethium. Its manufacture presented a somewhat different problem from that of technetium and promethium. Technetium can be made by irradiating molybdenum, the next lowest element, with neutrons or deuterons; promethium similarly can be made from neodymium, the next element below it. But in the case of element 85 the next lowest element, polonium, itself exists only in trace amounts in nature. Hence polonium cannot serve as the starting material. To make element 85 one must start with the element two numbers below it: bismuth. Consequently it is necessary to add not one but two charges, transmuting element 83 to 85. This can be done by irradiating bismuth with accelerated ions of helium, which has two protons. The synthesis was first accomplished by D. R. Corson, K. R. MacKenzie and Segrè at the University of California (to which Segrè had come from Italy). They named element 85 astatine, from the Greek word meaning "unstable." The -ine ending means that the element is a halogen, *i.e.*, a member of the chlorine family.

The particular isotope of astatine first made was At^{211}, an alpha-particle emitter. As a matter of fact, it exhibits a phe-

THE PERIODIC TABLE at the bottom of the opposite page presents the 97 natural and synthetic elements in horizontal rows to show similarities in their chemical properties. Elements of similar chemical properties are connected by the lines running from top to bottom. Above the symbol of each element is its atomic number, *i.e.*, the number of positive charges in the nucleus or the number of electrons bound by them. The nine synthetic elements are indicated in red. In each horizontal row is one or more half-brackets designated 1*s*, 2*s*, 2*p* and so on. Each of these brackets denotes the filling of a shell of electrons—more properly a subshell—in the succession of the elements. The electron shell structures of two synthetic elements are given in the schematic drawings at the top of the page. In X-ray terminology the shells are designated K, L, M, N, O and P. In spectrographic terminology they are designated 1, 2, 3, 4, 5 and 6. The spectrographic subshells are designated *s*, *p*, *d* and *f*. The maximum number of electrons in any *s* subshell is two, in any *p* subshell six, in any *d* subshell 10 and in any *f* subshell 14. The number of electrons in each subshell is indicated by a superscript; for example $6p^5$ in the outermost subshell of astatine (At) indicates that there are five electrons in the *p* subshell of shell 6. In the case of astatine all the subshells are filled except the last. The case of promethium (Pm) and the other rare earths, however, is more complex. In the rare-earth series from cerium (Ce) to lutetium (Lu) the number of 5*d* and 6*s* electrons remains the same; in successive elements electrons are added in the 4*f* subshell. Promethium thus has four 4*f* electrons. The transuranium elements appear to belong to a second rare-earth series.

nomenon known as "branched decay," which means that some atoms break down in one way and some in another, both sequences yielding alpha particles. One part of a sample of astatine emits alpha particles directly, thereby decaying to bismuth 207; the other part first captures an electron and becomes polonium 211, but the latter is extremely short-lived and promptly gives off a very energetic alpha particle. As a result, At^{211} is observed to decay with two alpha particles of widely differing energies. When observed with proper radiation-measuring equipment, this isotope is as distinctive as a cat with two heads.

The nuclear properties of astatine isotopes have been well charted and they lead to the conclusion that probably no species of this element will have a half-life greater than several hours. The chemistry of astatine has been investigated on the tracer scale by the methods of radiochemistry. Its behavior is that of a halogen considerably more electropositive than iodine, just as iodine is more electropositive than the next lightest halogen, bromine. One means of separating astatine from solutions is by electroplating or chemical plating. There is no easy way to prepare astatine in visible amounts, for its longer-lived isotopes can only be made by the use of a particle accelerator such as a cyclotron. Even these have half-lives of only a few hours, so that work with macroscopic quantities will be exceedingly difficult because of the intense radioactivity.

Element 87

The fourth and final gap in the periodic table was element 87. According to its place in the table, this element should be a member of the alkali family, which includes sodium, potassium and cesium. As in the case of the other missing elements, there had been a number of claims to the discovery of element 87 by conventional chemical methods; the substance so identified had been variously called virginium and moldavium. But we now are virtually certain that there can be no stable isotope of element 87, and furthermore the longest-lived known radioactive isotope of the element has a half-life of only about 20 minutes, so it could not have been detected by conventional chemical methods.

Actually element 87 was first discovered unmistakably through its radioactivity, and it was found as a product of the decay of a heavy element. To understand how it was identified, we must examine briefly the various processes by which the elements at the heavy end of the periodic table decay. There are three separate decay series among the natural heavy elements, known respectively as the thorium, uranium and actinium series. The first series starts with thorium, which breaks down by a number of steps through various isotopes of radium, actinium, polonium and other heavy elements until it finally becomes stable lead. The second series starts with uranium and goes through a number of transformations into other isotopes of these elements until it, too, degenerates to stable lead. The third series, starting with actino-uranium, or U^{235}, proceeds through actinium, from which the series derives its name, and finally ends as still another stable isotope of lead.

Soon after the significance of these decay processes became understood, and it was realized that a number of isotopes of elements between uranium and lead should be found as decay products, attempts were made to locate some isotope of element 87 in a decay sequence. Element 87 of course stands above lead, element 82, so it should be found somewhere in one of these series. It soon became obvious, however, that no isotope of element 87 would result from the known breakdowns in the main pathway of any of the three decay series. But in 1914 Stefan Meyer, V. F. Hess and F. A. Paneth of Austria noted that actinium, Ac^{227}, which was known as a beta-emitter, also decayed occasionally by alpha emission. Since actinium is element 89, its alpha-decay product must be an isotope of element 87, in this case 87^{223}. It was not until 1939, however, that Mlle. M. Perey of France succeeded, by very meticulous radiochemical separations, in obtaining a 21-minute beta-particle emitter which she proved to be the alpha-decay product of Ac^{227}. She later named this new element francium in honor of her native land.

The three natural radioactive series, as we have observed, almost miss element 87 completely. But when the artificial transuranium element neptunium was synthesized, a fourth series, starting with that element, was discovered. And this series yields an isotope of francium, Fr^{221}, in its main decay sequence. This isotope arises from the alpha decay of Ac^{225}. It has a half-life of only five minutes, decaying by alpha emission to an astatine isotope of .02-second half-life. Subsequently it was found that Fr^{221} is also obtained as a decay product in a sequence starting from the artificial isotope thorium 233 (*see page 45*).

The short half-lives and inaccessibility of the francium isotopes have discouraged chemical investigation of the element. It appears to behave like an alkali element in solution; one item of note is that francium has great volatility when the solution is evaporated to dryness and brought to a temperature of several hundred degrees. This is a property of alkali elements that begins to be prominent with cesium and is accentuated with francium.

Thus the gaps in the classical periodic system, covering the elements from hydrogen to uranium, are now completely filled. We turn next to the transuranium elements.

Beyond Uranium

The search for transuranium elements, a quest born of scientific curiosity, was destined to be the trigger for a series of events which within a decade were to rock the world and burst upon the consciousness of every literate human being. These events, of course, were the discoveries that led to the exploitation of nuclear energy, in particular as a weapon of mass destruction. Other fundamental scientific discoveries undoubtedly have had equal or greater effect on mankind's mode of existence in the past, but none literally exploded in his face as has this one.

In 1934 Frédéric and Irène Joliot-Curie of France made the exciting observation that an ordinary stable element could be made radioactive by irradiating it with alpha particles of natural origin. This discovery of artificial radioactivity immediately stimulated research toward preparing radioactive forms of many elements. Two other extremely important developments were taking place at about the same time. One was the development by E. O. Lawrence at the University of California of the cyclotron, which was soon able to accelerate charged particles to energies far beyond those of naturally occurring alpha particles. This discovery made it possible to bombard and transmute the heavier elements for the first time, for alpha particles from natural sources can penetrate the nuclei of only the lightest elements. The second development was the discovery by James Chadwick of England of the neutron, an uncharged particle capable of entering any nucleus easily. Neutrons will literally fall into any nuclei at which they are directed. Since neutrons could be prepared by directing radium alpha-particles at a light element such as beryllium, it became possible for anyone who could acquire 100 milligrams or so of radium to produce and study the transmutation of elements. Most prominent in such studies was a group working with Enrico Fermi of Italy. They soon found a means of preparing transuranium elements by making use of the great avidity of nuclei for neutrons.

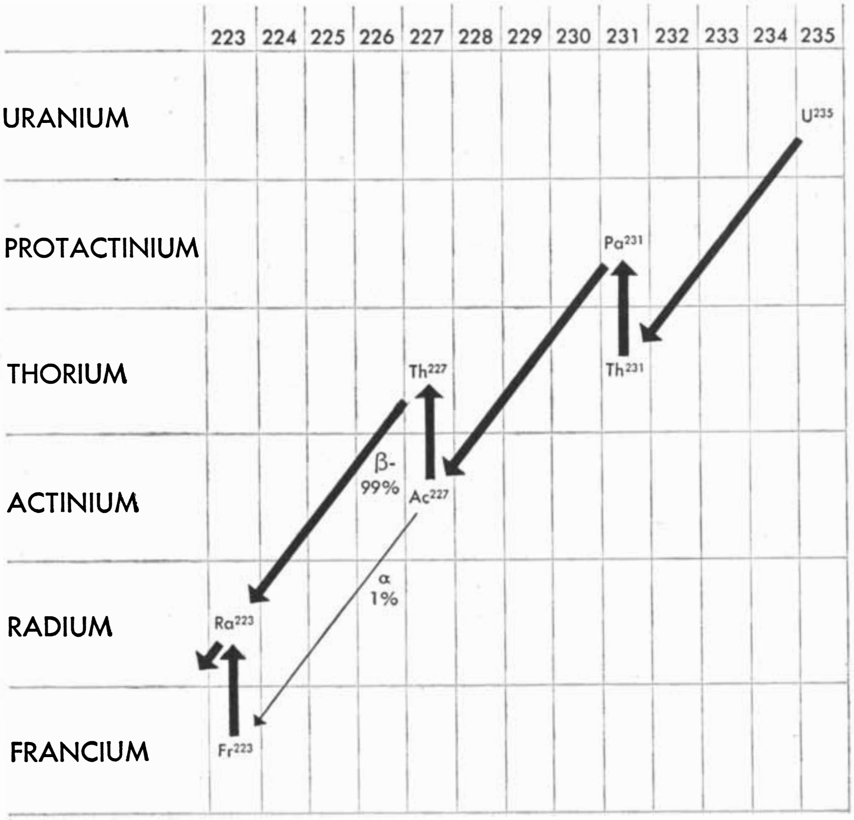
It was already known that if the heaviest stable isotope of an element captured a neutron, the nucleus became unstable and decayed to the next higher element by beta emission; this method, as we have seen, can be used to produce technetium from molybdenum and promethium from neodymium. Suppose this process were applied to uranium, the heaviest element. U^{238} should capture a neutron and become a heavier isotope, U^{239}, which would be beta-unstable and decay to element 93—a brand-new element outside the periodic table! When this experiment was tried, the experimenters experienced a shock: instead of observing just one or two radioactivities from the product, they found a bewildering array of radioactivities. For some time it was thought that these activities must represent a number of new transuranium elements. Not until several years later was it recognized that the activities came from fission products. Thus the discovery of fission was a by-product of the search for transuranium elements.

With poetic justice the actual discovery of the first transuranium element in turn resulted from experiments aimed at understanding the fission process. Several experimenters, including E. M. McMillan of the University of California, measured the energies of the two main fission fragments by observing the distances they traveled from each other as a result of their mutual recoil when the nucleus exploded. McMillan noted that there was another radioactive product of the reaction, with a half-life of 2.3 days, which did not recoil, at least not sufficiently to escape from the thin layer of fissioning uranium. He suspected that this was a product formed by neutron capture, which does not release much energy, rather than by fission. McMillan and P. H. Abelson early in 1940 deduced by chemical means that this product was surely an isotope of element 93, arising by beta decay from U^{239}. The latter had a half-life of 23 minutes. Element 93 was given the name neptunium (Np) because it was beyond uranium, just as the planet Neptune is beyond Uranus.

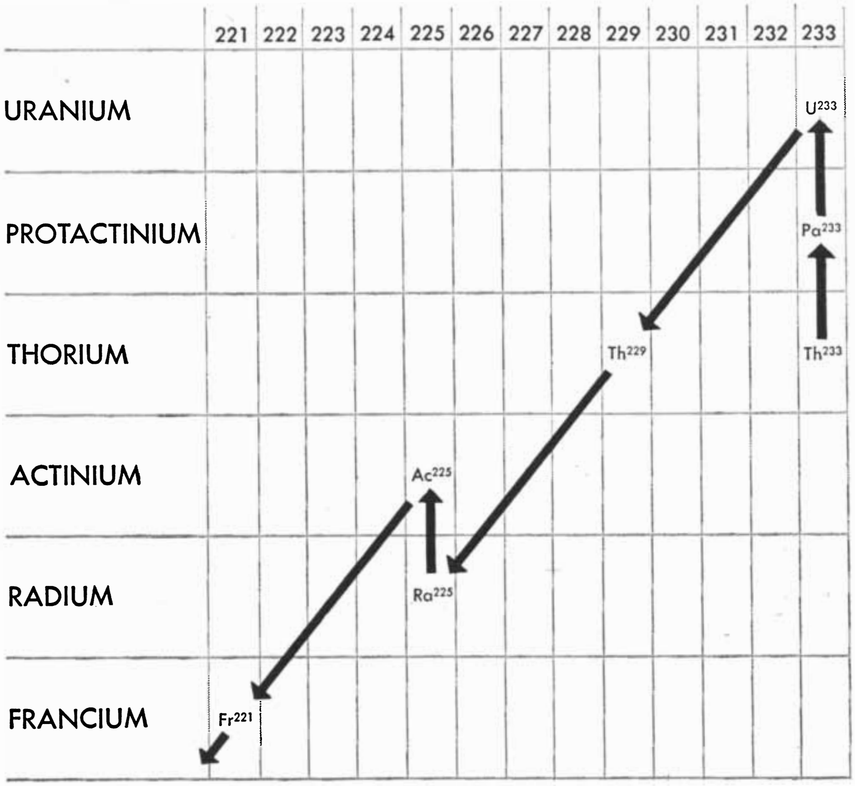
About this time the possibility of a nuclear chain reaction and the production of transuranium elements for military use began to take shape. With the war already in progress, further work on the transuranium elements and related subjects was conducted by physicists and chemists under self-imposed secrecy, at first informally and finally as an organized program.

A neptunium isotope of great practical interest is Np^{237}, discovered in 1942 by A. C. Wahl and Seaborg at the University of California. It is very long-lived (half-life: two million years) and can be made in appreciable amounts as a by-product in the uranium pile. Because it is relatively innocuous, it can be handled experimentally in principle like any normal element.

It was not obvious *a priori* what the electronic configuration and chemical properties of neptunium might be. Uranium was known to have some similarity to tungsten and it was thought that element 93 might be a homologue of the next element above tungsten, rhenium. Yet there was also a possibility that element 93 might be a member of a new



NATURAL FRANCIUM is the result of rare branched decay of actinium 227. Ninety-nine per cent of Ac^{227} decays by beta emission to thorium 227. An almost negligible amount decays by alpha emission to francium 223.



SYNTHETIC FRANCIUM is made in appreciable quantity by irradiating thorium 232 with neutrons. The irradiation forms Th^{233}, the starting point of this table. The decay proceeds through five other isotopes to francium 221.

transition series among the heavy elements, similar to the rare-earth group. It turned out that neptunium bears no resemblance to rhenium. It is much more closely allied to its neighboring element uranium. The evidence is mounting that all of the transuranium elements belong to a new transition series analogous to the rare-earth group. The transuranium elements parallel the rare earths in electronic configuration and have some strong resemblances to them in chemical properties. Just as lanthanum is the prototype element for the rare-earth series, so actinium is the prototype for the heavy-element series. Hence the new group may be called the actinide series. The members of this series known in nature—thorium, protactinium and uranium—had not appeared to be related chemically, but when the transuranium elements were studied latent similarities in the whole group began to appear. Because of certain differences in chemical properties the theory that these elements belong in one series is not accepted by all chemists. It is possible to answer the objections on the basis of a detailed analysis of the evidence, but this is not the place for such a discussion.

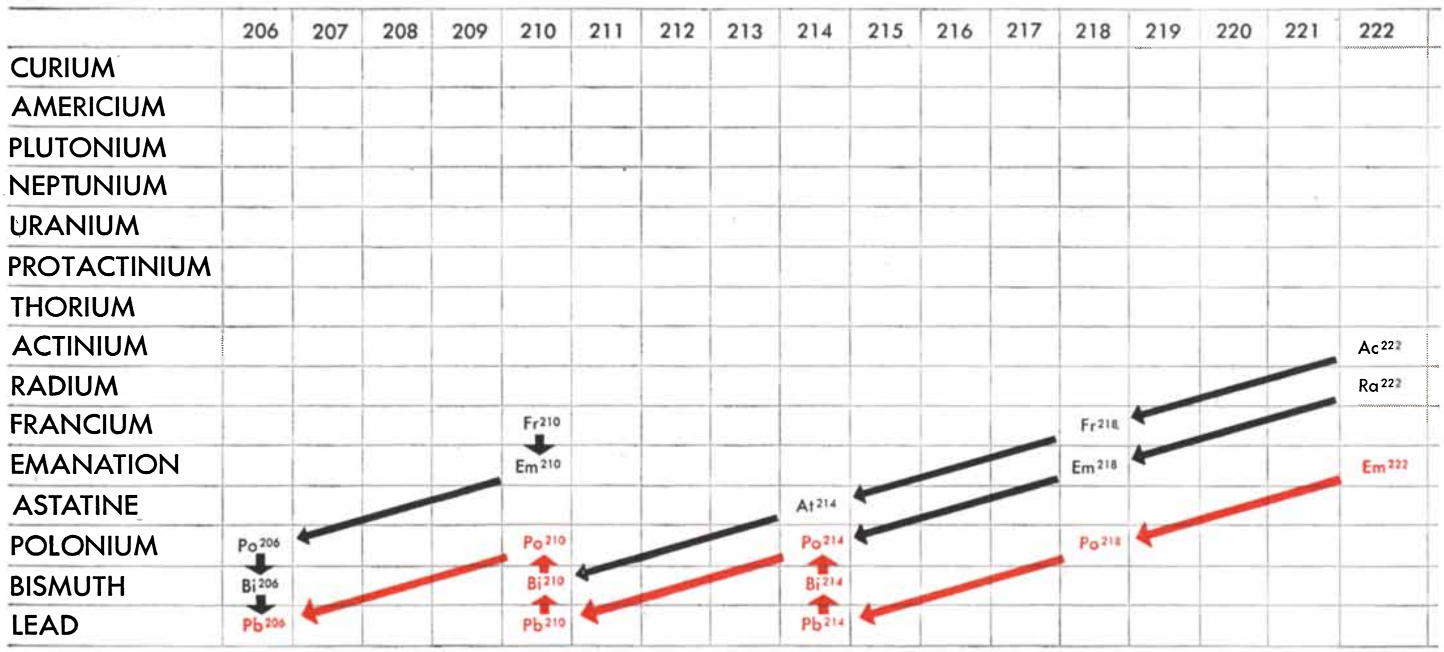
Let us note a few points here, however, on the chemical properties of these heavy elements as a group and their comparison with the rare earths. The rare-earth elements are predominantly trivalent, or in what the chemist now calls the "plus three oxidation state." (Most chemists now use the term "oxidation" to signify the removal or neutralization through bond formation of an element's electrons, whether this is accomplished by the specific method of adding oxygen or by any other means. "Oxidation state" is a somewhat more rigorous term for what we used to call the "valence" of an element.) Only a few rare earths can be induced to assume oxidation states other than the trivalent, and these with difficulty. The heavier elements, notably uranium, neptunium, plutonium and americium, are distinctly multivalent, with the trivalent state becoming progressively more stable along the series. Thus trivalent thorium cannot be obtained in aqueous solution; uranium can be reduced to this state only with difficulty; plutonium can be reduced to it fairly readily; for americium it is the principal state, and for curium it is the only one known.

The effort brought to bear on understanding plutonium chemistry has elevated it to the status of one of the common elements, insofar as knowledge of its chemical properties is concerned. The pronounced multivalent nature of an element such as plutonium makes it of great interest in chemical studies, for this single element affords means of observing most of the phenomena of inorganic chemistry. Plutonium is perhaps unique in having four different oxidation states, which coexist in easily measurable concentrations in aqueous solutions. The color changes from one oxidation state to another afford a fitting visual accompaniment to the curious existence of the many states. Plutonium in its trivalent state in solution is a beautiful pure blue; it changes to green or amber (depending upon solution conditions) when oxidized to the quadrivalent state. The next state, pentavalent plutonium, is colorless; the highest oxidation state, six, is bright yellow. It is unfortunate that plutonium, because of its radioactivity, may never be suitable material for classroom use, for it has superb attributes as a teaching material.

Element 94

After neptunium plutonium was of course the next element discovered; its name derives from the fact that Pluto is the next planet beyond Neptune. The work of McMillan and Abelson had shown that Np^{239} decayed by emission of beta particles; therefore the product should be the next higher element, number 94. However, the new element decayed so slowly that it could not be definitely detected through its radioactivity. By the end of 1940 Seaborg, McMillan, J. W. Kennedy and A. C. Wahl did discover element 94 by a somewhat different approach. By irradiating uranium with deuterons they made a new isotope of neptunium which also decayed to plutonium, but in this case the plutonium was sufficiently short-lived to allow its detection. This isotope of plutonium has proved to be Pu^{238}, with an alpha-decay half-life of 90 years, while that for Pu^{239}, the first isotope made, is 24,000 years.

Armed with the information on the chemistry of the new transuranium elements, Kennedy, Seaborg, Segrè, and Wahl in 1941 were able to identify Pu^{239} from strongly irradiated uranium and were able to prove that Pu^{239} would



THE URANIUM SERIES of radioactive elements is mapped on the basis of atomic number or number of protons in the nucleus (*column of elements at left*) and atomic weight or number of protons and neutrons in the nucleus (*numbers at the top*). In nature (*red symbols and arrows*) the series begins with uranium 238, which decays through 13 other isotopes to stable lead 206. The series has now been enlarged (*black symbols* undergo fission with slow neutrons. The most intensive cyclotron irradiations ever made were then carried out, with the objective of synthesizing sufficient plutonium to determine certain properties that could best be obtained with visible amounts. In September, 1942, B. B. Cunningham and L. B. Werner, working at the wartime Metallurgical Laboratory of the University of Chicago, isolated a few micrograms of Pu^{239}. Thus plutonium became the first man-made element to be produced in visible quantities.

The realization that plutonium could serve as a nuclear fuel like U^{235}, and that it might be made in quantity in a nuclear chain reactor, resulted in man's first practice of alchemy on a production scale. Plutonium is the only synthetic element yet made in kilogram quantities. The huge plants at Hanford (and presumably other plants considerably west of Hanford) are devoted to this task—the solid embodiment of ideas which sounded utterly fantastic a few years back.

Beyond Plutonium

After plutonium had been produced in quantity, the next higher elements, americium and curium, followed in short order. Based on methods worked out for producing neptunium and plutonium isotopes, principally by cyclotron bombardments of uranium, Seaborg and co-workers discovered elements 95 and 96 during 1944 and early 1945. The speed of discovery of these elements was largely due to the accurate forecast of their chemical properties. Element 96, found by Seaborg, R. A. James and L. O. Morgan, was actually discovered before element 95. It was made by the bombardment of plutonium with alpha particles in a cyclotron. This produced an isotope of mass number 242 with a half-life of half a year. Seaborg, James, and A. Ghiorso later produced element 95 by first preparing Pu^{241}, which decayed by beta emission to an isotope of element 95 with mass number 241 and a half-life of slightly less than 500 years.

The names for elements 95 and 96 were chosen with regard to their positions in the periodic table according to the actinide concept. The corresponding rare-earth elements are europium and gadolinium, named in the one case for Europe and in the other for J. Gadolin, a Finnish pioneer in rare-earth chemistry. Element 95 was accordingly named americium (Am) for the Americas, and element 96 curium (Cm) in honor of Marie and Pierre Curie.

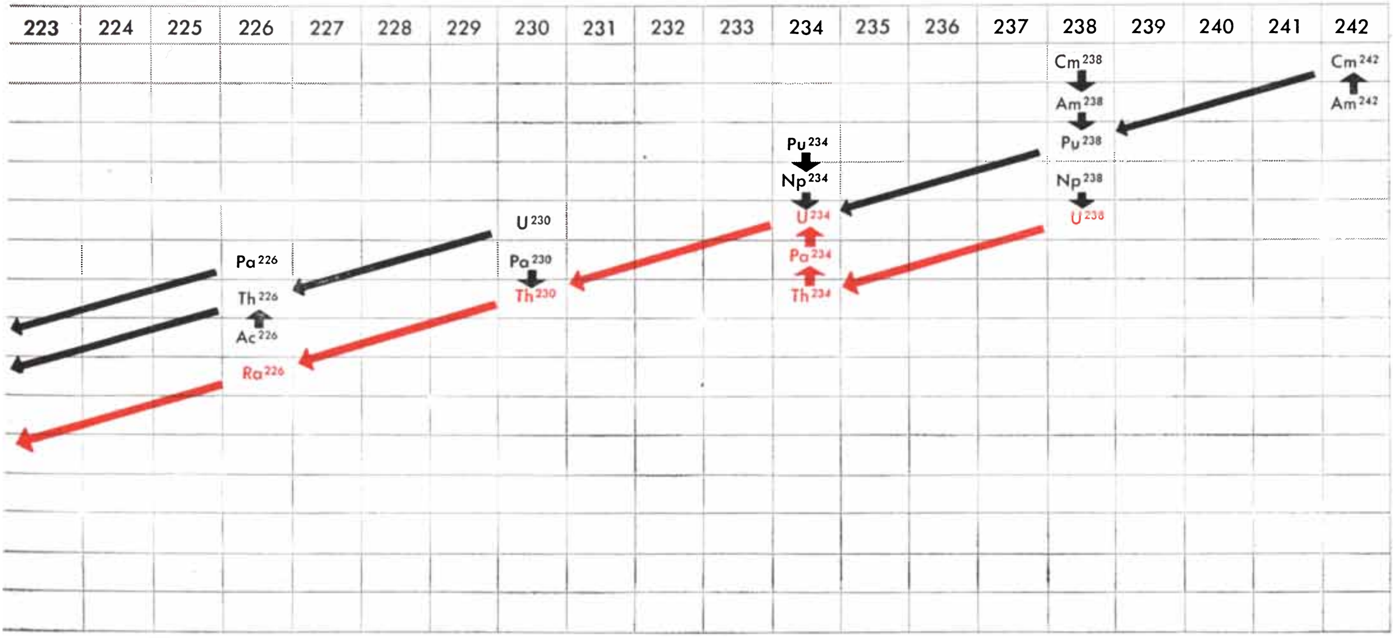
Both americium and curium have been isolated in a pure state by techniques of ultramicrochemistry. Cunningham was the first to isolate visible amounts of americium. Using some isolated americium, it was possible to convert an appreciable percentage to curium in a pile. From this Werner and Perlman obtained the first curium in the free state. The subsequent work with pure americium and curium has provided abundant evidence for the similarity of these elements to their prototype, actinium.

The elements so far discussed fill in the periodic table completely from hydrogen through curium. If any new elements are to be added, they must lie above curium in atomic number. The beginning of 1950 saw the announcement of the discovery of the first transcurium element, number 97, by S. G. Thompson, Ghiorso and Seaborg at Berkeley. In the naming of element 97, the same convention was used as for the preceding elements. The element in the rare-earth series that corresponds to element 97 is terbium, named for Ytterby, Sweden, where extensive rare-earth deposits were found. It is therefore proper that the new element be called berkelium (Bk), in view of the role played by the University of California at Berkeley in the preparation of most of the synthetic elements.

An isotope of berkelium was first prepared by the irradiation of a minute quantity of americium with cyclotron alpha-particles. Isolation of its radioactivity was accomplished in December, 1949, culminating four years of work on the problem.

Further new elements doubtless can be expected. The difficulty of finding new elements in the transuranium region becomes increasingly severe, however, principally because it becomes less and less likely that isotopes can be prepared with sufficiently long half-lives to allow time for the intricate chemical separations. At what point more basic difficulties will arise cannot yet be said.

I. Perlman and G. T. Seaborg are professors of chemistry at the University of California.

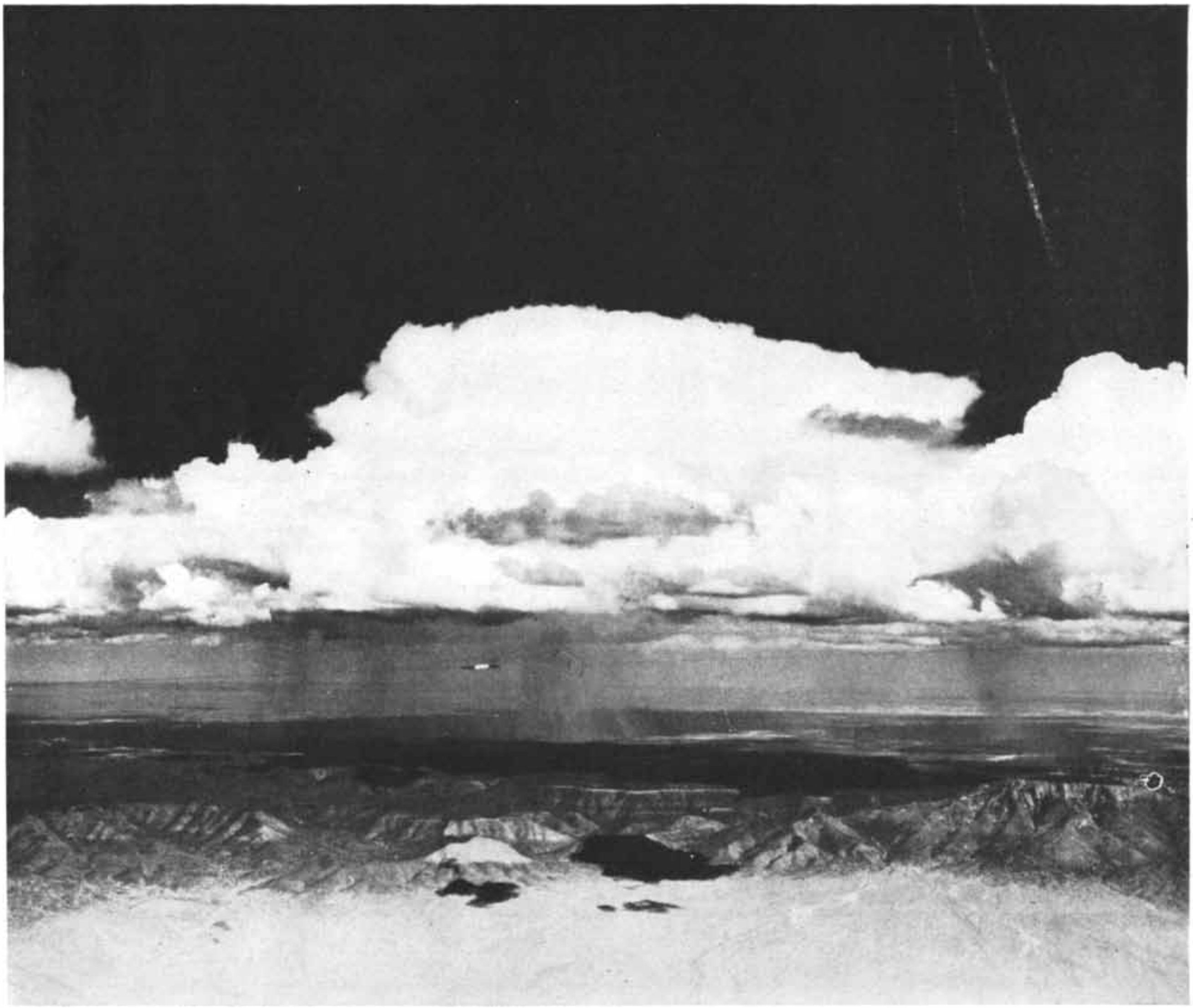


and arrows) by transmuting natural isotopes into artificial ones with such methods as pile and cyclotron bombardment. These artificial isotopes doubtless existed in nature at one time. Isotopes that decay by emitting an alpha particle lose an atomic number of two and an atomic weight of four. Those that emit a negative beta particle gain an atomic number of one; those that emit a positive beta particle lose an atomic number of one.

THE CHANGING CLIMATE

There is little doubt that the averages of conditions which make up the weather have changed during the course of history. What about man's efforts to alter them further?

by George H. T. Kimble



CUMULUS CLOUDS shed rain on the arid earth of New Mexico. This aerial photograph was made on July 21 of last year after Irving Langmuir and his associates had sown the air with crystals of silver iodide (*page 50*).

THE one point on which most people agree when they talk about the weather is that things were very different when they were young. Beyond that, differences of opinion begin to creep in quite rapidly, for memory plays queer tricks with all of us where the weather is concerned. We tend to be exceptionally good at recalling certain kinds of weather, because of the effect they may have had upon our outdoor sports or our rheumatism, and exceptionally bad at recalling other kinds that did not happen to matter to us.

What, exactly, is happening to our climate? Is it merely fluctuating on a short-term basis or is it undergoing a major long-term change?

Some investigators have been at considerable pains to show that the world's climate has remained essentially stable since early historical times. The late geologist J. W. Gregory argued convincingly that because the distribution of the date palm in the Levant was practically the same in Biblical times as it is today, the mean temperature of Palestine has not altered materially. Others have argued that, because the olive can still be made to grow in North Africa near the margin of the desert, the climate has not deteriorated significantly since the days when the Roman settlers around Timgad carried on their highly profitable trade in olive oil. Moreover, it must be admitted that a change of landscape is no proof of a change of climate. The decay or disappearance of once-proud cities that stood in areas now barren does not necessarily mean a decrease in rainfall; it may have resulted, in part at least, from overgrazing of the surrounding pastures and the improvident use of the plow. Soil erosion was an empire-killer long before the 20th century.

Nonetheless we do have evidence of marked changes in climate during recorded history. Consider the following three cases, taken more or less at random.

The first concerns the climate of Egypt. In the second century A. D. Claudius Ptolemaeus of Alexandria, who on all counts was one of the greatest geographers of antiquity, kept a systematic diary of the Egyptian weather. He had no thermometer or rain gauge, but he faithfully recorded thunderstorms, rainy days, winds and so on. From this record it is possible to reconstruct the main features of the climate of his day. The difference between 150 A.D. and 1950 A.D. could hardly be more striking. Nowadays Egyptian summers are rainless; then they had almost as many rainy days as the winters. Today thunderstorms are unknown; then they were frequent in the hot season. Now the prevailing, almost the only, summer wind is from the north; then it alternated with winds from the south and west.

The second illustration is even more dramatic. In the 11th century, almost 1,000 years ago, there was a flourishing Norse culture in Greenland. Its sagas relate that there were some 300 farmsteads along the West Coast of the great island, supporting 10,000 people and large numbers of sheep and cattle. This colony continued to lead an almost self-supporting existence until the 14th century, when it appears to have fallen on grim days. By 1400 A.D. very few settlements were left, and these were fighting a losing battle. While we are not going to suggest that the depopulation of Greenland can be explained solely in terms of climatic change, archaeologists have provided irrefutable evidence that the climate did undergo a deterioration. There are ancient Norse graves in the southern part of the island, with tree roots intertwined among the bones, in soil that is now permanently frozen.

The third illustration is taken from the British Isles. At the present time the summer season in England is not warm enough to ripen grapes except in a very few sheltered locations, and then only if the summer is unusually hot. But at the time of the Norman Conquest things were different. The Domesday Book mentions no fewer than 38 vineyards, in addition to those of the Crown, in England. In the 12th century vine dressers are frequently mentioned in abbey chronicles as forming part of the normal staff of an ecclesiastical estate. One William of Malmesbury, writing about 1150 A.D., assures us that the vale of Gloucester "exhibits a greater number of vineyards than any other county in England, yielding abundant crops and of superior quality: nor are the wines made here by any means harsh or ungrateful to the palate, for in point of sweetness, they may almost bear comparison with the growths of France." A century later such references became much less common, and by the end of the 14th century they had disappeared almost completely. It would seem, then, that the English summers were distinctly warmer during the 12th and 13th centuries than they normally are today.

WE know for certain that important changes in the climate of the Northern Hemisphere are going on at the present time. These are not merely short-term fluctuations. In Philadelphia the mean annual temperature has risen by four degrees in a century—from approximately 52 degrees F. in the 1830s to over 56 degrees in the 1930s. In Montreal the rise has been from 42 degrees F. in the 1880s, when observations began, to 44 degrees in the 1940s. In Spitsbergen the rise since 1912 has been approximately four degrees. In Scandinavia and the British Isles rises of the order of one to two degrees have been general over the period of the last 100 years or so.

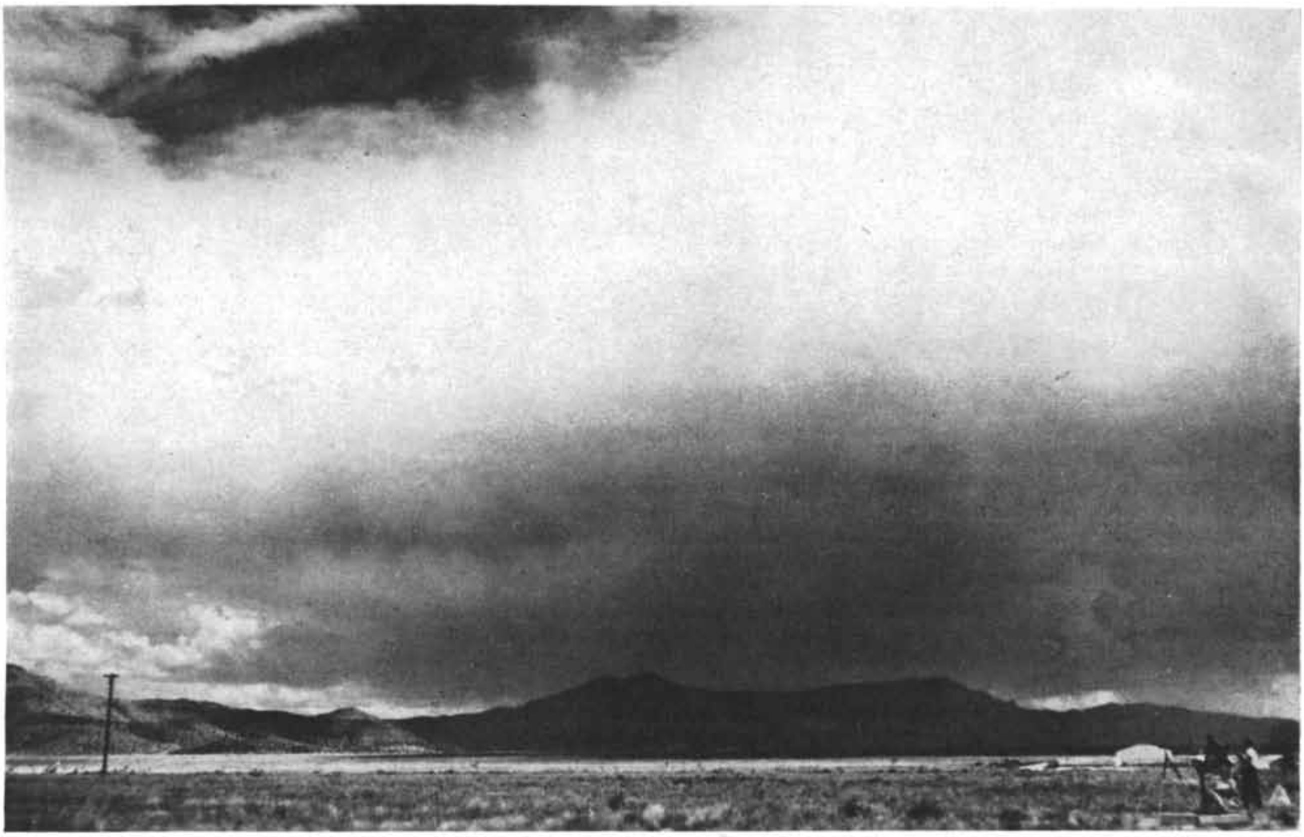
More emphatic than the rise in mean annual temperature has been the warming up of the winter half of the year. At Washington, D. C., during the 20-year period ending with 1892 there was a total of 354 days with freezing temperature during the spring months; for the 20 years ending with 1933 the corresponding total was 237. At Montreal subzero temperatures are now only half as common as they were 75 years ago, and the mean temperature for March has risen more than six degrees. In Spitsbergen the average December temperature nowadays is more than 10 degrees higher than it was 30 years ago!

The upward trend in temperature has been accompanied in several parts of the world by a downward trend in precipitation. Particularly noticeable has been the decline in snowfall in parts of North America. At Montreal, for instance, the expectation now is not much more than 80 inches of snow in a season, as against 130 inches or so in the 1880s. Including both snowfall and rainfall, the total winter precipitation (in terms of water) has declined from 22.12 inches in the 1900s to 19.80 inches in the 1940s.

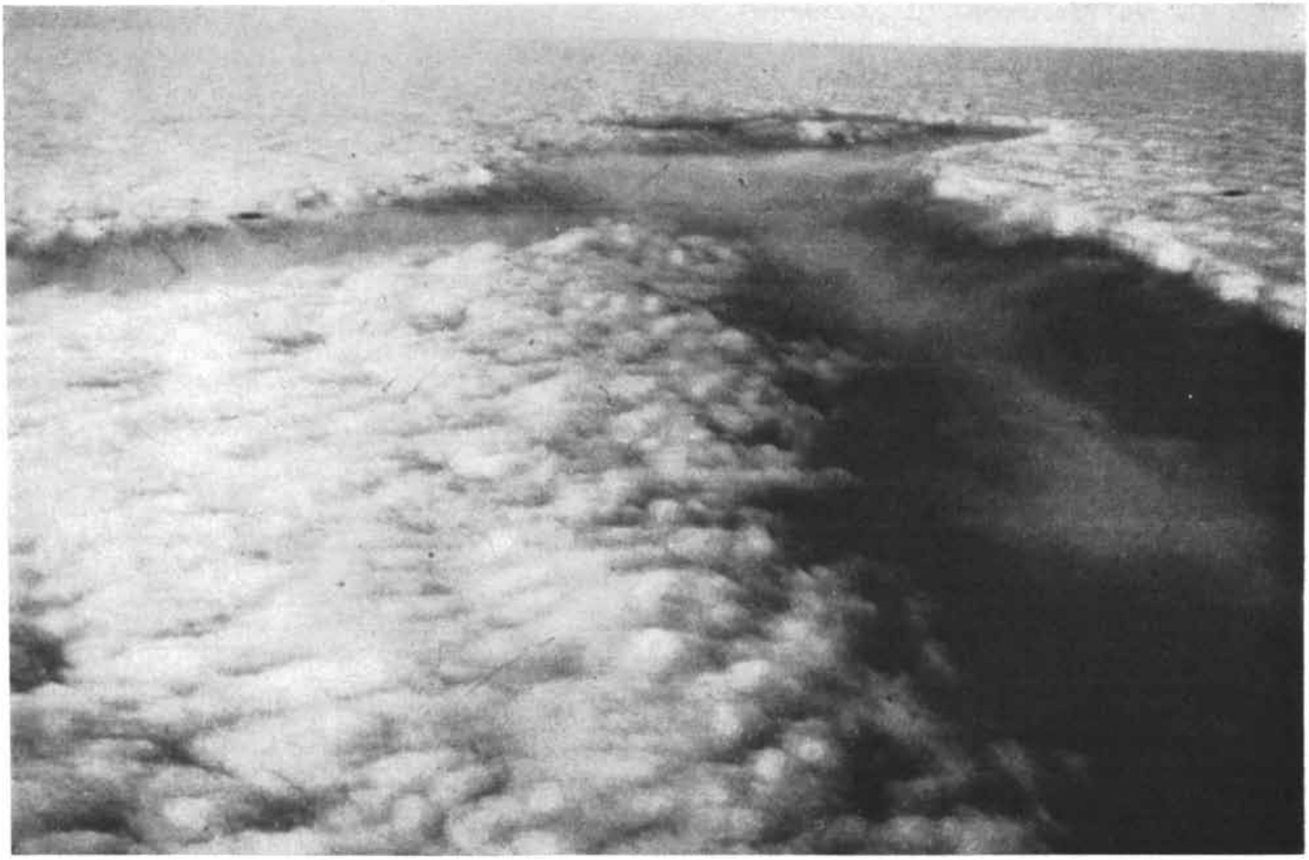
These temperature and precipitation trends are far from being world-wide, however. It is the Arctic, sub-Arctic and mid-latitude zones that have experienced the major increases of temperature; the tropical and subtropical zones have become a little cooler, if anything, in the past half-century. The decline in precipitation has occurred chiefly in North America, Africa, Australia and Brazil.

Already some of these changes are clearly reflected in human affairs. For instance, shipping operations in the White Sea and the Gulf of Bothnia can frequently be continued three to four weeks longer into the winter than formerly. In parts of Siberia the southern boundary of the zone of permanently frozen ground is receding poleward several dozen yards per annum. In Northern Hemisphere waters various kinds of commercially valuable fish have migrated northward. The common cod now is found as far north as the 73rd latitude off the West Coast of Greenland; the cod catch off this coast amounted to 13,000 tons in 1946 as against five tons in 1913.

On land the warming up of the climate has begun to make itself felt in the acceleration of plant and animal growth and the poleward extension of various plant and animal habitats. In Iceland there has been an extension of barley cultivation. The same is true of Norway, where there has been a noticeable spread of farming up the sides of some of the mountains. In Sweden, Finland, Alaska, and northern Quebec the coniferous forests are growing faster and are begin-



NEW MEXICO TEST observers (*right*) watch thunderstorm over a mountain range nine hours after "seeding" with silver iodide. Seeding began at 5:30 a.m. First cloud appeared at 8:30; first cumulus cloud at 10:30.



RIFTS APPEAR in a formation of stratus clouds after they are sown with dry ice crystals. The clouds were sown in a pattern of the Greek letter gamma. The rift in the right foreground is 20 miles long and two wide.

ning to colonize new ground. In eastern Canada the northern limit of feasible cultivation for crops such as wheat has advanced 200 to 300 miles. Some farmers in southern Ontario are even beginning to experiment with raising cotton!

We shall not concern ourselves here with the reasons for this climatic trend, except to note that in all probability long-term variations in the amount of radiant energy received by the earth from the sun have something to do with it. It is also worth pointing out, incidentally, that the artificial heat of modern cities has a far from negligible effect on the local climate. Heat engineers have concluded that in a North American city the size of Montreal (1,125,000) the amount of heat escaping into the lower atmosphere from factories, offices and homes on some days could raise the air temperature by three to four degrees.

WHAT, if anything, can man do about the weather today? It goes without saying that the changes we have mentioned are not pleasing to everybody. The decline in winter precipitation suits city street-cleaning departments, which have to clear the snow away, but the watershed engineers of North America are not nearly so happy about it. The smaller the snowfall over their catchment basins, the lower their water-storage reservoirs are likely to fall during the summer. This was dramatically shown in the city of New York during the past winter, when the city was caught in a grave water shortage because of abnormally low precipitation. As a result the city fathers are investigating the possibility of manufacturing rain by the cloud-seeding technique.

Of course there is nothing very new about the idea of tinkering with the climate. The folklore of primitive tribes is rich in magic formulae for rain-making. Around the turn of the present century great interest developed in projects for controlling the elements. There were even international congresses on how to prevent hail from damaging crops. It was thought that a bombardment of storm clouds by gunfire might do the trick, but the only result achieved was a high accident rate among the scientists! About the same time the U. S. Government carried out a rain-making experiment in Texas. Balloons fitted with gas and dynamite were released under likely clouds. Admittedly a little rain did fall, but the Weather Bureau, on examining its charts, said it would have rained anyway.

Since then there have been plenty of other novel suggestions as to how the weather might be controlled in a given particular. Prior to 1939 most of them went into the wastebasket. During the war, however, several such devices got a trial. One was a new technique of fog dispersion used at airfields: the burning of gasoline vapor, sprayed through perforated pipes that were laid along the edges of the runways, generated intense heat which evaporated the moisture in the air and so "burned" off the fog. But the cost was terrific: the gasoline consumed amounted to an average of 6,000 gallons per plane per landing.

Certainly the most interesting of the new ideas is the cloud-seeding method for making rain, the development of which is said to have been stimulated originally by the possibility of its use as a weapon. (It does not require a very lively imagination to picture the havoc that could be wrought upon a nation unlucky enough to have its clouds dehydrated by an enemy situated to windward!) What is the theory behind the technique, and what results have been achieved to date?

According to one modern theory about precipitation, the formation of rain in a cloud requires the presence not only of water droplets but also of ice crystals. Thus clouds situated below the freezing level of the atmosphere cannot form rain. So the idea naturally suggested itself: why not provoke such clouds to precipitate their moisture by supplying ice crystals artificially? Such crystals, it was argued, should grow like seeds in fertile soil, and it would be only a matter of time before they would be big enough to overcome any updrafts and so force their way down to earth. The theory was first put to the test by the U. S. physicist Irving Langmuir and his associates on November 13, 1946. Six pounds of granulated dry ice were "seeded" into a four-mile stretch of supercooled strato-cumulus over Massachusetts. A few minutes later light snow was seen falling out of the cloud, but so far as could be observed none reached the ground. Other experiments followed in fairly quick succession. One of the most spectacular took place in Australia. A large cumulus cloud, one of many nonprecipitating clouds in the sky at the time, was induced to produce rain and to grow into a cumulo-nimbus cloud extending almost 20,000 feet above the other cloud tops. This cloud continued to yield showers throughout the afternoon. Another experiment in New Mexico in the summer of 1949 produced a much heavier rainfall. Nevertheless the results of the experiments in general have been inconclusive. Of the dozens of tests made in many different parts of the world, only a few have produced convincing amounts of rain. In a series of 45 seeding experiments over Hawaii only one yielded rain of any duration.

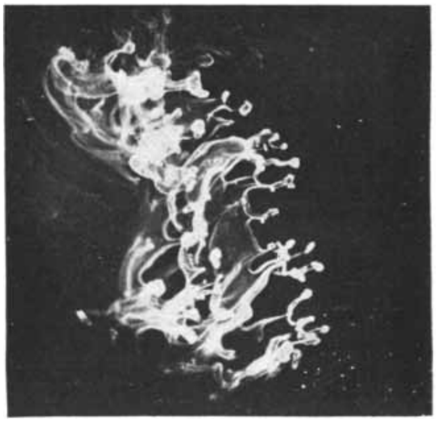
It seems that the crystallization theory is not quite satisfactory. Surprisingly some of the best results have been obtained in clouds where ice crystals could have played little if any part in the formation of the rain. For instance, over the Hawaiian Islands in September, 1947, a cumulus cloud below the freezing level was seeded with dry ice. This cloud commenced to precipitate within 10 minutes, and rain fell continuously from it for several hours before the cloud reached the freezing level.

As the physicists have since discovered, a number of conditions have to be satisfied before rain may be released from a cloud simply by seeding it with dry ice or silver iodide. In the first place, the cloud must be at least 4,000 feet deep, and dense enough to contain a large number of water drops; thin stratus or strato-cumulus clouds will not do. Secondly, the temperature and wind conditions must be just right to maintain turbulence in the cloud. Thirdly, and closely related, the vertical velocities within the cloud must be appreciable; in the case of a cloud that does not penetrate into the freezing zone they should be of the order of 15 to 20 feet per second. If the rain is to be stimulated by collisions of supercooled waterdrops and ice crystals, the cloud must extend several thousand feet above the freezing level. Such a combination of atmospheric conditions probably is rare except in a cloud that is already on the verge of precipitating. Indeed, some physicists have gone so far as to suggest that in every case where rain or snow fell after seeding, the state of the atmosphere was such that the precipitation would have occurred in any event.

It is evident, therefore, that the technique is unlikely to be of any assistance in helping to break a drought, for most of our prolonged dry spells are associated with anticyclonic conditions which seldom yield clouds of any depth. The same objection applies to the view that countries of low rainfall, like Australia, can be given a new climatic deal. E. G. Bowen of the Australian Council for Scientific and Industrial Research has categorically declared that "it will be quite impossible to do anything for the desert areas by this method; the right types of clouds do not exist there in sufficient quantity."

THE seeding technique holds out other useful possibilities, however, which should not be overlooked. The seeding with dry ice of a large uniform stratus cloud which is below the freezing point is capable of dissolving the cloud —sometimes temporarily, often permanently. Obviously this treatment might be turned to good account, particularly in winter, when anticyclones are frequently accompanied by a stratiform cloud cover that produces dull, depressing weather and sends up the daytime consumption of gas and electricity for lighting. Some of the experimenters hold that many of our worst winter fogs could be dissipated simply by scattering a few handfuls of dry ice or other

WATER VAPOR is supercooled in a tank during laboratory experiment in precipitation by dry ice crystals.



VAPOR CONGEALS into a curious pattern after the tank has been sown with a few crystals of the dry ice.

foreign particles into a supercooled ground fog.

Vincent Schaefer, an associate of Langmuir and one of the chief pioneers in this field, has recently said that the seeding technique may well prove to be more efficacious in making it disintegrate a storm cloud than in precipitating it. In this way many a valuable fruit crop might be saved from a disastrous hail or rain storm. Schaefer also believes that it may be possible to eliminate, or at least to reduce, the icing hazard to aircraft by patrolling airline routes with scout planes and seeding dangerous clouds to disperse them. Others are of the opinion that similar "interference techniques" might be successful in combatting the hurricane and tornado menace.

Suppose for the sake of argument that physicists and technologists are eventually able, by one means or another, to effect a radical change of climate: Ought we to allow them to do it? It appears to me that there are at least two reasons why we should be slow to give them their head. In the first place, the results would be very difficult to forecast; they might be the opposite of what was intended. There are too many unknowns in the atmospheric equation. In the second place, even if a given operation was successful, the outcome would be sure to please fewer people than the weather we have come to expect. A big freeze might gratify the winter sports enthusiasts of Lake Placid, but not the hotel keepers of Palm Beach. One farmer might decide he wanted to manufacture rain for his grain, while his neighbor wanted sunshine for his strawberries. Surely the world has enough troubles on its hands at the moment without spawning more!

WE have recently had an eloquent demonstration of the troubles that arise when men suspect their neighbors of tinkering with the weather. The people of Reno, Nev., decided they would like to anoint the slopes of nearby Mount Rose with snow to provide skiing and other snappy sports for the rich transients who had tired of playing with slot machines. Apparently the plan worked beautifully—until the people in the neighboring state of Utah got wind of what was happening. The farmers of the Mormon state, who depend upon snow-fed streams that flow down from the lofty Wasatch Mountains, naturally take the greatest interest in the year-to-year variations of the winter snowfall on these mountains. Noticing that the mountains did not seem to be accumulating snow at the normal rate, they sent a surveyor up with a foot-rule. He reported that there were only 40 inches of snow up there instead of the usual 60 or so. This could mean only one thing: the wicked Nevadans had tampered with the course of nature and diverted the snowfall to their side of the mountains. Now there is the making of a first-class legal battle between the two states, for the Utahans have unearthed a law in the statute books making it illegal to divert water. The lawyers of Reno, experienced as they may be, will have their work cut out to prove that the snow in those diverted clouds did not contain water!

Since the lawyers started to take this rain- and snow-making business in hand, the enthusiasm of many of its erstwhile supporters has flagged. In Canada the mere threat of legal action by farmers, foresters and other interested parties was enough to put a stop to all cloud-seeding operations for a time, while in the U. S. it constrained one of the industrial companies that had pioneered the technique to cease all outdoor experiments.

This is not to say that we must or ought to leave the world's weather exactly as we find it, for in some respects it has deteriorated as a result of human folly, while in others it can easily be "touched up" to the advantage of all. Many a fruitgrower, for instance, owes his prosperity to the smudge-pot or orchard heater, which enables him to ward off untimely frost. The planting of shelter

SNOW CRYSTALS fall to bottom of tank. Experiment was performed in the General Electric laboratories.

belts has had similarly beneficent results for the life and economy of many a Midwestern farmer. Not only do the trees give shade to animals and men; they also break the force of the wind, anchor the snow and retard the rate of evaporation of ground water, thus conserving moisture. There are indications that the construction of great water-storage reservoirs in the Sudan, the Punjab and the U. S. West has reduced the extremes of summer heat and winter cold in the nearby regions, and in the long run it may possibly increase the rainfall.

A striking illustration of the measure of man's power to change his climatic environment, in this case for the worse, is evident in a part of the mountain country of Tennessee. There in the Copper Basin is an area of 7,000 acres that was once heavily forested but has now been completely denuded by smelter fumes. Weather observations taken at different stations show that during both winter and summer the average daily temperature in this blighted area is three to four degrees higher than in surrounding lands still covered with forest; that the average wind velocity in the denuded area is seven to 10 times as great in winter and 30 to 40 times as great in summer; that evaporation is twice as great there in winter and seven times as great in summer, and that the annual precipitation is some 28 per cent greater in the forested than in the open area.

Somewhere in all this there must be a moral. This much at least seems clear: scientists and technologists are likely to add far more to the sum-total of human happiness by restoring the lost equilibrium between earth, air and water than by attempting to produce a new one of their own contriving.

George H. T. Kimble is professor of geography and director of the meteorological observatory at McGill University.

"SOCIAL INSTINCTS"

It is too often assumed that the law of nature is: kill or be killed. Presenting an argument for the opposite principle: a natural law of cooperation

by Ashley Montagu

Now this is the Law of the Jungle—as old and as true as the sky;
And the Wolf that shall keep it may prosper, but the Wolf that shall break it must die.
. . . the strength of the Pack is the Wolf, and the strength of the Wolf is the Pack.

—Rudyard Kipling

IT is curious that generally "the law of the jungle" has come to have an entirely different meaning from the one Kipling suggested. Most people would say that the rule of the jungle is: kill or be killed. Rugged individualism, aggressiveness, warfare—these have been thought to be the natural tendencies throughout the animal kingdom. Kipling's sentimental verses suggest that, on the contrary, the law of the jungle is not the law of tooth and claw but the very opposite—cooperation. And strangely enough a great deal of modern research in various sciences indicates that Kipling was right. Through many laboratory experiments and observations in the field we are being shown that we have been close to 100 per cent wrong in thinking of animal life as a dog-eat-dog existence. The truth seems to be that nature adheres to the principles of the highest ethics: the Golden Rule is sound biology.

This concept is so far-ranging in its implications for human beings and for nations that a long-term research program has been started to collect and synthesize pertinent data from all parts of the world. The sponsor of the project is the Foundation for Integrated Education, a recently organized group of scholars and businessmen.

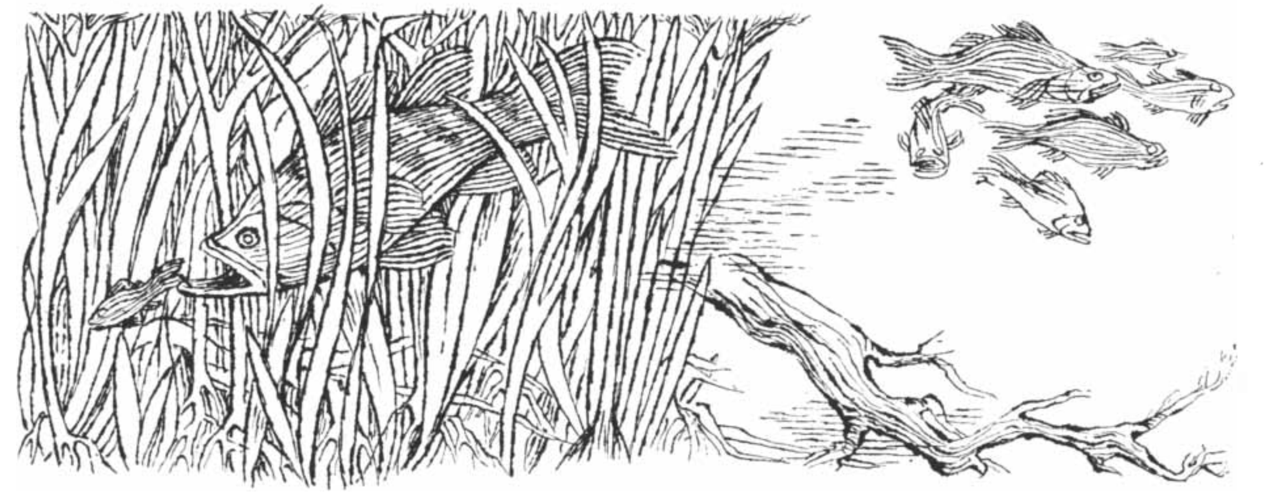
Examples of cooperation in the animal world are not at all difficult to find, and they turn up in the most surprising places. Take the case of African elephants, which are notoriously savage and resistant to taming. Hunters in Africa have seen elephants stop beside a wounded comrade and laboriously lift him with their trunks and tusks, when the so-called law of self-preservation should have made them run to safety. The noted explorer Carl E. Akeley several times saw threatened herds of elephants gather in a ring, with the younger and huskier beasts forming the outer circle to protect the older ones.

Or consider chimpanzees, traditionally regarded as self-centered little creatures. Workers at Yale University's Yerkes Laboratory of Primate Biology in Florida have seen chimps helping each other carry loads and even passing food to one another through the bars of their cages.

Even so lowly a mammal as the mouse is known to cooperate with its fellows. A Polish experimenter named T. Vetulani found that white mice isolated in separate cages failed to grow as fast as those that were grouped two, three or four in a cage. The grouped mice huddled together and kept each other warm, thus conserving energy for growth, and they also healed one another's sores by licking.

At the University of Chicago the zoologist W. C. Allee and his co-workers have discovered tendencies toward mutualism among goldfish. For example, a young goldfish will grow more rapidly in water that has previously been inhabited by another goldfish than in clean, uncontaminated water. The reason is that the second fish feeds on food regurgitated by the first.

Allee made a systematic investigation to determine whether animals survive a catastrophe better in a group than singly. The most interesting of several experiments on this problem involved planarian worms. The catastrophe was ultraviolet radiation, which is deadly to these animals. The worms were arranged in Petri dishes, the experimental animals



BASS are frequently cannibalistic when they live alone. Bass isolated in weedy ponds were observed to eat smaller bass (*left*). Bass in ponds cleared of vegetation, however, swam in groups and eschewed cannibalism (*right*).

being crowded 20 to a dish and the control animals isolated one to a dish. The worms were then irradiated. All the worms died eventually—but the crowded worms hung on to life much longer. In one test they lived an average of 517 minutes after radiation, while isolated worms lived only 41 minutes.

One possible explanation is that the crowded worms tended to shade one another from the lethal radiation. But that is not the whole story, as was proved by another experiment. This time all the worms were irradiated in groups of 20; none was isolated until after the damage had been done. Then 10 worms were taken from each group and placed singly in separate dishes, while the other 10 were left together. Again the grouped worms lived much longer than the isolated ones, surviving an average of 148 minutes to the latter's 78. The worms that were together somehow lent strength to one another. How? Whatever the factor is, it has not yet been identified.

ALLEE and other investigators have found that this rule of strength in numbers holds true practically everywhere they have looked. For example, a sea gull breeds more young when it lives in a large flock than in a small one. A salamander tadpole whose tail has been cut off will regenerate it more rapidly when other tadpoles are in the tank than when it is alone; the probable explanation is that the presence of several tadpoles raises the salt content of the water to approximately that of the cut surface and thus favors growth. An ant digging a nest moves more dirt when it works in the company of other ants than when it works alone. The spermatozoa of the sea-urchin retain their ability to fertilize eggs much longer in a heavy concentration than in a diluted one. And so on; the examples can be multiplied.

But all these examples deal only with cooperation among animals of the same species. What of the so-called warfare between different species? Lions kill zebras—no question about that. But the lions do it only for food. This type of aggression can no more be considered war than man can be said to war on oysters and chickens. Lions do not kill for sport or out of blood lust; they kill only when hungry. African explorers have seen them trot through herds of easy game without making the slightest attempt to attack.

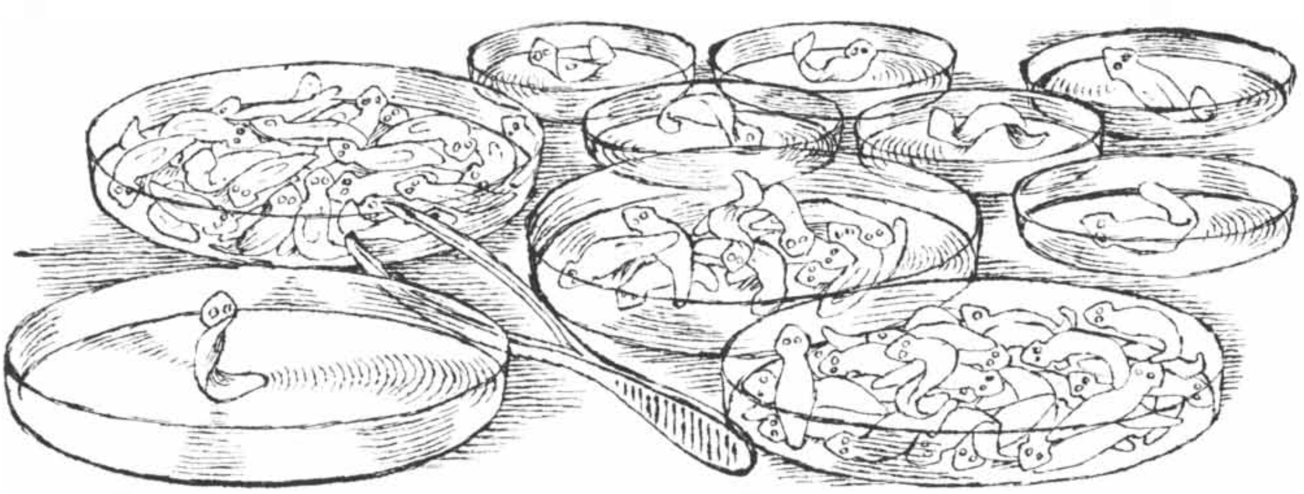
Surely cats and rats are instinctive enemies! Actually they are not: a cat has to learn to kill rats. A Chinese investigator named Zing Y. Kuo raised three groups of kittens under different conditions. Group A were left with their mothers, and from the first days of life saw how rats were killed. Group B were not allowed to see killing until they were several months old. Group C never saw killing at any time, and were raised in the same cage with baby rats. The upshot was that in Group A 85 per cent of the kittens became rat killers; in Group B only 45 per cent killed rats; in Group C the kittens lived in peace with their rat cagemates and all other rats of the same species. Kuo concluded: "If one insists that the cat has an instinct to kill the rat, I must add that it has an instinct to love the rat, too."

The traditional belief in "hereditary enemies" among animals is constantly being refuted by the Sunday supplements, which dote on printing pictures of dogs that have adopted cats, and tame foxes that play with chickens. The Philadelphia Zoo has witnessed some remarkable examples of such friendships. There a cat and a Senegal parrot became so attached to each other that they slept together. Another cat struck up an acquaintance with a deer, and chose the deer cage to have her kittens. The deer took special care not to step on the litter. A female goat was cautiously introduced by the zookeepers to a female black rhinoceros, a creature of very savage temperament. The rhino, instead of attempting to eat the goat, befriended her. The two were inseparable for the rest of their lives.

PERHAPS the most remarkable story of the effects of companionship comes from the Ohio Bureau of Fish Propagation. The Bureau chief, T. H. Langlois, has persuaded the bass in the Bureau's rearing ponds to give up cannibalism—a practice long supposed to be instinctive with these fish. Langlois noticed that if bass are put into weedy ponds, they tend to become separated by the vegetation and fail to form large social groups. Some of the fish take up lodgings in secluded spots and apparently develop a gangster psychology. Any small outsider unlucky enough to stray into these restricted territories gets eaten. The cannibalism does not stop when other food is thrown into the water by the fisheries men. The gangsters either fail to see the food because of the intervening vegetation, or are just not interested. Langlois' solution was simply to clear the vegetation out of the ponds before stocking them with bass. Now all the fish had to mingle. When food was thrown to them, they all ate together. With everybody well fed and everybody acquainted with everybody else, nobody tried to eat anybody.

These examples and scores of others recorded by scientists in many parts of the world emphasize how strong and deep-seated is the urge toward social life and mutual aid throughout animal life. What is the basis of this urge? The answer proposed here is that the social nature of all living things has its origin in the relationship between offspring and parent—the fact that the one is for a time dependent on the other. This hypothesis appears to bind together a large mass of facts not previously known to be related.

Consider a unicellular organism, the amoeba. When the amoeba reaches a certain size, it can avoid death only by



PLANARIAN WORMS survive longer in groups than alone. In one series of experiments the worms were placed in dishes and exposed to ultraviolet radiation. The more worms in the dish, the longer they survived.

dividing. Its continued existence is dependent on the proper formation of the daughter cells, and their existence in turn is dependent on the proper functioning of the parent through the various stages of mitosis. Here is a real instance of interdependent, social life; it exhibits in miniature the pattern of cooperative behavior that we see throughout nature. Cooperation is the mechanism by which every new individual is formed, whether sexually or asexually. Cooperation is the means by which it keeps alive through the first precarious stages of existence. Cooperation is as basic to its nature as are irritability and motility.

Let us consider our theory in terms of man. In the first weeks of life the human infant appears solely concerned with satisfying its physical needs, such as food and warmth. But gradually its feelings of satisfaction are transferred to the person or persons who make the satisfactions possible. From then on the baby is not content with merely getting enough to eat; it also needs a close emotional connection with the provider—the mother or mother-substitute. It cannot live by bread alone. Thus the mutuality that governed the infant's life in the uterus is raised to the psychic level. The baby now has a social "inclination." This characteristic can never be thrown off; it is too closely interwoven with the individual's first encounters with the surrounding world.

This is the pattern in which every adult human being is molded. There are no exceptions; infants who do not go through these stages, who are not cared for or "mothered," do not survive. Hence we may infer that what the human being desires most of all is security. He wants to feel related to something, whether to family, friends or deity. Man does not want independence in the sense of functioning separately from the interests of his fellows. That kind of independence leads to lonesomeness and fear. What man wants is the positive freedom that follows the pattern of his life as an infant within the family—dependent security, the feeling that he is part of a group, accepted, wanted, loved and loving.

In human beings who develop normally, this feeling of love and unity with the group continues to grow all through life. It is a common observation that the happiest persons are those who most strongly feel a sense of connection with the whole community. They are happiest because they are giving fullest play to their innermost tendencies.

Thus we reach the conclusion that the ethical idea of love is no artificial creation of philosophers but is rooted in the biological structure of man. To love thy neighbor as thyself is not only religion's edict but nature's as well. Men who act in disregard of this principle are actually warring against their own bodies. The result is bound to be havoc for themselves and for those around them.

HERE is a conclusion fraught with great significance for mankind. It gives support to all forces that are attempting to weld men closer together and so to increase the quantity of security for all individuals. It turns the weight of science against all advocates of separatism, isolationism, aggressive individualism. It brands the theories of the hatemongers not merely as immoral but as unnatural. If this conclusion were widely propagated, it might help strengthen the average man against the appeals of ultranationalist demagogues.

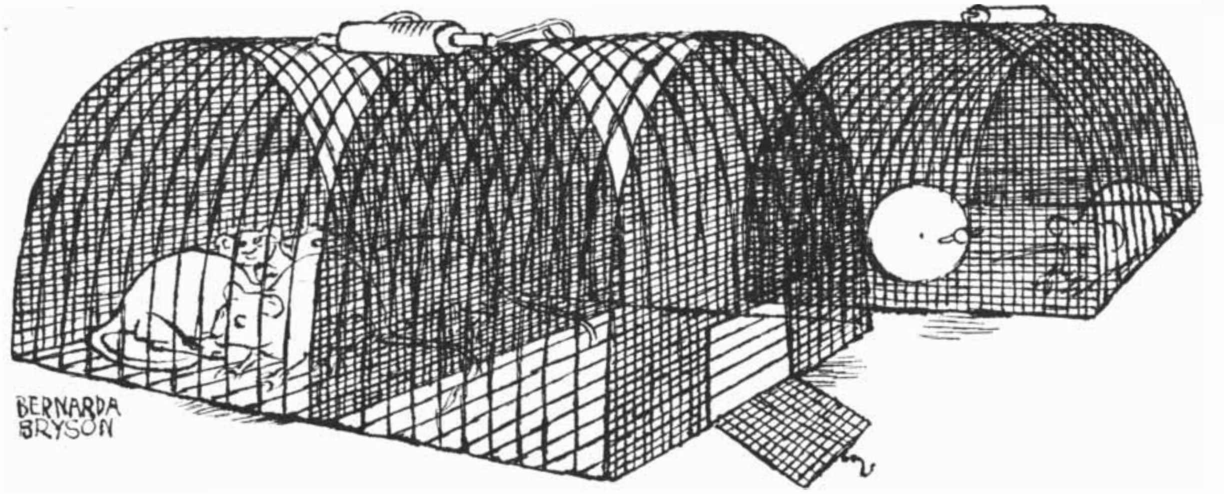
Now it must be acknowledged that the opposite conclusion is deeply rooted in modern thinking, and that a seemingly powerful objection may be offered to our theory. This objection derives from what people suppose to be the Darwinian scheme of evolution. If the dominant impulse in all animals is cooperation, if man's biological structure is rooted in love, what becomes of Darwinism? What about "the struggle for existence," "natural selection," "the survival of the fittest"?

The answer is that these conceptions are only one side of the picture. Certainly aggressiveness exists in nature, but there is a simultaneous drive toward cooperation. And the evidence strongly indicates that the latter is the stronger and biologically the more important. For if struggle and conflict had dominated life back to its very beginnings on this planet, how would unicellular animals ever have joined forces to produce the first multicellular creatures? Without cooperation, evolution as we conceive it could never have started. Furthermore, the coexistence today of so many different species of animals throughout the world is sufficient testimony to the existence of a principle of mutualism, tolerance, live-and-let-live.

It is a narrow interpretation of Darwinism, indeed a perversion of it, that has given rise to the belief that combat and conquest are nature's whole plan, and that as a consequence rivalry, aggression and imperialism are the inevitable way of personal and social life. Actually Charles Darwin's own attitude was altogether different. He appreciated the powerful role of cooperation, and made this clear in *The Descent of Man*. In a passage to which his disciples have given too little attention he said:

"As man advances in civilization, and small tribes are united into larger communities, the simplest reason would tell each individual that he ought to extend his social instincts and sympathies to all members of the same nation, though personally unknown to him. This point being once reached, there is only an artificial barrier to prevent his sympathies extending to the men of all nations and races."

Ashley Montagu is professor of anthropology at Rutgers University and author of On Being Human, *to be published this month.*



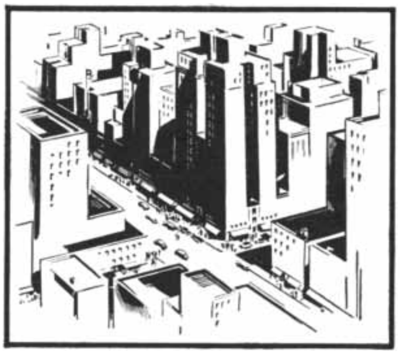
MICE also exhibit the benefits of social behavior. One experimenter found that white mice alone in a cage failed to grow as fast as those grouped two, three and four in a cage. The mice also licked each other's sores.

BUSINESS IN MOTION

To our Colleagues in American Business . . .

Because everybody spends a lot of time indoors, under a roof of one kind or another, the building industry has always been of prime interest to Revere. There are two reasons for this concern. One is the obvious consideration — a good, weather-tight, long-lasting building should contain adequate amounts of sheet copper in the appropriate places. The other is our feeling that, as a leading producer of sheet copper, we have an obligation to the public to see that there is an understanding of the economy and satisfaction obtained through the correct use of this metal for waterproofing.

Hence Revere some years ago embarked upon an extensive program aimed at developing the engineering principles, specifications and designs for successful application of sheet copper to all types of buildings. The information thus obtained has been freely published for all to follow, with assurance of lasting protection, whether for a home or a hospital, an office building, hotel or factory. Though anybody's copper can be used according to these specifications and designs, naturally Revere hopes it will be Revere copper, and indeed we are getting our share of the business. It is a great satisfaction to us not only to sell the copper, but to know that it is being applied in such a way as to give economical, enduring protection. This is especially important in these days of high labor costs, which make repairs due to the use of inferior materials or improper installation cost so much more than the price of good materials and workmanship, if used in the first place.



Now Revere has expanded its service to the building trades by offering solid copper flashing for masonry construction. The flashing is of chief interest to those designing and building large commercial structures, though of course it is also applicable to the private homes built of brick and stone. There is now available thru-wall flashing for economical and enduring protection against seepage and leaks at copings, parapets, belt courses, sills, spandrel beam facings and similar masonry applications. There is a reglet and reglet insert, also of solid copper, for waterproofing spandrels at costs comparable with or less than mopped-on waterproofing. There is vertical rib siding for use on high parapet walls, penthouses, and so on. All these items are pre-formed, and the simple directions for their use can be easily followed by any contractor, builder, or sheet metal worker. These new Revere Copper Products are available through sheet metal distributors throughout the country.

Though we have given these new items the widest possible publicity, we realize that in this vast country it is unlikely that absolutely everybody concerned will learn immediately about them and how much they can add to true economy. It takes time for news to get around. This time-lag is a problem for every company offering a new service or product. Recently we saw an advertisement of an important industrial material (felt) in which it was suggested: "Write us what you make, and benefit by our constructive ideas." That is good advice. Revere therefore recommends that no matter what you buy, whether metals or felt, chemicals or plastics, building materials or containers, you give your suppliers the opportunity to collaborate with you on the selection and application of new as well as old materials.

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The Probability of Death

It varies considerably with age and species. Man, however, has manipulated his curve of survival so it rather resembles that of the starved fruit fly

by Edward S. Deevey, Jr.

IN a world where the only certainties are death and taxes, and where even taxes can sometimes be avoided, how certain is death? There can be no doubt that this question has been asked since earliest times, when men painted the bodies of their dead kinsmen or provided them with goods for the journey to the hereafter. From poets and philosophers we have had melodious answers to the question—defiant, anguished, acquiescent or exultant according to the authors' personality and culture. From science, as we have come to expect, we get a statistical expression, not of certainty but of probability.

How probable, then, is death? At birth the probability of death at the end of the life span is of course 1, but this is not exactly helpful. To know the probability of death at any given age, one needs to observe the mortality of a population, substituting the universality of averages for the chancy behavior of individuals.

Actuaries, on whose skill depends the whole ingenious procedure by which insurance companies convert the probability of death to the certainty of making a profit, have devised a handy scheme for expressing the facts of mortality. Their "life tables" become rather complicated, but the principles on which they are constructed are not difficult to understand if we deal with a population of experimental animals instead of a human population whose members were born at various times.

A group of fruit flies is allowed to be born in the usual half-pint milk bottle, and a daily census is taken until the last survivor is dead. The "raw data" then give the number of deaths, d, at any age, x—which is written d_x. We convert this figure to a percentage of the total original population. At any given time the percentage of deaths, subtracted from 100 per cent, gives the percentage of survivors, l_x. When the survivorship column of the life table is graphed, we can see at a glance the pattern of fruit-fly mortality. Thus if we assume that the initial population had 100 members, those dying in their first day of life leave $100-d_1=l_1$ survivors, those dying in their second day leave $l_1-d_2=l_2$ survivors, and so on until on the nth day the last survivor dies and $l_{n-1}-d_n=0$. The mortality rate at any age (q_x) is the ratio of those dying during the given day to those alive at the beginning of that day: $q_x=d_x/l_x$. Instead of taking a day as the time unit, we can of course use any interval, such as a year or a decade, but for accurate results the age intervals must be short in relation to the total life span.

If survivorship is graphed on a logarithmic instead of an arithmetic scale, so that a straight line represents equal rates rather than equal amounts of decreasing survivorship, q_x can be read directly from the graph. Other columns of the conventional life table are derived almost as simply from one or another of these values. In particular, if one were to sell insurance policies to fruit flies, one would need to know the expectation of life (e_x), better described as the mean subsequent life span.

It is easy enough to perform this kind of manipulation on data from any laboratory population, and the comparative mortality of lower organisms is full of interest for the student of man, as comparative studies usually are. The rate at which organisms die expresses the balance between the tendency of their cells and tissues to maintain their organization and the relentless hostility of the world in which they exist. In other words, the survivorship curve of a population is a mathematical life line, recording in its sinuosities the contest between physiology and environment which we call life—and which Herbert Spencer defined as "the continuous adjustment of internal relations to external relations."

A famous essay by Raymond Pearl and John R. Miner pointed to three distinct types of life curve: 1) Some animals, such as the mildly organized *Hydra,* appear to die without regard to age; no one age is more exposed to risk of death than another, and the l_x curve is a straight line. 2) Under special circumstances, as when adult fruit flies are given no food but are granted a barely sporting chance to show their tenacity of life, they live their few allotted hours together and die almost simultaneously. 3) More usually an organism, typified at the extreme limit by so insecure a creature as an oyster or a dandelion, runs a heavy risk of death in infancy, but the few survivors to advanced age die at low and comparatively constant rates.

WHAT of man's mortality? Is it like that of *Hydra* or of an oyster, or is it completely flexible, varying from type to type according to circumstances? How far can man control his own survival? To appreciate the answer it is important to realize that the evidence is not so easily gathered as it would be if men were born all at once at the will of some supreme experimenter. Under the conditions in which men live and reproduce, the facts of death relate to individuals born at various times and places in the past. To calculate a rate of mortality it is necessary to know not only the ages of those dying but the number alive at any age and exposed to the risk of death. Thus the basic datum of the human life table is not d_x but q_x.

Such data are obtained from censuses and from bureaus of vital statistics. When they are cast up, they do not describe the mortality of a defunct population, as in our experiment with fruit flies, but instead predict the future mortality of a hypothetical group. The members of this group are imagined as born within the year of the census and exposed throughout their lives to death risks at particular ages equal to those observed for those ages in the year of the census. Insurance companies have not failed to note that any general improvement in health as time goes on is a guarantee of profit, for the longer the average policyholder lives beyond the age at which he was expected to die, the more premiums he pays—at least in the case of "ordinary life" insurance. Customarily such profits are shared with the policyholders, but it is a fact that until

1948 all American insurance premiums were calculated on a life table worked out in 1868.

The human survivorship curve displays a remarkable sinuosity, corresponding to real variations in the chances of death according to age. Mortality is relatively heavy in the first years of life, especially so in the first week and month. Beyond age 4 the modern American child has an excellent chance of living to maturity. Throughout middle life survival ratios are high and rather constant. As old age approaches the rates of mortality begin to increase more sharply, but in extreme age, beyond age 90, it appears that one has almost as good a chance of living an additional 10 years as at age 80. This part of the curve is inevitably based on inadequate information, but assuming that its form is correct, it recalls that of an oyster from maturity onward, when the period of most excruciating hazard is over and a tiny fraction of survivors live to become literally superannuated.

The curve as a whole shows a kind of oscillating compromise among the theoretical types of Pearl and Miner: In infancy man is a little like the oyster or the mackerel; in childhood, when mortality rates are decreasing, a temporary approach is made to the "rectangular" curve of starved fruit flies; in the middle years the constant risk of death resembles that of *Hydra;* in old age man comes once more to imitate the oyster. Probably other mammals in a state of nature have life curves much like man's. Of the few for which data are at hand the one that most resembles man's is that of the bighorn sheep of Mount McKinley, which in extreme youth and in old age appear to be especially likely to fall prey to wolves.

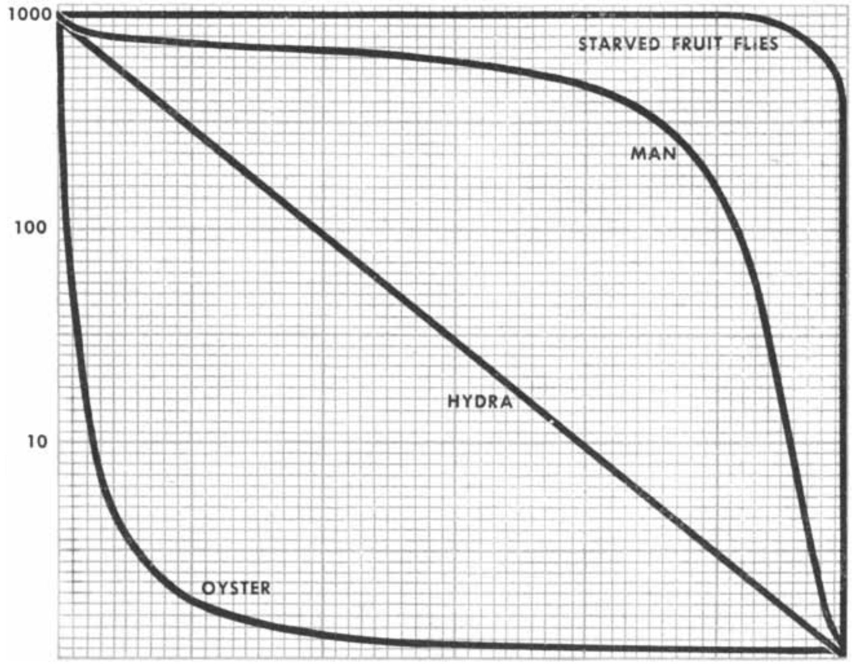
It must not be forgotten that this human survivorship curve represents a hypothetical modern population. To judge the extent to which the life span may be modified, it is necessary to consider other groups of other times. Though we cannot easily look far forward, we can look backward. We see then a remarkable thing: in the so-called Western countries in general, and the U. S. in particular, the average length of life has increased in spectacular fashion. Between 1838 and 1844 the expectation of life at birth of a male born in England was 40.19 years; a century later, in 1937, it was 60.18 years. The life span of the men of Massachusetts rose from 38.3 years in 1850 to 63.3 in 1939-41. Since 1900 in the U. S. as a whole the average life span has risen from about 48 to about 63 years. In short, the average length of life has nearly doubled in a century. But it is important to remember that this gain has come only in the average, which is dependent on the general level of public health, *i.e.*, on the physical and social environment. There is no evidence that the oldest people are living to greater ages than before; the maximum length of human life appears to be fixed at about 115 or 120 years.

If the upper limit of age is determined by man's genetic constitution, obviously the elimination of all environmental causes of death, such as disease and accidents, would yield a population whose every member lived to about the same age. The survivorship curve would become a rectangle even sharper than that of starving fruit flies; birthdays would no longer warrant congratulation, and at age n—1 (114 years?) people would start to dispose of their belongings. But you and I will probably not enjoy the dubious pleasures of that day. The recent improvement of man's allotted term of years is almost entirely the result of a concerted attack on deaths in infancy and childhood; the ills attending old age have scarcely begun to attract medical attention.

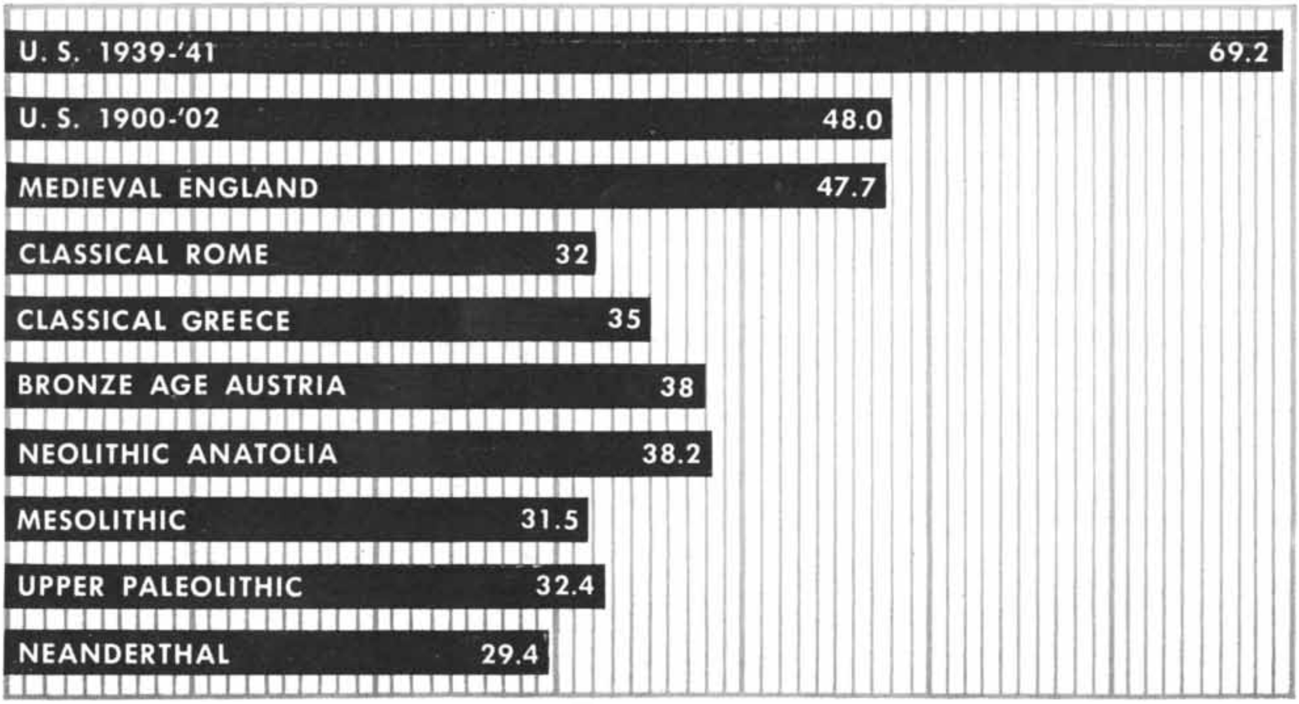
"Death from old age" is a legal fiction, not a medical fact, but it is deeply ingrained in our thinking, even among physicians. Geriatrics has a long way to go to match the triumphs of pediatrics. That the infant science of aging is due for a boom is certain, if only as a matter of social justice. Partly because of declining birth rates, and partly as a result of the greatly increased mean life span, the proportion of U. S. people over 65 rose from 2.6 per cent in 1850 to 6.8 per cent in 1940; by the year 2000 it should approximate 13 per cent. Thus the U. S. as a whole is fast approaching the peculiar situation of southern California, where political and moral pressure is strong to "do something for the aged."

Whether anything can actually be done for the oldsters beyond providing them with more elderly companions is a question that cannot be answered, for it hinges on the unsolved problem of the

TOMBSTONES provide accurate data on the life span of man in Roman times. Birth dates were carefully preserved for astrological purposes.



CURVES of survival for several organisms are plotted on the basis of survivors per thousand (*vertical coordinate*) and age in relative units of mean life span (*horizontal coordinate*). Most oysters die in infancy; most starved fruit flies in old age. Death rate of *Hydra* appears to be the same at all ages.



AVERAGE LIFE SPAN of man has varied greatly through history and prehistory. The average life span in Greek and Roman times was shorter than that of certain prehistoric peoples whose remains have been found in fair numbers. Greatest increase has come in the past 50 years. Maximum life span appears unchanged.

relative importance of heredity and environment in governing length of life. There is evidence that exceptional longevity runs in families, but studies of lower organisms suggest that when the *rate* of living is taken into account, the total living that individuals can pack into their natural lives is about constant. In other words, if we live longer for genetic reasons we probably do so at a feebler rate, and may not enjoy life so much.

QUESTIONS about longevity might be more easily answered if man were not among the least convenient of organisms for breeding experiments. For some light on the matter we may look to history. As it happens, historians and archaeologists have lately begun to take an interest in population problems and to collect their scattered data.

It is not absolutely necessary to start with mortality rates in constructing a human life table. If the assumption can reasonably be made that the total population is neither growing nor declining, the distribution of ages among its members can be taken as constant in time, and a life table can be computed directly from records of the age at death, as in our fruit-fly study. Such an assumption would be grossly erroneous for populations in the Western world today, but it may not always have been so. At worst, the historian who is forced to make this assumption in order to use his data is in the same position as the animal ecologist attempting to study mortality outside the laboratory. The life table for the bighorn sheep, for example, was computed in this way from skulls picked up on the range and apportioned to age groups by the growth rings on the horns.

So it was not altogether improper when the Scottish investigator W. R. Macdonell, following a suggestion of the great English statistician Karl Pearson, studied mortality in ancient Rome and some of its provinces by making use of ages at death obtained from tombstones. Such information is more accurate than might be supposed, for the astrology-minded ancients paid attention to precise birth dates. Other sources of data are court records, especially those having to do with inheritance of property; records of burial-insurance societies and other agencies granting annuities, which existed even in Roman times; genealogical tables; and ages determined on skeletons by the surprisingly accurate methods of physical anthropology. Much more remains to be learned, but a few inferences can be made now without much fear of contradiction.

FOR one thing, human survival has seldom or never been so successful as it is today in the U. S. and western Europe. No ancient or medieval population boasted a mean longevity greater than about 35 years, whereas the white male born in the U. S. in 1945 can expect to live 65.8 years. Primitive man appears to have had a negligible chance of surviving even to age 60. Longevity appears to be related to culture; however, "civilized" men as such live only a little longer than tribal huntsmen, for urbanization has unfavorable consequences which have been circumvented only in modern times.

For another thing, there is a stubborn suggestion in some of the data that the well-known enhanced survival of females over males is a relatively modern phenomenon—primitive societies seem to have worked their women to death at earlier ages. But perhaps the most interesting finding from all these data is that despite the recent dramatic gain in average life span, there has been no appreciable gain in maximum longevity. People of great age were undoubtedly less numerous in ancient populations than they are now, but there is no reason to think men and women of that time could not live to 115 or 120 if they were lucky enough. There are several authentic-sounding centenarians among the Romans studied by Macdonell, including one of 120, and there may even have been some among the 14th-century British group whose vital statistics are preserved in the *Inquisitiones Post-Mortem*.

It would be ironic if all the "progress" implicit in modern life tables, and in the medical science that has so changed them, were to come to this: that we have been saved from measles to die of cancer or heart disease. That, however, is the outlook, as well as we can judge it, and the best recipe for longevity would still appear to be the nonoperational one: "choose long-lived parents."

Edward S. Deevey, Jr., is assistant professor of zoology at Yale University.

What GENERAL ELECTRIC People Are Saying

W. L. FLEISCHMANN

Apparatus Department

TURBINE ALLOYS: The application of alloy steels to high-temperature steam-turbine service relies on the accumulation of metallurgical data which are unique in some respects. Where it can usually be assumed that the properties of metals do not change, under the influence of high temperature continuous changes take place. Where ordinarily it is correct to assume that plastic deformation will occur only beyond a certain stress, at high temperatures even low loads cause constantly increasing deformation.

With a long-life turbine, the data obtained from laboratory tests are then in reality only guides which, by extrapolation, become the bases on which the alloy is formulated and the design stress set.

To allow extrapolation, one constantly has to search for indications which may be small in even a year-long test—but may become important in the long life of a turbine. Constant refinements in the test procedures and the theories of the mechanical and thermal behavior of metals under the influence of stress and temperature are, therefore, necessary to enable us to design the heat-resistant steels.

We are confident that this approach is sound, based upon the year-by-year improvement in thermal efficiency of turbines to 37 per cent, caused in no small measure by the average yearly advance of 12 F in steam temperature maintained for 40 years. These metallurgical developments benefit all of us, since, with the modern efficient turbines, the power industry is able to deliver electricity at low cost to the consumer.

Louisiana Engineering Society,
New Orleans,
January 13, 1950

★

F. B. SCHNEIDER

Apparatus Department

CYCLONE DUST COLLECTORS: Independent of the design, all "cyclones," from the ancient centrifugal dust collectors to the modern vortex collector, suffer from a common handicap. This disadvantage is the large pressure drop caused by the whirling motion of the gas while performing the cleaning action. In addition, with higher dust-separation efficiency, the pressure drop increases, so that the highly efficient vortex collectors have a pressure drop which is a multiple of the pressure drop of the common centrifugal separators. Since the latter are mostly used in connection with the cleaning of large volumes of air, the power consumed is considerable, and even small reductions of the pressure will provide substantial savings of horsepower.

The pressure drop across cyclone dust collectors can be reduced by relatively simple means. A recovery of 75 percent can be attained on centrifugal separators by employing gradually enlarged tangential inlets together with cylindrical hoods at the outlet. The pressure drop across vortex collectors can be reduced by approximately 80 percent by using diverging inlets and recovery drums at the outlet which discharge clean air into ducts. If the vortex collectors discharge the air into the atmosphere, the pressure drop across them can be decreased by 34 percent with two concentric cones at the outlets, and by amounts up to 80 percent when these cones are combined with a diverging tangential inlet.

General Electric Review,
February, 1950.

★

R. O. FEHR

General Engineering & Consulting Laboratory

SOUND PLEASANTNESS: The pleasantness or unpleasantness of a sound determines if an equipment is acceptable from the acoustical standpoint. Sound intensity meters now being used in industry do not give this answer . . . they tell as much about the pleasantness of a noise as a light meter tells about the quality of a painting.

Instruments based on new concepts must be built. We believe that the ultimate will not be achieved in the near future, but we are well on the way to obtaining practical instruments which are far superior to anything we had several years ago.

American Society for Metals,
Terre Haute, Ind.,
January 9, 1950

★

K. H. KINGDON

Knolls Atomic Power Laboratory

ATOMIC-ENERGY TRAINING: About 60,000 people are now engaged in the new and potentially large field of atomic-energy work. At present these people are employed directly by the Atomic Energy Commission and its contractors. If the production of power from atomic energy becomes an economic reality, such production will doubtless be participated in by private industry and will demand additional technical people.

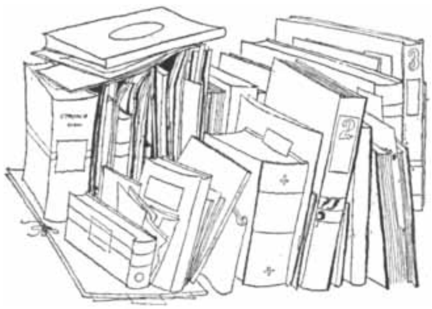
Most of the technical people to be used in the atomic-power effort in the future will need training in special fields of current engineering, and in physical, chemical, and metallurgical skills. Perhaps ten percent will need the new fission and neutron knowledge of modern nuclear physics. Some of this they will be able to get in universities, but security restrictions and the probably continued general unavailability of nuclear reactors and other expensive and restricted equipment and materials will mean that much of the specialized technical knowledge will have to be obtained on the job.

A considerably larger group than the ten percent mentioned, and consisting of chemists, chemical engineers, and health physicists, will need practical knowledge of how to handle radioactive materials in bulk. Here, again, this knowledge will probably have to be obtained on the job.

General Electric Review,
February, 1950.

You can put your confidence in—

GENERAL ELECTRIC



BOOKS

The fighting ship and the airplane as artifacts of modern civilization

by James R. Newman

JANE'S FIGHTING SHIPS, 1949-50, edited by Francis McMurtrie. JANE'S ALL THE WORLD'S AIRCRAFT, 1949-50, compiled and edited by Leonard Bridgman. McGraw-Hill Book Company ($16.50 each).

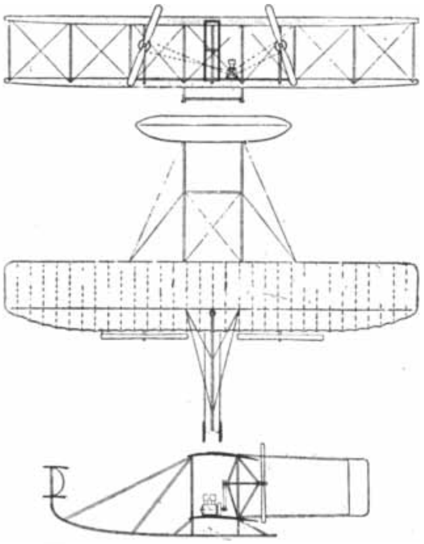
THIS is the 40th anniversary of the book that was "turned round" in order to distinguish it from an older and more famous companion. The initiate will know at once that I refer to that tall book *Jane's All the World's Aircraft* and its squat elder brother *Jane's Fighting Ships*, which last year celebrated its 50th birthday. The issuance of these annuals is always news because of their authoritative review of naval and aviation advances during the preceding year. In a publishing season prospectively as dismal as this one, the *Janes'* appearance is no less than an occasion. It is the aircraft volume that will receive attention in this review, but I may mention that *Fighting Ships* is fully up to standard and you will not want to miss it if you are a devotee.

All the World's Aircraft is not, one may as well concede, an item for the personal bookcase. It is expensive, somewhat unwieldy and specialized in content; it will not cut into the market of *This I Remember, Decision in Germany, My Three Years in Moscow* or *The Seven Storey Mountain*. Yet in many respects it is a more important and a more interesting book than any of these—more interesting especially if one reads it with sufficient imagination to realize how numerous are its social, economic and political clues, entirely apart from its wealth of reliable technical data. *All the World's Aircraft* is an economic geography, relating how and where the nations of the world carry on a great manufacturing industry; it illuminates the international situation in providing more formidable evidence of the armaments race than can be found in any other single source; it reveals the tension of our period, the growing restrictiveness of secrecy, as much by its gaps as by the fullness of its disclosures; it is an impressive chronicle of scientific and technological progress—largely by way of preparation for world conflict. There is much more of war than of peace in this account of the world's aircraft—which is a commentary on the prevailing political weather and not an indictment of a faithful reporter.

The work also has its less ominous aspects: the freak craft; the colorful nomenclature; the stories of companies that have become dominant in the industry and of others that from year to year barely manage to survive; the many handsome plates; the occasional sidelight or diverting anecdote; the artists' "impressions" of experimental planes not yet unveiled or, as in the case of Russian aircraft, never to be shown to outsiders unless it be in combat. It is altogether a remarkable achievement of the editorial and book-designing arts—the perfect book, if one's tastes are so inclined, for desultory browsing.

The current edition reports on American and British innovations in jet planes; on Russian aviation progress (unfortunately your guesses in this field may be almost as good as *Jane's*); on the B-36. Although the details are meager, *Jane's* tells what is known about Bell's 1,000-m.p.h. rocket-propelled monoplane X-1 and the stainless-steel X-2, designed to obtain even higher speeds. Also described are several other experimental planes: Boeing's six-jet light bomber XB-47, which crossed the U. S. last February at an average speed of 607 m.p.h.; Douglas' extraordinary D-558-2 Skyrocket, which resembles a cross between a swordfish and a shark; and the same company's XF3D-1 Skynight, a jet-propelled, carrier-based, all-weather fighter. Fairchild is investigating the use of nuclear energy for aircraft propulsion; Martin has two prototypes of a six-jet experimental bomber; North American is producing a jet fighter, the Sabre, which has exceeded the speed of sound in a dive, and was, according to *Jane's*, the first American fighter to achieve this feat; the Russians have their four-jet Ilyushin medium bomber, have re-established the German Junkers plant in Russia, and are working intensively on air-to-air rocket missiles, pilotless aircraft, and the Gurevich, Ilyushin, Lavochkin, Mikoyan, Tupolev, and Yakovlev jet bombers and fighters, many of which have been seen to fly over airfields at "impressively high speeds." I must not forget Northrop's eight-engine jet-propelled Flying Wing. Judging from appearances, this is probably the private craft used by Captain Midnight.

As an antidote to this report on unfriendly craft it is agreeable to learn that the Compagnie Française d'Aviation makes an 85-horsepower monoplane named the Cri-Cri, and that Instruments de Precision M.D.G. manufactures a light biplane known as the Midgy Club—the French pronunciation of which is a matter not without interest. Civilians may also take joy in the Fulton aluminum Roadable Airphibian, which in three minutes can be turned from a monoplane into a convertible coupe; in the Hall plastic-bodied Flying Automobile, almost ready for production; in the Helicopters, Inc., five-seat helicopter, which looks exactly like a June bug; in the Hoppi-Copter, early models of which weighed 90 pounds, could be strapped to the back, flew very well, and continue in development for their "military possibilities"; in McDonnell's J-1 Little Henry, the world's first ram-jet helicopter, which weighs only 280 pounds, hovers nicely with two people, looks rather as if it were made of several large paper clips, and is of serious interest to the Air Force; and in the fact that Piper now has an Aerial Station Wagon, a Vagabond and a Family Cruiser.



WRIGHT BIPLANE was in first edition of *All the World's Air-Ships*.

The fact that this is the 40th anniversary of *All the World's Aircraft* led me to look through a few of the earliest issues of the annual to see what aviation was like four decades ago and to get a view, in fresh perspective, of the rapidity of its evolution.

When Fred T. Jane, a most prolific writer, decided in 1909 to put out his "flying annual" *All the World's Air-Ships*, he had reason to believe that aviation would be on a "practical commercial or even military footing" before very long. Dirigibles, the Zeppelin in particular, were well established; the Wright brothers had made their triumphal tour of Europe, and "concessionaires" were building copies of their famous biplane in Britain, France, Germany, Austria, Spain, Italy and Denmark; Blériot's Model XI monoplane had flown across the Channel; Voisin, Farman, Handley-Page and Santos-Dumont were among those engaged in aeronautical research and construction.

Jane was handicapped in his "plunge into unknown and unexplored waters" because his editorial labors had to be carried on, as he said, "in a generally unresponsive ocean." Many of the pages of the first annual in 1909 were virtually blank, lacking any photograph and merely reporting that a certain kind of plane, dimensions and attributes unknown, was under construction in a particular locality. Even so there was much accurate information, and an abundance of the bizarre.

In general the planes of 1909 were light, underpowered, unreliable, unpredictable and fairly cheap. Austria, which had "only just commenced to take much interest in aviation," had a few viable types: mono-, bi- and triplanes, including a machine known as the Nemethy which weighed 66 pounds and flew —if at all—with a three-quarter horsepower single-cylinder engine. Belgian engineers had hatched the De La Hault and the Vandenbergh "Flappers"—craft whose wings gave "bird action" if not bird results—but more plausible engines were also being developed in Belgium. Of China Jane remarks that while no flying machines were yet to be found there, it should not be forgotten that these people "with their thousands of years of kite flying, are likely to be apt pupils in all that pertains to the science of wind resistances, etc."

In England flying attracted "neither interest nor attention," apart from balloon ascensions, until 1908. Then suddenly new machines began to appear and popular concern with aviation became widespread. Jane records that in 1909 there were six "aerial societies," five "aerial journals," and no fewer than seven "flying grounds." But he laments the "extreme tendency of the British inventor to isolate himself and work in secret," which is responsible for the fact that so many of the pages in his British section are bare of detail. British manufacturers in 1909 were building the Antoinette monoplane, a very respectable-looking affair with warping wings and a 100-horsepower engine; the Blériot monoplane; the Handley-Page, whose design required that it leave its wheels behind when it took off and land on fixed runners; the Cody military biplane, later models of which were used in the early part of the First World War; a Windham monoplane with nonrigid wings and large bamboo booms, exactly resembling the flyers that children make out of single sheets of paper; and, among many others, a Saul I that weighed 160 pounds, had an eight-horsepower motor, was made of hickory wood, and could not possibly have flown unless borne aloft by a tornado.

In those days France held the first position in aviation. It had 13 societies, 14 journals, 13 fields with hangars, Antoinette planes, Blériot biplanes and monoplanes, 39 Voisins, 59 Wrights and Santos-Dumont's several models of *La Demoiselle,* a very successful craft though it was the "smallest man-carrying aeroplane in existence." France also had its own curiosities: the Marquis d'Equevilley's oval craft, resembling the cross section of a pumpkin; Levy-Caillat's monoplane, an obviously earth-bound sled on wheels; a Witzig-Liore-Dutilleul which looked like a flight of stairs and probably performed as well in the air; several helicopters, one of which, the Bartin, was quite modern in appearance; and finally Givaudan's inert affair—two concentric drums joined by a triangular girder, which, it was said, could not heel over when turning and was "unaffected by side gusts of wind" and, no doubt, by any other efforts to get it aloft.

Germany was industrious as always, but her main success up to 1909 had been with the Zeppelins. By 1913, however, Jane found in Germany well over 80 "aerial societies," Army flying schools, 200 "war-effective planes" and 200 more building. All in the latter group were equipped with "bomb droppers" and photographic apparatus. Another ambitious people, the Japanese, had a similar record. In 1909 Japanese aviation consisted of a single Yamada biplane (a copy of a Wright) and a biplane "designed by the American steel capitalist John W. Harrison," which was described as a "street car with the sides knocked out and replaced by slender rods." Four years later Japan had a military and a naval air arm, numerous flying grounds, half a dozen new models and at least two dirigibles—copies, to be sure, of German and American types. Of Russian craft, *Jane's* had not a picture to show in 1909, though at least nine types, including Farmans, Voisins and Wrights, were said to be building. Five years later general attention to military aviation in Russia was "only second to France." By then even Mexico, Peru, Norway, Serbia, Portugal and Rumania had military air forces.

The first issue of *Jane's* appears to have approached the subject of aviation in the U. S. with an air of condescension and occasional incredulity, not to mention a considerable body of misinformation. Jane noted that no fewer than 8,000 persons in the U. S. were reported to have flying-machine designs "in some stage or other," but he skeptically cut this figure to 800. One is interested to read in the 1909 *Jane's* of such flying fields as Hemstead [*sic*] and Westburg [*sic*] on Long Island. Among the more interesting planes were Curtis' improved June Bug biplane, Eichenfeldt's extraordinary-looking biplane priced at $1,000 ("very successful and remarkably stable"), and the Wright brothers' beautiful machine, of which 82 had already been ordered. In the odd category I should mention V. L. Ochoa's Jersey Mosquito ("shown at Arlington, May, 1909, but did not fly"); Kimball's biplane, which was christened by the "famous American actress Vera Held" but failed to live up to this accolade because its five "propellers would not all work"; Rickmann's combination bicycle and umbrella, which neither flew, rode nor protected one from the rain; Thompson's Air Sucker; Roshon's Multiplane with 13 wings, and Irvine's flying Ferris wheel.

From these beginnings came the aircraft of today; and studying *Jane's* in 1950 one wonders whether some of the oddest specimens at the bottom of the tree did not contribute almost as much to the process of evolution as did their more respectable and rational relatives. One point is quite clear: the emphasis on military aviation is a characteristic disease of the century and not merely of its mid-point. In 1909 *Jane's* spoke with optimism of the peacetime potentialities of aviation. But even in this first issue there was an article on aerial warfare by Admiral Sir Percy Scott and another on the political aspects of aviation, mostly military, by L. Cecil Jane. (This Mr. Jane aired a number of interesting opinions, among them the thought that while "international war, commerce and locomotion will be in some degree affected by aviation . . . it may be suggested that the forcible carrying through of the 'social revolution' is no longer possible" because aircraft denies the "masses of the people" the "supremacy" needed to bring about abrupt political change. "Even one solitary airship would be sufficient to disperse a crowd; a fact which makes [dangerous and subversive] fraternisation even less probable.")

The fifth issue in 1913 left no doubt of the military trend. Its preface observed that five years earlier the aeroplane had been regarded only as a machine which was "going to oust the motor car as a sporting vehicle. . . . Beyond that, nothing!" The 1913 preface went on: "Today everything is completely changed . . . and it is as a war machine that the aeroplane has come into its own."

THE HISTORY AND SOCIAL INFLUENCE OF THE POTATO, by Redcliffe N. Salaman. Cambridge University Press ($10.00). Dr. Salaman spent over 40 years studying this "inoffensive vegetable," and a great social and economic history is the crown of his labors. It begins with the cultivation of the potato in South America, perhaps 2,000 years before Columbus, traces the story to modern times, and examines the potato's effects upon the social structure of those peoples—principally in the United Kingdom—who "adopted it as a staple article of diet or an essential product of their economy." In Salaman's account of its earlier history, of the potato's many names and aliases, of the differing opinions as to its " 'vertues,' vices and values," of the Raleigh legend and other legends about its origin, of the varieties of potatoes, "past, present and future," of its crucial role in Irish history ("after proving itself the most perfect instrument for the maintenance of poverty and degradation amongst the native masses, the potato ended in wrecking both exploited and exploiter"), of its relation to labor problems and politics, of its appearance in literature and art—in short, in the many pages of his monumental treatise there is scarcely a dull passage.

THE MATHEMATICS OF GREAT AMATEURS, by Julian Lowell Coolidge. Oxford University Press ($6.00). Sketches of the original mathematical contributions of 16 "amateurs," that is, men most of whom are known principally for their activities in other fields. The group includes Plato (numbers, commensurability, mean proportion), Omar Khayyám (cubic equations), Leonardo da Vinci (areas of lunes, inscription of regular polygons, etc.), Albrecht Dürer (descriptive geometry), Blaise Pascal (arithmetic triangle, Pascal's theorem, etc.), John Napier, Baron of Merchiston (logarithms), Viscount Brouncker (continued fractions, etc.), Guillaume L'Hôpital (infinitesimal analysis, conic sections, etc.), Comte de Buffon ("moral arithmetic" and geometric probability), Denis Diderot (vibrating strings, involutes), William George Horner (his "method"), Bernhard Bolzano (function theory, paradoxes of the infinite). While the choices, as the author concedes, are a trifle inconsistent (Fermat, for example, is omitted because he was the "Prince of Amateurs"; Napier and Horner are included though clearly not "known for their activities in other fields"), this is an uncommonly interesting work—scholarly, readable, well illustrated.

NOTHING NEW UNDER THE SUN, by J. P. Lockhart-Mummery. Andrew Melrose Ltd., London (12 shillings sixpence). A collection of popular essays, mostly on out-of-the-way subjects in natural history, loosely brought together under the theme which has been expressed in many ways, and which in Robert Herrick's line goes: "Nothing is new; we walk where others went." Dr. Lockhart-Mummery, a surgeon, writes easily and well and his little book is as pleasant an hour or so of reading as you are likely to run across in this field.

MATHEMATICS IN ARISTOTLE, by Sir Thomas Heath. Oxford University Press ($5.50). In this posthumous work Sir Thomas Heath, a noted historian of Greek mathematics, presents a fresh translation of Aristotle's mathematical writings and an appraisal of his contribution to the subject. Aristotle was clearly not a professional mathematician and shows in his works no acquaintance with the higher branches—conic sections for example. Yet he was fully abreast of the elementary mathematics of his time, was much given to mathematical illustrations—the incommensurability of the diagonal of a square was one of his favorite didactic devices—and threw a "flood of light," as Sir Thomas points out, on the accepted principles and methods in use immediately before Euclid. A careful and, as is always the case with Heath's writings, readable study, of particular value to philosophers, mathematicians and historians of science.

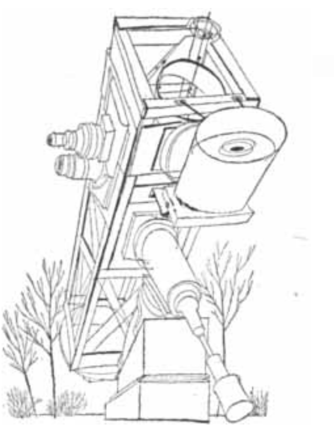
NOT SO LONG AGO, by Lloyd Morris. Random House ($5.00). A palatable social history of the three machines—automobile, motion picture and radio—that made us what we are today. Mr. Morris' irony and deprecating wit are well suited to the story he has to tell, especially to its many biographical and anecdotal byways. But for all its color this is little more than a surface account—a stereopticon view giving a first illusion of three dimensions but actually possessing no more than two.

THE CONQUEST OF SPACE, by Chesley Bonestell and Willy Ley. Viking Press ($3.95). Ley, who has long been absorbed in this business, reports on prospective rocket-travel to the moon and to some of the less inhospitable planets, describing the theory of transportation, the sights en route, the scenery on arrival and the chances of returning to earth if that should seem desirable. Bonestell provides the accompanying illustrations. Now and then Bonestell succeeds in tearing the imagination from its earth-bound orbit, leaving one awe-stricken and quite alone on some desolate moon crater such as Theophilus, or worse, on Pluto's snow-covered mountains.

PHILOSOPHY FOR PLEASURE, by Hector Hawton. Watts and Co., London (10 shillings, sixpence). This is a fresh and agreeable introduction to philosophy intended for adults whose curiosity quotient remains high and who are still capable of moderately sustained thought. Hawton starts with the Greeks and wends his way easily through various systems of metaphysics up to the logical empiricists, demonstrating persuasively en route that the perennial problems of philosophy are urgently relevant to the problems of society.

ANTARCTIC CONQUEST, by Commander Finn Ronne. G. P. Putnam's Sons ($5.00). SIBERIAN PASSAGE, by I. P. Tolmachoff. Rutgers University Press ($3.50). Although these two books are minor items in the literature of polar travel, thanks to their subject they keep a firm hold on the reader's attention, even as to the most ordinary details. Commander Ronne led a small Navy-sponsored expedition to the Antarctic in 1946 to survey lands and certain unknown portions of coast line between the Weddell and Bellingshausen Seas, and to carry out a number of other research projects. The expedition also had the secondary objective of buttressing U. S. territorial claims in the region by deputizing Ronne as polar postmaster. The best parts of his unpretentious account have to do with wintering and flying in the Antarctic and with various mishaps, all, fortunately, of happy ending. That of Peterson, the physicist, who was rescued whole after spending eight hours hanging head down in a crevasse at 20 degrees below zero, is surely unique. Tolmachoff's story of his expedition 40 years ago to survey the northwestern Siberian Arctic coast line between the Lena River and Bering Strait, one of the most desolate and forbidding areas of the globe, is a much more colorful and imaginative tale. It records the impressions of a perceptive young scientist in his encounters with Czarist bureaucracy; his observations of life in the remote Yakutsk province; his description of a long, hazardous reindeer and dog-team sledge journey in midwinter; and, especially, his detailed account of the Lamuts, the Tungus and the extraordinary Chukchi, who regularly strangled their aged and infirm. An uncommonly interesting book but lacking even one decent map to orient the reader.

AMERICAN WILD FLOWERS, by Harold N. Moldenke. AMERICAN SPIDERS, by Willis J. Gertsch. D. Van Nostrand Company ($6.95 each). These clearly written, accurate and well-illustrated books—first members of a promising new series—are among the best popular nature guides to have appeared in some time. Dr. Moldenke, Curator of the New York Botanical Gardens, covers some 2,000 varieties of wild flowers, giving not only the principal botanical facts but much other related material of general interest. Dr. Gertsch, of the American Museum of Natural History, presents an absorbing account of the evolution of spiders, their life history, engineering feats, social and personal habits (including courtship and mating) and their economic and medical importance. The accompanying photographs, colored and black and white, are fascinating.



THE AMATEUR ASTRONOMER

Conducted by Albert G. Ingalls

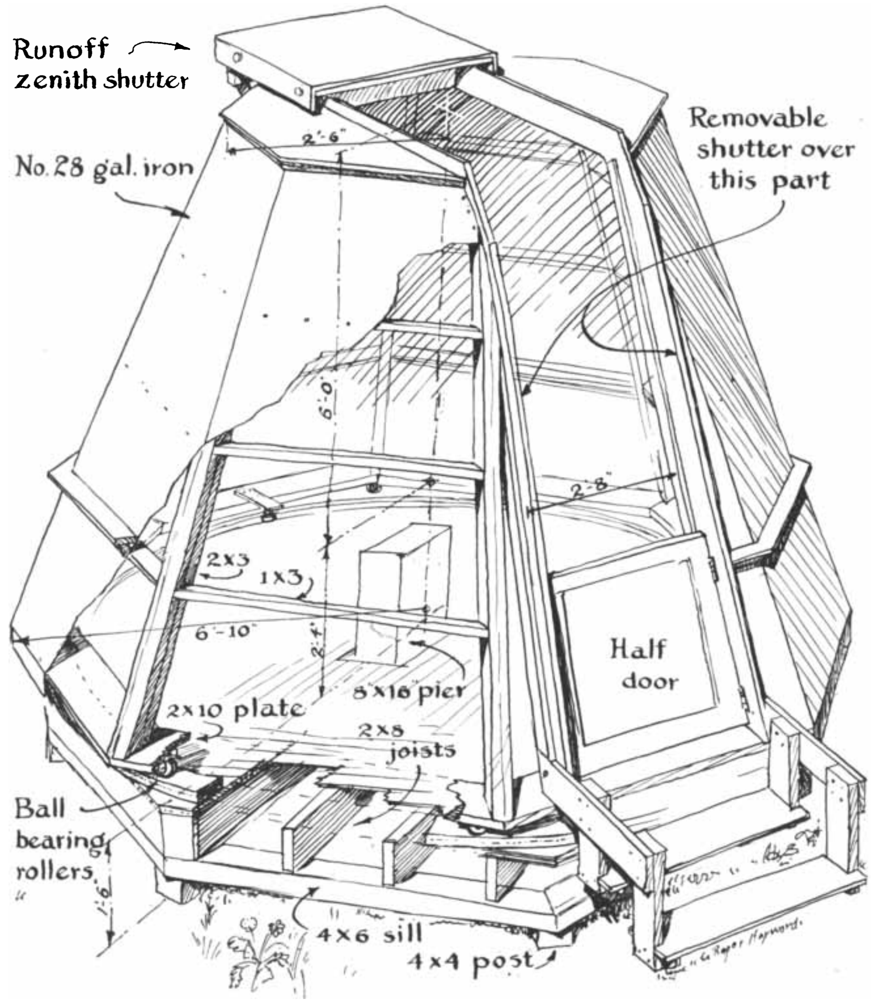
MORE than half of the telescopes made by amateurs are portable types that weigh less than 100 pounds, and may be carried out-of-doors for temporary use or separated into several parts and transported in a car. Another large fraction of amateurs' telescopes are kept permanently out-of-doors. These are usually bolted to concrete or iron-pipe pedestals and are protected from the elements by tarpaulins or simple boxlike housings that can be rolled aside.

Nearly every telescope user dreams, however, of housing his instrument in a fixed observatory structure. A wide variety of such structures, all good, none perfect, are discussed in *Amateur Telescope Making—Advanced.* One rare type, shown in Roger Hayward's drawing below, was designated the "teepee" observatory by the late H. Boyd Brydon in a series of articles on "The Small Observatory and its Design," published in 1938 in *The Journal of the Royal Astronomical Society of Canada.* Its chief merit is its simplicity. It roughly approximates the hemispheric dome that pleases the geometric or esthetic sense, yet it does not require building the curved shape of such a dome. Not shown in this drawing is a third section of the slot closure that may be removed and set aside during use of the telescope.

An example of the teepee dome is shown on the opposite page. Here it is set on top of a square building instead of on the ground. This is the observatory of Thomas R. Cave, 265 Roswell Ave., Long Beach, Calif. The simple 12-sided wooden frame of the teepee is covered with aluminum-painted heavy roofing paper. Though unbacked, and in use for some years now, it does not show the starved-dog's-rib effect of sagging that one might expect.

In the top of this dome is a hatch that affords telescopic access to the zenith. The hatch is lifted by an automatic spring that is held down at other times by a line from below.

The dome weighs about 400 pounds and rotates on 12 ball-bearing roller-skate wheels. It houses an eight-inch long-focus ($f/10$) reflecting telescope used for planetary observation by its owner. Cave is the Recorder of Observations of Venus for the Association of Lunar and Planetary Observers. The Association's mimeographed periodical, *The Strolling Astronomer,* enables amateur observers to "meet" each month and discuss their ordinary observations less formally than in a full-dress printed publication.



The teepee type of dome for a small observatory

MOST amateur astronomers would be happy to have in their back yard the combined garage-workshop-observatory shown in the drawing on page 70. It was planned and built by R. C. Barton of 3265 Garfield Ave., Alameda, Calif., an electrical engineer and a former president of the Eastbay Astronomical Society of Oakland. Because of this observatory's height above the ground, surrounding trees (which never get shorter) are less likely to limit its visible sky than if it were situated at ground level.

The building is 16 by 18 feet, large enough for a two-car garage. But only one car is kept in it, the remaining space being occupied by the workshop filled with machine tools and benches. To gain space for any large job the car may be run outside temporarily.

A practical consideration in the planning of this kind of unit is the fact that, if the owner should later wish to move, the building could easily be converted to a two-car garage by the next owner. Thus expenditure for the observatory is justified on other than "frivolous" grounds. If suitably planned the entire observatory might easily be moved from the building beneath it.

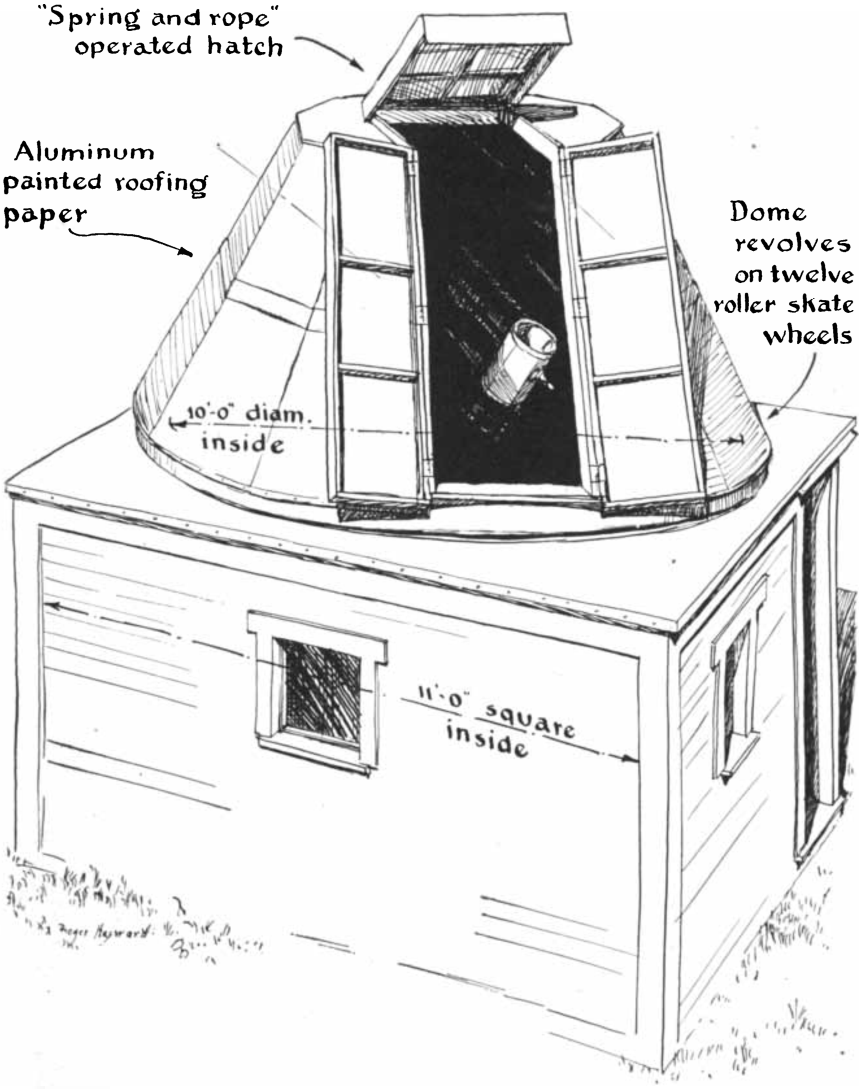
There is no inside stairway. The observatory is reached by climbing the outside stairway shown, crossing a sunny, south-facing lounging deck and entering through a large French door. In the daytime such a door lights the interior well enough to make adjustments on the telescope possible in comfort. Some observatories are cavelike in the daytime even with the shutters open.

The upper part of the Barton observatory is 10 feet square. Its top is finished to a circular opening with a wooden collar on which are fixed eight rubber-tired rollers. One of these is driven by an electric motor and rotates the dome. "Traction is obtained by levers and pulley blocks that permit me to control the upward thrust of the drive roller," Barton states. There are light fixtures in all four corners. Whole paragraphs of description of this dome are contained in the detailed drawing.

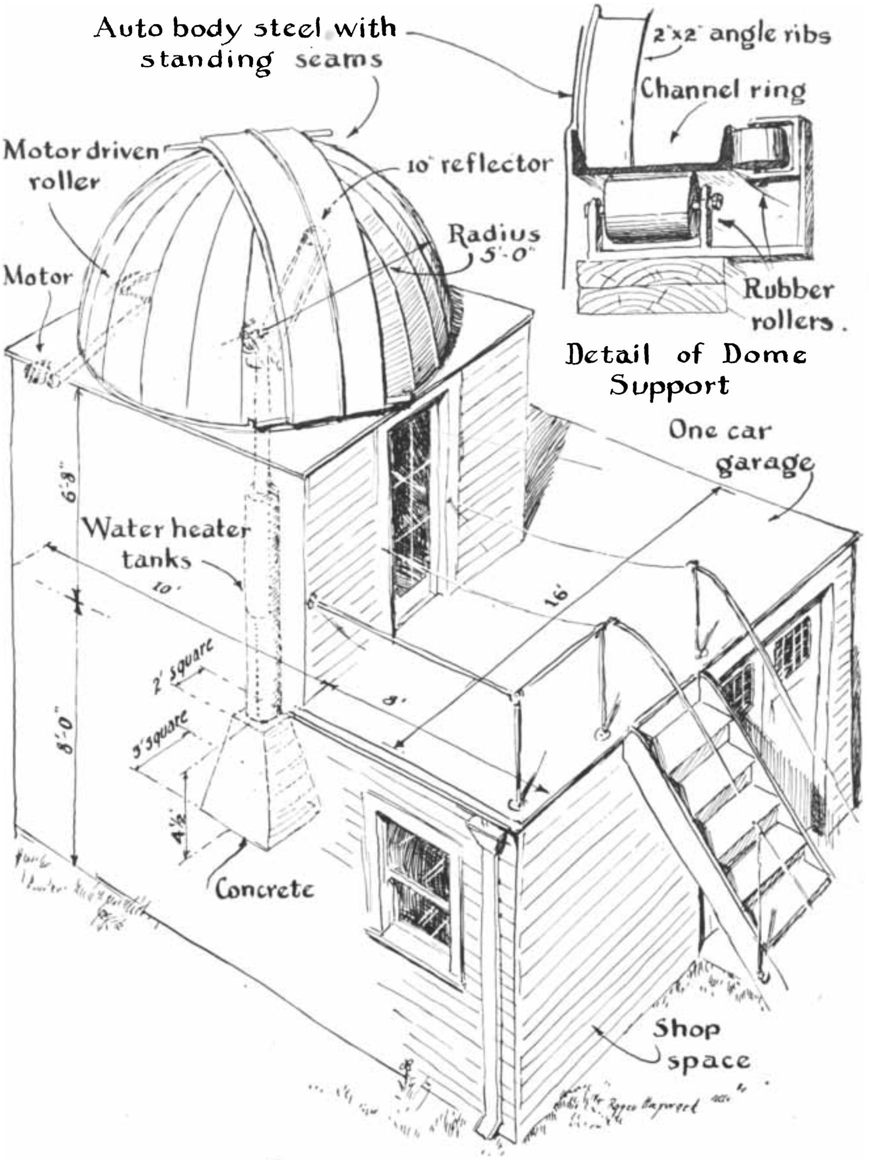
The observatory walls are finished in plywood panels two stages high that can be lifted out and reversed so that charts may be attached to both sides. One panel is painted black for use as a blackboard in answering the neighbors' questions and in discussions among observers. The telescope is a 10-inch reflector.

A type of observatory that no amateur has built, so far as is known, consists of two half-domes, one slightly smaller than the other, each of which can be rotated independently and entirely around on its own base circular track. It has no shutters. Because of the simplicity of its working principle, its architectural cleanness and its mechanical allure, this type of dome is most seductive.

The prototype of this design was built many years ago at the Washburn Observatory of the University of Wisconsin to house a six-inch refractor with an Alvan Clarke lens once used by the famous amateur-professional S. W. Burnham of lynx-eyed fame. This type of dome has therefore become known by association as the "Burnham dome." Learning that this beautiful dome had been converted some years ago to the conventional type with slot and shutter, this department sent an inquiry to Joel Stebbins, then Director of the Washburn Observatory. The disillusioning reply was: "All I can say is that after some years of experience we all looked upon the double dome as nothing but a nuisance. The inner dome worked very hard and had to be opened very wide in order to get near the zenith. For stars at the zenith the dome is exceedingly awk-



The teepee dome on top of a small building



A combined garage, workshop and rooftop observatory

ward, and to turn from one star to another in that region might require revolving the whole dome 180 degrees. All told, we have never regretted the change, and we think the ordinary dome with a good wide slit is still the best arrangement."

FOR the defense, Walter Scott Houston, an amateur astronomer of Cincinnati and a former University of Wisconsin student, has listed some advantages of the Burnham dome:

"It favors those who locate stars without use of setting-circles; they can see a large expanse of sky.

"When photographing, one can open wide (I have just been to the dentist) and not have to recap the camera because of vibration while the dome is shifted.

"In comet seeking it is a big help.

"The top of the dome structure is not cut away whereas the conventional dome is structurally weakened by the slot.

"If the pier of the telescope is placed off-center in the dome, the zenith can be observed."

Lyle T. Johnson of La Plata, Md., points out that some conventional domes also give trouble at the zenith, and that, even if the pier is centered, telescopes on German or English mountings will already be eccentric when pointed to the zenith, thus reducing the blind spot if any remains.

Roger Hayward mentions that the high solar towers at the Mount Wilson Observatory are topped by domes of this construction, though here the sun is never at the zenith and the nested domes are therefore ideal.

It is unlikely that the above *pros* and *cons* exhaust the subject. Perhaps the *cons* will act as a challenge to some amateur, leading to a practical solution, so that the elegant Burnham type of structure may be used.

IN March, 1949, this department described experimental attempts of several American amateur telescope makers to polish mirrors on paper laps. None turned out well. One worker reported that these laps gave heavy drag. The figure was easy to control, but contact was hard to maintain, and the surfaces produced were "lemon peel." Another worked 180 hours, using a machine, but always obtained lemon-peel surfaces. A third had contact troubles. Yet Father M. Daisomont of Ostend, Belgium, the leading exponent of the paper lap, stated without hedging that a six-inch mirror he polished with rouge in 10 hours on a dry paper lap showed Saturn's rings well at 350 diameters. Regardless of long-standing dogma about the inferiority of paper laps, this statement remains as a challenge to be not merely disproved but investigated objectively.

None of the experimenters followed Father Daisomont's working directions. I tried to do this, and experienced no troubles with contact, scratches or lap. The directions follow.

Use common, rough, unfilled mimeograph paper of the kind available at any commercial stationer. Cut out a rough circle an inch or so larger than the tool. Dilute white library paste until sloppy and smear it on the tool with the fingers, using a minimum covering amount. Dip the paper in water, lay it for a moment between blotters, and then place it on the tool. Smooth it out and leave it to dry for a while with no mirror on top. When the paper is finally dry, trim off nearly all the overhang with a razor blade.

Dab a dry wad of tissue or rag in dry rouge and dab this on the lap. Instead of attempting to spread it evenly, which may result in too much rouge, dab it in evenly distributed blotches, which will spread under work. If the lap remains red instead of pink after a little polishing, with paper showing through white, make another lap. To remove the old one soak it a minute and scratch it off with the fingernails.

An important source of satisfaction with a paper lap is the ease of making another, so that there is no reluctance, as with a prized pitch lap, to destroy it. It also permits resumption of interrupted polishing with no preliminaries whatever. To those who do not enjoy the fragrance of hot pitch, or who are repelled by lovely messes, or find pitch possessed of seven devils, the paper lap is a lily-handed escape.

On the other side of the ledger are two embarrassing facts. In the short tests made thus far the paper lap was much slower than pitch laps, and the surfaces produced were not up to pitch standards, but were a borderline lemon-peel-pitch. Can the rather broad gap remaining between these results and the paper-polished mirror successfully used on Saturn at 350 diameters be narrowed by the readers of this department, working experimentally?

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

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