Life's Beginning on the Earth

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By

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PREFACE

The question of the origin of life on our earth is of such fundamental importance that science should make every conceivable effort to solve it even though up to a short time ago very little was known about it. We should realize that the difficulties which we experience in handling this great problem are entirely within ourselves; they are due partly to the incompleteness of our knowledge and partly to the narrowness of the viewpoints which result from our too limited experience.

In 1933 I made the following statement in my book, *Physical Chemistry of Living Tissues and Life Processes as Studied by Artificial Imitation of Their Single Phases:*

> "In order to understand the origin of life, it would be necessary, therefore, to synthesize enzymes" (those chemical activators which initiate chemical changes without being changed or destroyed themselves) "which reproduce themselves in a natural environment and to study their actions. At present synthetic chemistry is not nearly sufficiently developed to venture the synthesis of such compounds, but who can claim that it will never develop that far? If a self-regenerating enzyme of such a kind could be made it would certainly be a carbonic compound. Life, therefore, in spite of all its complexity, seems to be no more than one of the innumerable properties of the compounds of carbon."

This prophecy was vague enough to justify its insertion in a scientific book, but in the five years which have elapsed a part of it has come true. We have of course not yet learned to synthesize self-regenerating enzymes; this task would take perhaps 500 instead of 5 years; but Dr. W. M. Stanley of The Rockefeller Institute at Princeton, New Jersey has discovered where such substances occur in nature: a virus which causes infectious diseases, and hence constitutes a living entity, is at the same time a substance which can be obtained in pure form as crystals. Here is indeed a substance which is an enzyme capable of regenerating itself in a natural environment.

Through Stanley's epoch-making discovery, more definite assumptions on the origin of life can now be made than ever before. A plain presentation of all pertaining facts has here been attempted. I would welcome suggestions and constructive criticism from those who think that some of the ideas in this book deserve discussion.

R. BEUTNER.

Philadelphia, October 1938.

ACKNOWLEDGMENT

My special thanks are due to the Provost, Dr. F. J. von Rapp, to the Dean, Dr. W. A. Pearson, and to the Medical Council of the Hahnemann Medical College and Hospital of Philadelphia, particularly to Dr. H. M. Eberhard of this group to whom I herewith wish to dedicate this book; also to the following members of the staff of the Hahnemann Medical College: Dr. G. P. Miley, Dr. R. E. Seidel, Dr. H. Wastl, Miss A. Bechtel, Miss K. G. Smith and Miss E. Colie for their help and advice.

I am particularly indebted to Colonel John W. Tucker, LL. D. whose great experience was invaluable in editing this book; and to Mr. Robert S. Gill, treasurer of The Williams & Wilkins Company, whose encouragement and help in editing the manuscript were indispensable for its completion.

With best thanks I wish to acknowledge the help of Mr. George Callé, a skillful mechanic of the Hahnemann Hospital of Philadelphia who prepared excellent drawings for the illustrations in this book; finally I wish to thank my good wife and my son Karl R. Beutner, a student at Dickinson College, Carlisle, Pennsylvania, for their devoted help.

R. Beutner.

Philadelphia, October 1938.

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EVOLUTION OF LIFE ON THE EARTH

The search for the causes and conditions which are the basis of life has in all ages and climes aroused an all-absorbing interest. Up to this time, however, the problem has not yielded to solution, since countless attempts made to solve it have ended in apparent failure.

It is hardly surprising therefore that many, even ardent students of this perplexing problem, have been driven to the conclusion that the forces producing life are wholly different from anything occurring in inanimate nature. They feel it hopeless to try to understand the nature of life processes or even to expect that we can reproduce artificially anything remotely similar to living creatures.

Such a pessimistic statement is undoubtedly the cry of despair. It is true that science in its present state of development is not equal to the task of solving these problems. But it should be remembered that the present stage of science is certainly not its final one. Some of the forces which act in living organisms have recently been explained and artificially imitated, although they had been previously shrouded in the deepest mystery. We may indulge in the hope that those problems of life which are still so puzzling may be solved at a future time.

Tradition often handicaps us when we approach such fundamental problems as the origin of life. But perfect freedom of thought must be the basis of science. If we can free our minds from all prejudices, we find no evidence in nature of anything like a purpose or an aim in creating life. We may therefore state that the appearance of life on the earth is nothing more than a cosmic event. In other words: just as mountains, rivers and oceans are formed by the play of the forces of nature, so also arise living structures on the surface of the earth.

This statement will probably arouse much opposition. The objection will be raised that it is impossible to understand on such a simple basis all the wisely planned arrangements by which an animal is enabled to maintain itself. Does this ability not point to the presence of a creator or to a universally present spirit, who inspires the organization of matter so as to develop life?

Or perhaps a philosophical explanation may be preferred. Novel modes of expression may be utilized in an attempt to explain the purposefulness of life. The propounding of new and strange names and terms has been an established privilege of philosophers of all ages. Formerly it was more widely exercised, but even today it is continued by the biological specialist. By a variety of elaborate terms our mind is time and again impressed with the fact that life is planned according to a scheme and for a definite purpose.

Can such expressions be looked upon as an objection to the assertion that life is merely one cosmic event among many?

The fact is that they are identifications of an inherent difficulty of the great problem, but they contain no suggestions as to the underlying causes. Indeed the development of living organisms in nearly identical forms, generation after generation, their adaptation to their environment, their seeming skilfulness and resourcefulness in overcoming innumerable handicaps, are all a matter of the most common observation. We may explain these facts as the result of "determinism" or of a "vital force." Or we may substitute various other terms such as Aristotle's "Entelechia," or Driesch's "Psychoid," or Bier's "Physis." Such explanations are similar to the dialectic explanation of olden times which stated that "a stone falls on account of gravity." This statement means no more than that the stone falls because it is heavy or that it falls because it falls. Such a play on words has nothing in common with the explanations of modern science.

The explanations of today's scientists are thoroughly different from those of past times. Scientific research of our days attributes *no* importance to the cleverest inventions of the mind. It considers as its task a knowledge which can only be acquired by indefatigable labor and toiling. If a modern scientist wishes to explain a natural phenomenon such as the burning of a candle, the growth of a plant, the freezing of water, the bleaching of a dye, he asks the question not to himself, not to his mind, but to the phenomenon or to the condition itself. When trying to explain a natural phenomenon the modern scientist, first of all, inquires what precedes this phenomenon and what follows after it. . . . (Quoted from J. Liebig, *Chemische Briefe*, 1850.)

From this viewpoint, if we attempt to find explanations for what is termed "determinism," etc., we have to confess that we know very little indeed. Our ignorance is so great that we may truly feel alarmed about it. Many may doubt whether our science will ever grow wise enough to clear up the underlying causes thoroughly. But even in such a case we should not mask our ignorance under high-sounding technical terms.

It is quite obvious that the originators of all the elaborate terms such as vital force or determinism took it for granted that nature aims primarily at creating purposeful organisms. But in this regard these learned men were thoroughly mistaken since an unprejudiced investigation proves that enormous numbers of plants and animals with an inadequate make-up are constantly being formed. The late J. Loeb, biologist of The Rockefeller Institute, has demonstrated this fact through his studies on cross fertilization in marine animals; he showed that by fertilization of the eggs of one fish by the sperm of another fish, animals are generated in which some of the organs indispensable for life are absent. Since sperm or eggs of countless fish freely float in the ocean water and since cross fertilization frequently occurs, deficient creatures must be generated in a number probably equaling that of animals with adequate organs. Naturally only the latter survive.

The plain fact is that all plants or animals that have no organization adequate to meet the requirements for their existence have disappeared from the earth. This is why we see nothing but purposefulness in life. This statement seems to be so self-evident that it hardly requires further elucidation. The puzzling feature, however, is the boundless variety of the forms of life we see around us.

How can we hope to account for this variety? A thoughtful student of nature finds an answer by considering all living things as documents of the history of our planet. Thus he looks upon life in its entirety, its continuous variation of size, form and mode of existence. He realizes that nothing on this earth remains unaltered.

This is the point at which our modern conception of the living nature differs thoroughly from older views on this subject. Formerly it was questioned whether living organisms are subject to any changes of form at all. As we know, children resemble their parents and the human race has apparently changed but slightly within the entire period of its recorded history. Historic studies therefore readily convey the impression that the world of today has existed from all eternity with only slight alterations.

But the period of recorded human history is only one diminutive fraction of the total existence of the earth. Even within such a limited period we find many exceptions to the rule that the offspring resembles the parents. This rule holds only if the conditions under which the offspring exists remain unchanged; and even then spontaneous variations may sometimes appear.

We observe baffling variations of the form of animals in consecutive generations when we perform breeding experiments where many conditions are varied and where abnormal, spontaneously appearing types are propagated on purpose. Darwin has strikingly demonstrated this fact through his renowned studies on domesticated pigeons, since pigeons are particularly suitable for such experiments. Pigeon breeding was pursued by the ancient Egyptians 3,000 years B. C. In Roman imperial times enormous sums were spent. Pedigree registers for pigeons were as carefully kept as for human families or for race-horses. In the course of several milleniums the diversified methods of breeding in different parts of the earth resulted in an amazing multitude of races and varieties.

One of the most striking races of pigeons is the well known peacock pigeon which has a tail similar to that of a turkey with 30 to 40 long radially arranged feathers, while the other pigeons have 12, as a rule. Other pigeons are marked by a bunch of neck feathers which form a kind of wig; others by an odd transformation of the beak and of the feet, or by peculiar and very striking cutaneous outgrowths on the head, or by a very large maw. Very strange are the peculiar habits acquired by some pigeons, as those of the turtle dove, the drum pigeons with their musical tendencies, the carrier pigeon with its geographical instinct, the tumbler pigeon, which has the habit of dropping down from mid-air as though dead. The shape, size, color-patterns and habits of these different pigeons vary much more than those of the wild birds. Also their internal organs exhibit striking variations. Even the bony skeleton shows marked differences, for instance the number and shape of the ribs vary widely (Fig. 1).

It was formerly believed that the different domesticated races originated from different wild types. Darwin, however, definitely demonstrated that they come from a single wild type: the blue rock pigeon (*Columba Livia*). This huge number of variations has been possible in the course of only a few thousand years. Reflect then how much change may have occurred during the entire existence of life on the earth!

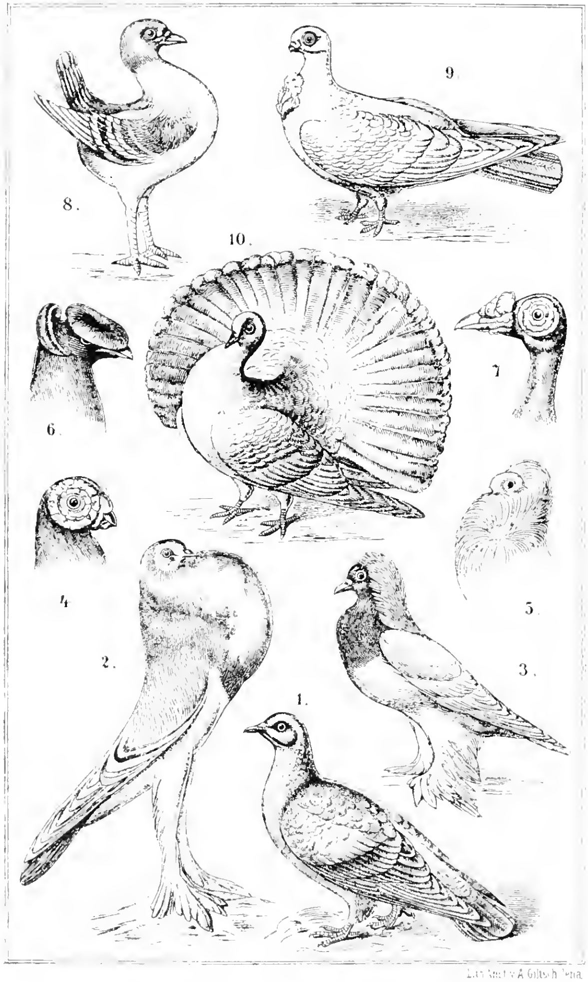


FIG. 1. RACES OF DOMESTICATED PIGEONS

1, Wild Rock Pigeon (Columba Livia), the common form of origin of all domesticated pigeons. *2*, English Cropper (Columba Gutturosa). *3*, Nun (Columba Livia Cucullata). *4*, Head of the Barb Pigeon. *5*, Head of the Wig Pigeon. *6*, Head of the Drum Pigeon (Columba Livia Dasypus). *7*, Head of the English Messenger Pigeon (Columba Tabellaria). *8*, Livornian Pigeon. *9*, African Owl Pigeon. *10*, Peacock Pigeon (Columba Livia Laticauda). All these widely different varieties of domesticated pigeons have been developed from one and the same wild pigeon, thus demonstrating the enormous variability of life in the course of several thousand years.

We are thus induced to explore the approximate age of the earliest living things. Light has been thrown on this extremely difficult problem by the science of geology through studies of rocks and petrifications.

About 40 different ways have been suggested for estimating the age of the earth. Earlier estimates were based on the rate of the loss of heat of the sun and the earth, on the rate of erosion of land, on the rate of formation of sediments in the ocean, also on the amount of salt in the ocean, assuming that the ocean was originally fresh and gradually became salty from the rivers that flowed into it. After numerous surveys this method led to the assumption that the age of the oceans of the earth is about 100 million years, but this figure is much too low as compared with the results of other calculations. In recent studies, A. C. Spencer and K. J. Murata of the United States Geological Survey found that some of the salt carried into the oceans is again removed by clay and held as a deposit on the sea floors. After correcting the old figures for this removal of salt, the age of the ocean is reestimated at 500 to 700 million years.

In order to determine the approximate age of the earth, which is of course considerably older, we use the modern and more accurate methods based on studies of radioactivity. Uranium, a radioactive metal and the heaviest chemical element, disintegrates at a slow, constant rate; in one year one gram of uranium produces $\frac{1}{1,250,000,000}$ gram of lead. The age of certain rocks can be calculated from the ratio of lead to uranium in them as determined by chemical analysis. These results can be checked by several independent methods all of which are based on transformations of one chemical element into another by means of radioactivity. The final results of these different methods check as near as can be expected. The final result is an estimate of about 2 billion years for the earth's age.

From the age of rocks in which petrified remains of life are demonstrable we may infer the age of the earliest beginnings of life. Owing to the indistinctness of the earliest remains, such estimates are very vague, but it is likely that the earliest beginnings of life date back to about one billion years. The base of a petrified tree from the Devonian period is known to be 350,000,000 years old. This specimen is on

FIG. 2. PETRIFIED TRUNK OF TREE 350,000,000 YEARS OLD

The petrified remains of this tree may teach us how long life has existed on the earth, even though it is by no means the oldest living thing. This specimen is put up on the campus of the Oklahoma State Teachers College as a memorial to the late Dr. David White, geologist of the United States Geological Survey. (Courtesy of Science Service.)

permanent exhibition on the campus of the Oklahoma State Teachers College at Ada, Okla. (Fig. 2). Although it may be one of the oldest petrifications of its kind, yet that tree was certainly not the oldest living plant. Life had to develop many hundreds of millions of years to produce such a tree.

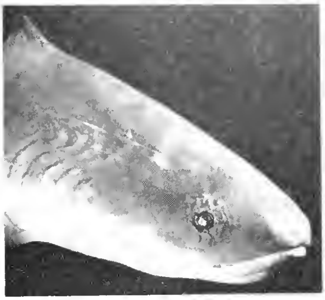
Considering that only 5000 years sufficed to change domesticated pigeons as described how much more must have happened in a billion or half a billion years! A thousand years may be an enormous span of time in human history, but in the history of the earth it is infinitesimal. It is not unreasonable to assume then that all the plants and animals of the earth have developed from one or a few very simple forms of life. Within several hundred millions of years, evolution might have passed through the whole range of the development of the vertebrate animals from fish to men (Fig. 3 see following pages).

In bare outline we can thus grasp the essence of the well-known theory of evolution. But it is extremely difficult to investigate the causes of all the amazing variations of life. The real problem is to determine by what mechanism this great evolution came about. More important still, how did life originate on the earth? Originally the surface of the earth was red hot and could have borne nothing but inert lifeless matter. How did life arise from it after it cooled?

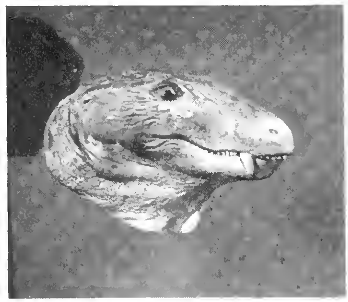
There was probably some sort of development, perhaps extending over millions of years before life appeared. We may assume that the first primitive forms of life must have arisen from non-living matter, although they did not persist. Others may have been formed and vanished, until finally those creatures arose which were sturdier, capable of reproducing themselves and of developing themselves to organisms of ever-increasing complexity. The development in the very first period would be the most important part of the history of life. Is there no way of finding out anything about it?

Something can be gained if we investigate how, in a lifeless world, lifelike processes might have started before the beginning of life proper. Another point worth studying is the power of lifeless matter to organize itself. Thus links between non-living matter and life can perhaps be found.

We can hardly expect to find traces of their past existence in the crust of the earth. In the laboratory, however, we can find some developments of non-living matter which show a faint resemblance to certain features of life. To the description of studies of this type we devote this book.

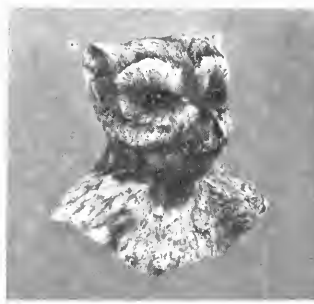


SHARK



ALLIGATOR

OPPOSSUM

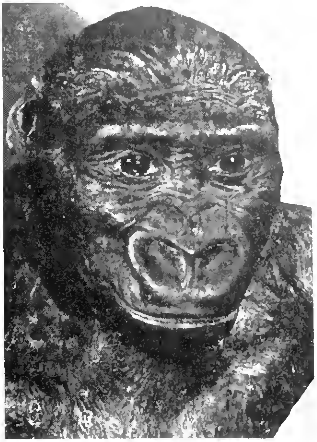


LEMUR

FIG. 3. DEVELOPMENT OF THE HEAD, FISH TO MAN
(series continued on next page)

In order to understand the origin of life, it is not sufficient to describe in all details the make-up of the countless types of living cells, or the functioning of organs of living animals. We must seek additional avenues of approach by finding life-like features in non-living matter. This line of investigation is still much neglected at present on account of the prevailing impression that a gap exists between living and non-living nature.

MONKEY



GORILLA

AUSTRALIAN BUSHMAN

CLASSIC GREEK

FIG. 3. DEVELOPMENT OF THE HEAD, FISH TO MAN (contd.)

The varieties of domesticated pigeons shown in Figure 1 were obtained within a few centuries. These pictures visualize what probably happened in 100,000,000 years.

Man evolved from fish. Note how the mouth gradually recedes, until it is below the eyes instead of in front of them. The nostrils move closer together and the nose becomes more prominent. The monkey is the first animal to develop a steeper forehead. (By courtesy of *Life* magazine.)

The form however in which the subject is presented will not be that of a ponderous scientific report. No techniques are described in detail; no mathematical equations or curves are derived or interpolated; no preliminary study of the basic sciences is expected of the reader. We shall try instead to animate our story by inserting in it scenes which may be looked upon as fragments of a dramatic performance.

The stage has already been set for the opening. The Manager of the Performance stands before the curtain to explain how he has gathered his material for the drama from near and far, much from foreign lands, all dealing with fascinating discoveries of distinguished scientists, obtained from sources which were scrutinized for reliability. He tells us that exploration trips will be presented to show how facts can be gathered, and that facts indeed will be stressed according to the spirit of science which demands care in drawing conclusions.

Furthermore, he expresses the hope that this performance will appeal to those who have contemplative and inquisitive minds, and will arouse in them a love for the search for truth. And with this and a bow to his patrons the Manager retires and the curtain rises.

The First Approach

VITAL GROWTH AND CRYSTALLIZATION

The First Approach

VITAL GROWTH AND CRYSTALLIZATION

1. THE DEVELOPMENT OF CRYSTALS UNDER VARIOUS CONDITIONS

Let us start then on our journey of exploration to search for those features of non-living matter which imitate life. Let us see whether we can find any similarity at all.

The most universal feature of all life is, of course, growth. The growth of a large tree from a diminutive seed, or the development of a large animal from a microscopic germ cell, seems to be far beyond the reach of any explanation. The multiplicity of the components of the human body is so enormous that their mere enumeration and description form the object of an entire science, that of anatomy.

How is it possible for all these structures to arise from a plain round cell which is not much more than a simple ball and smaller than a dust particle floating in the air?

Since science is obviously not in a position to answer this question, it is wiser to start on a simpler problem. Simpler forms develop in lifeless matter: the growth of a crystal is an example. Any salt or sugar and many other substances form crystals which can be recognized by their definite shape, such as needles, pyramids, or cubes, having sharp edges and smooth planes. Such crystals form when a salt solution slowly evaporates in a flat dish.

Water alone if sufficiently cooled will crystallize or freeze, as we call it; thus snow crystals form from water vapor in the cold upper reaches of the atmosphere. The variety and beauty of these crystals is strikingly revealed under slight magnification (Fig. 4).

We can well understand the nature of crystallization, this type of growth which is so typical of the non-living world. A crystal grows by slow gradual apposition of diminutive particles—molecules—each of which has the same shape. They are attracted to the surface and attached to it in such a manner that the whole crystal maintains its shape, no matter how much it grows. Yet these particles are so small that they cannot be seen even with the highest power of magnification available; hence there is no visible break in continuity in the appearance of the

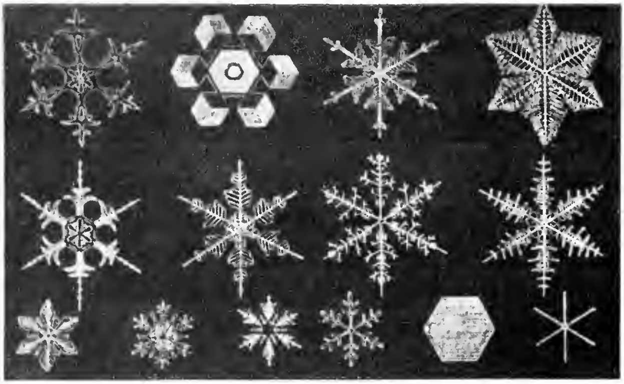


FIG. 4. SNOW CRYSTALS

Note the sharp edges and smooth planes of these crystals. All these different forms arise by the combination of small ice crystals in various ways. Similar crystals are formed when any dissolved solid substance like sugar or a salt settles from its solution in water, if the water is slowly evaporated.

crystal. This is the generally accepted explanation of crystalline growth. Science may still find unsolved problems here as everywhere, but undoubtedly the process is not nearly as involved as that of the growth of a plant or animal.

The problem is whether any similarity can be found between the growth of a crystal and the growth of living organisms. The perfectly smooth planes and sharp angles of a crystal are, of course, quite unlike the general appearance of any plant or animal. Moreover, the crystal looks the same all the way through, as is evident when it is cross-sectioned. Such uniformity is never found in any living thing.

However, by a slight modification of the conditions of any crystallization we can see that a general similarity to life appears. We add gelatin, or starch, or another similar slimy material to a salt or sugar solution from which crystals

FIG. 5. LEAF-LIKE FORMS PRODUCED BY CRYSTALLIZATION OF ORDINARY TABLE SALT IN A MEDIUM CONTAINING GELATIN

If ordinary table salt crystallizes from a water solution to which gelatin is added, the small crystals formed join to build up an aggregate which resembles a leaf; this is a striking example which shows that crystallization can produce life-like forms under certain conditions. Natural size.

are growing. With such an addition, there is no longer a growth of one, or of a few large crystals, but the crystal now breaks up into countless small ones which group themselves in such a manner that the entire aggregate presents the outline of a leaf (Fig. 5). Similar aggregates of crystals are formed which resemble trees or plants with twigs and branches. We see, therefore, that under proper conditions crystallization may lead to life-like forms, a fact which seems to indicate that the building forces of living growth and of non-living crystallization have some relationship. Here is one of the links between the non-living and the living world—just a group of plain salt crystals, not a bit of life in them, yet manifesting an ambitious tendency to resemble the outline of real living things.

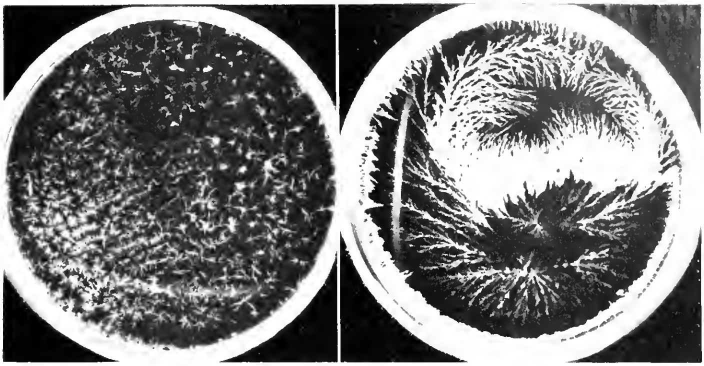
One possible explanation for this resemblance may be that gelatin or starch are materials of organic origin; gelatin is extracted from bones while starch is a plant product. No wonder the addition of such organic materials alters crystalline growths so that they resemble organic forms! Some life-like property may still reside in this organic material. An objection to this explanation is that we can obtain a similar effect with a purely inorganic slimy or gelatinous system such as silica gel. Life-like crystalline structures may arise in the entire absence of any material derived from organisms.

But when we add different materials to the growing crystals we find that each of them has its own way of changing the appearance and arrangement of the crystalline aggregate.

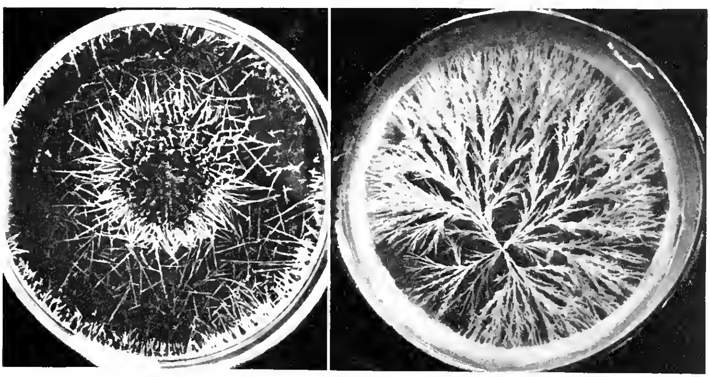
2. PFEIFFER'S METHOD OF "SENSITIVE CRYSTALLIZATION"

The character of the added material determines the type of the alteration of crystalline aggregates even if only traces are added. If extracts freshly prepared from plants or blood of animals or men are added to the growing crystals, striking new forms appear. These forms are so varied that it takes almost a life-time's work to thoroughly study their appearance.

Ehrenfried Pfeiffer, a Swiss research chemist, devoted years of intensive studies to these forms, some of which are reproduced here with his permission (Figs. 6–12). These pictures reveal astounding facts. They show how a copper salt which crystallizes irregularly when nothing is



a *b*



c *d*

FIG. 6. PHOTOGRAPHS OF PLATES WITH CRYSTALLIZING COPPER CHLORIDE ACCORDING TO PFEIFFER'S METHOD

($\frac{1}{2}$ natural size)

(*a*) Copper chloride without addition.

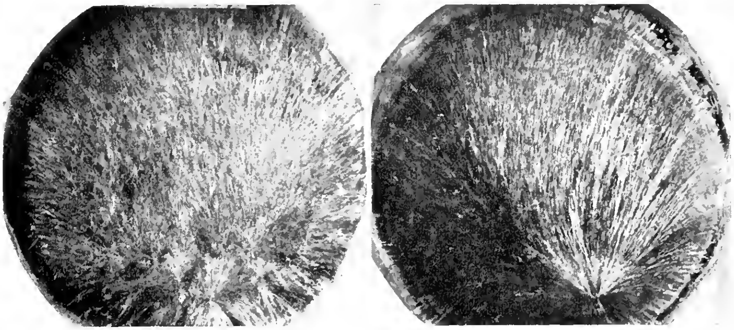
(*b*) Copper chloride crystallizing with addition of one drop of an extract of a water-lily flower to 1 cc. of the 25 per cent copper salt before crystallization.

(*c*) Same with the addition of one drop of extract from an agava.

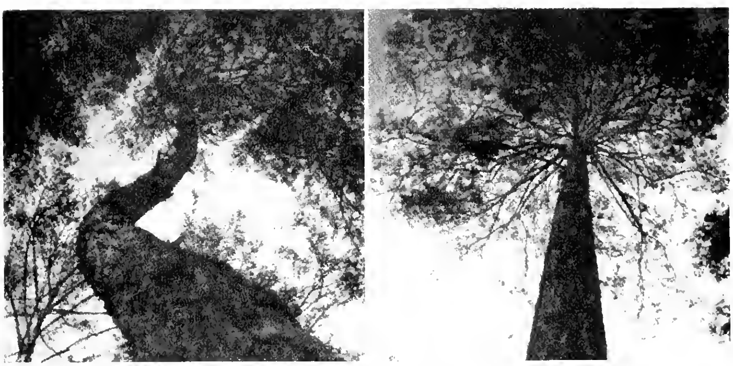
(*d*) Same with the addition of one drop of extract from a camomile flower.

All the pictures reveal the striking formative influence of the addition of plant juices to the otherwise shapeless crystalling salt. Note particularly the appearance of thorn-like crystalline needles after the addition of the agava juice.

added, takes on typical plant-like forms following the addition of a plant extract. If an extract of water lily is added,



½ nat. size



Photographs of pinetrees

FIG. 7. THE FORMATIVE POWER OF AN EXTRACT FROM HEALTHY PINE TREE SEEDS AS CONTRASTED WITH THAT OF AN EXTRACT FROM SEEDS OF A DISEASED TREE, ACCORDING TO PFEIFFER'S METHOD

The upper picture shows crystallizing copper salts with the addition of extract from seeds of these two different seeds. Note the symmetrical lines of crystallization in the former case, upper right, and the irregular crystalline lines emerging from several centers in the case of the diseased tree, upper left.

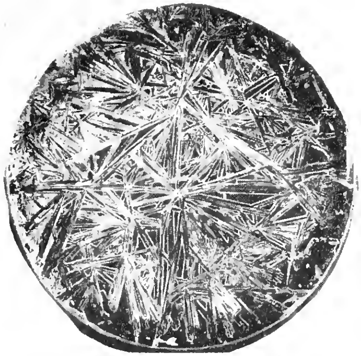
the pattern of the salt imitates the gracefully curved outline of the lily. If a drop of an extract from an agava is added, the salt crystals form what looks like spikes or thorns; again with extract of a camomile flower, a delicately ramified pattern of great regularity and beauty appears (Fig. 6).

Even more striking variations appear if extracts from healthy and diseased plants are added to the crystallizing salt. Pfeiffer took seeds of a healthy straight pine tree and seeds from another pine tree which grew crooked. Both kinds of seeds were crushed in a mortar, water was added, and the extract thus prepared was separated from the seed fragments. A few drops of the two extracts were added to crystallizing copper salt. Where the extract from healthy seeds was added, a crystalline picture with perfectly straight or gently curved lines developed, and all these lines radiated from a common center in perfect harmony (Fig. 7a). The extract from the crooked tree's seeds, on the contrary, produced an irregular picture. The lines do not radiate from a center, but seem to converge to several points which are irregularly distributed (Fig. 7b).

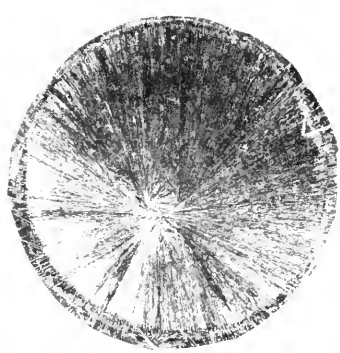
These experiments demonstrate the presence of mysterious form-producing forces, or properties, in the living substance. And these forces manifest themselves not only in the living plant, but can also be put to work in a crystallizing salt.

Next, Pfeiffer investigated the forms produced in crystallizing salts by the addition of traces of human blood to see whether it was possible by this method to find differences between the blood of healthy and sick persons. From 1930 to 1935 he performed more than 30,000 crystallization experiments which show that there is a difference.

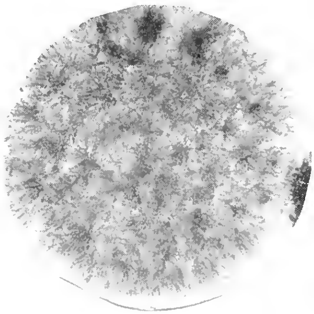
He took two or three drops of fresh blood, mixed it with about five times as much water, and added two drops of this diluted blood to a third of an ounce of salt solution. This mixture was poured on a flat round dish, about three inches in diameter, where it slowly evaporated. For a control, the same solution, but without any addition, was allowed to



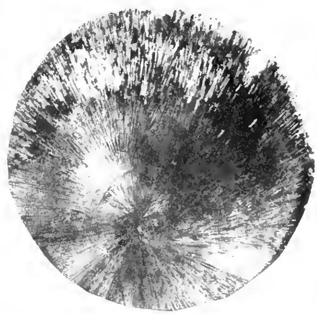
20% Solution of Magnesium Sulfate



Same with trace of healthy human blood

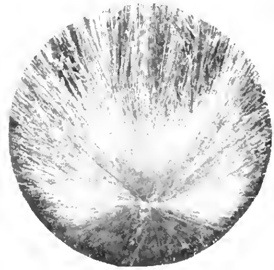


10% Solution of Copper Chloride



Same with healthy human blood

10% Solution of Lead Acetate



Same with the addition of healthy human blood

FIG. 8. THE FORMATIVE INFLUENCE OF HEALTHY HUMAN BLOOD UPON VARIOUS CRYSTALLIZING SALTS

(½ natural size)

On the left hand side we see the pictures resulting from the crystallization of various salts without addition. On the right hand side we see the same salts crystallized after addition of a diminutive amount of healthy human blood. Note that the change brought about by the addition of blood is nearly the same no matter how these salts crystallized without addition.

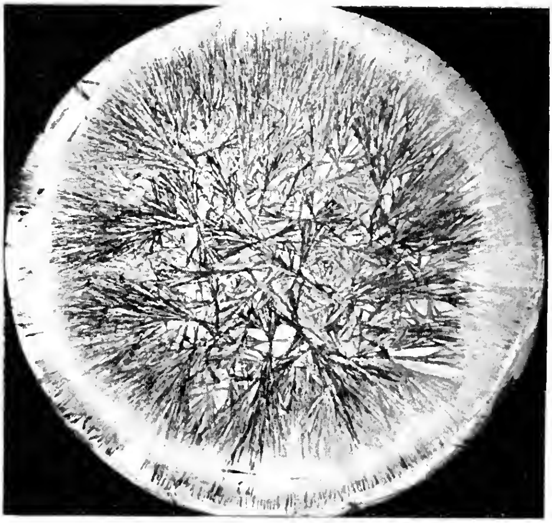
evaporate in exactly the same manner. Figure 8 shows how these traces of blood change the picture presented by the salt crystals. Three different salts were used: a copper salt, a magnesium salt, and a lead salt; each with and without the addition of blood. Without an addition the salts crystallize in an irregular manner, the one differing from the other; but the addition of traces of blood changes the picture in every instance to produce almost identical pictures, although different salts are present. This normal "blood picture" shows clear-cut, straight, fine lines all radiating from one point of the plate.

This normal picture is obtained relatively rarely after addition of human blood. The "blood picture" of various people may differ considerably. The simplest variation is that in which the crystals radiating from a center are not fully developed up to the margin. At a certain distance the dense rays cease; a delicate network of a thin layer of crystals is formed as a margin. Or there arise encrusted areas or gaps, resembling the controls without addition. This means that the formative force of the added blood is deficient or fails to work entirely. Another change is the appearance of several centers. . . . The normal blood picture is obtained only from men who feel perfectly fine. . . . The same case which had once given an entirely normal blood picture may exhibit a completely different blood picture several months later during an attack of fever.

Now we approached several physicians for a systematic coöperation and obtained from them definitely diagnosed cases for investigation. . . . It appeared that various very typical deformations of the normal blood picture can be correlated with various diseases. . . . Cases appeared in which the pictures were at first contradictory or not readily accessible to interpretation; here a finer differentiation was necessary. (Quoted from E. Pfeiffer, *Sensitive Crystallization Processes, a Demonstration of Formative Forces in Blood*, London 1936, Rudolph Steiner Publishing Co.)

It is evident therefore that considerable difficulties are involved in the practical application of Pfeiffer's method to medicine. The entire method is a research problem at present not as yet bearing the endorsement of the medical and scientific professions.

Technical details cannot be discussed here in detail but some of them can be found in Pfeiffer's publication by all those who are interested in this line of development.



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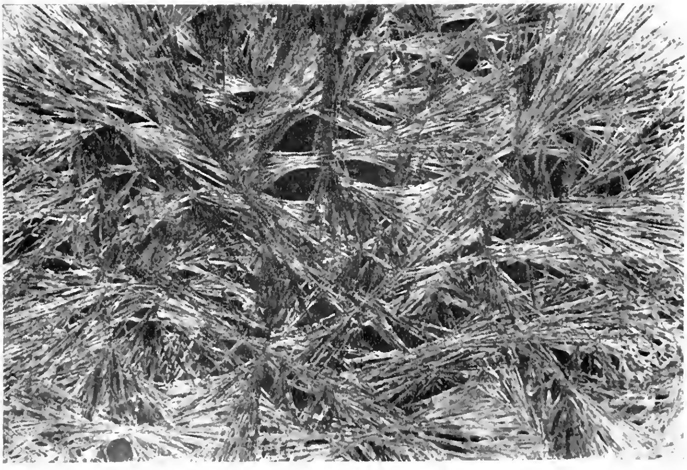

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Fig. 9. The Formative Influence of the Blood of a Tuberculous Patient upon a Crystallizing Copper Salt
(½ natural size)

Figs. 9 to 12 are inserted here to show the type of changes which may occur in diseased human conditions but as already stated the interpretation is not an easy matter. It should be remembered that we are dealing here with delicate forces which for countless unknown reasons can be diverted in different channels so that the desired supposedly typical pictures do not appear.

In the case of plants and plant diseases, Pfeiffer's method gives rather definite results. In this line it has acquired practical importance in several countries in Europe where the condition of health of plant seeds is commercially investigated by Pfeiffer's crystallization method as described (see Fig. 7). Obviously such an investigation is of considerable importance in agriculture and forestry. The human or the animal organism, however, is a much more complicated piece of machinery than a tree or a plant. Many more highly involved forces of development act in it. All these forces may also act in crystallization superimposing one upon each other until there arises an almost inextricable maze of lines. This is bound to occur particularly if the body is diseased from any cause since foreign forces derived from infection, "new growth" or other causes are then active besides the normal causes of development.

(Concerning the details of Figs. 9 to 12 the following remarks may be added: The majority of the severely ill patients whose blood Pfeiffer investigated had either cancer or tuberculosis. In tuberculosis sturdy lines of crystals appear which cross each other at right angles, thus producing a pattern that looks like a Maltese cross (since the crossing lines are contracted toward the center). A similar picture is produced more distinctly if, instead of blood, an extract of a tuberculous lung is added to the crystallizing salt (Figs. 9 and 10).

This "Maltese cross" which is hardly of great practical importance has been a little too much emphasized in an

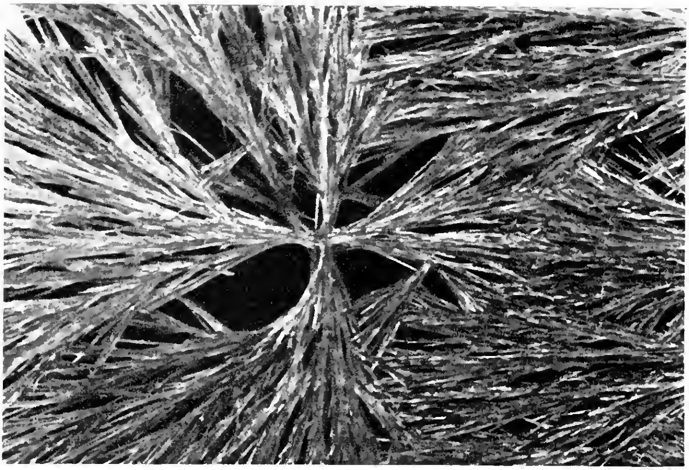


Fig. 10. Formative Influence upon Crystallizing Copper Salt of an Extract Made from Tuberculous Lungs

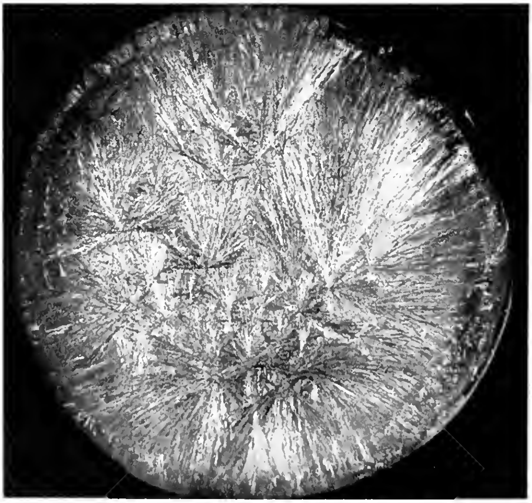
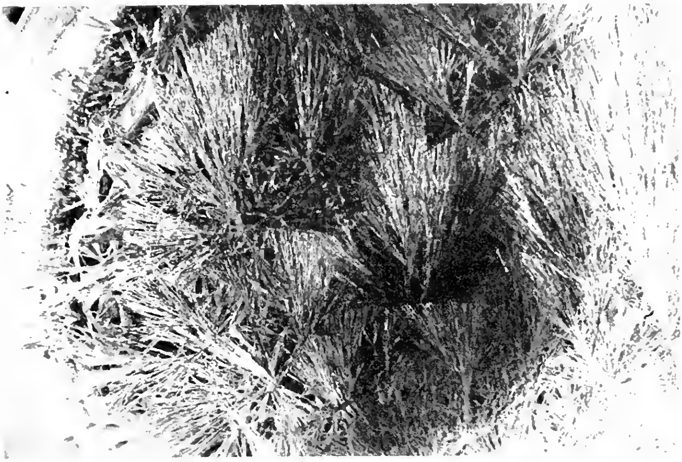


Fig. 11. The Formative Influence upon Crystallizing Copper Salt of the Blood of a Patient with Cancer of the Stomach



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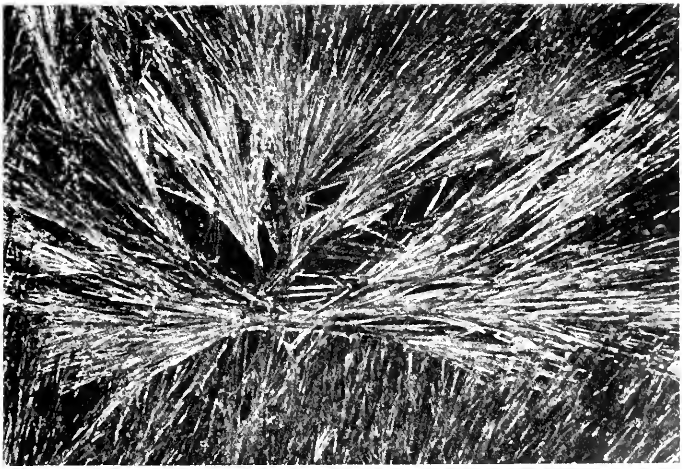

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Fig. 12. Formative Influence upon Crystallizing Copper Salt of (*a*) the Blood of a Patient with a Tumor of the Esophagus (*b*) the Extract from a Surgical Specimen of Tumor of the Esophagus

article in lay literature, which publicized Pfeiffer's method (see "Coronet," of June, 1937, "Finger Printing Disease")

The blood picture obtained in a cancer patient is shown in figures 11 and 12. These pictures can only be interpreted by an expert.

This book is frankly not concerned with the unsolved problem of the application of Pfeiffer's method to medicine. It is to be emphasized here that the mysterious forces of development in plant life and even animal and human life, both in health and disease do exert a demonstrable influence upon the delicate forces of crystallization. It might be added that Pfeiffer had been induced to start this line of research by observing the "frost-flowers" forming at the windows of shops during cold weather; at a butcher shop he saw grossly irregular pictures, while at a flower shop delicately developed patterns of great beauty appeared. These alterations are due to diminutive amounts of plant or animal extract picked up by the air and desposited at the ice-cold window with the moisture.

3. NETWORK AND STRIPE FORMATION IN GELATIN

Our journey of exploration now takes us to another territory of scientific investigation. Unsatisfied with the knowledge acquired so far, we want to know *why* a crystallizing salt produces those life-like forms after the addition of slimy or organic material.

Take the crystallization of table salt after the addition of gelatin (Fig. 5). That leaf-like picture obviously comes about through the fact that the salt while crystallizing breaks up into a large number of small crystals. These small crystals then arrange themselves in such a manner that their aggregate resembles a leaf. The question is by what mechanism this action comes about. Is there any obstruction in the gelatin which prevents the crystal from growing freely?

Yes indeed! The gelatin forms a network resembling a honey comb which holds the crystals in its meshes. This net can be seen under a powerful microscope, magnifying more than 2,000 times, when a gelatin solution is spread out in a thin layer upon a glass plate and allowed to dry (Fig. 13). It is not surprising that a crystal growing in such a net is broken into small units which are attached one to the other as the growing crystal works its way through the net.

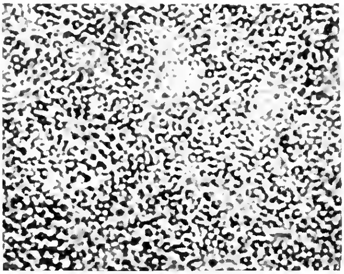

FIG. 13. HONEY-COMB STRUCTURE AS APPEARING IN MANY GUMMY SOLUTIONS

Structures similar to the one here appear in solutions of gelatins, starch, or gums, if spread out in thin layers on a slide and viewed under high magnification. This one has been magnified 1,380 times.

[FIGS. 13, 14, 16, 17, 18 and 19a are microphotographs from O. Bütschli's Atlas zu den Untersuchungen über Strukturen, Leipzig, 1898.]

Such a network is formed not only in gelatin, but also in any other slimy material, such as egg white or various lacquers like shellac. Moreover, the gelatin or other organic material attaches itself to the surface of the growing crystal, and in this way blocks the growth and development of salt crystals. This interference with crystallization through blocking of the surface of the crystals plays an important rôle in Pfeiffer's "sensitive crystallization."

The network of the gelatin is by no means invariably of a simple uniform pattern. It may be modified under the influence of various conditions. By simply stretching the gelatin, the "cells" composing the network arrange themselves in a line, giving the whole the aspect seen in Figure 14, which shows the appearance of stripes in the direction of the tension.

Stripe formation is visible also in quite a few living structures such as fibers and tendons. As is well known, a tendon is a connecting band in the human body which is naturally subjected to pull and stress. The stripe formation which it exhibits when seen under the microscope is the result of this stress, and by no means a purposeful arrange-

Fig. 14. Microscopic View of a Stretched Thread of Gelatin

This photograph shows that by stretching the network structure of the gelatin, it has taken on a more striped appearance. (Magnified 700 times.)

ment to increase its strength. Similarly in the bone, the solid bony material is not evenly distributed, but collected or condensed in a network of thin sheets. The arrangement of this network coincides exactly with the lines of the greatest compression which the bone suffers under the load which it has to carry while supporting a part of the human body.

The story is told of an engineer who happened to see a sketch showing how this bony material was arranged in the thigh bone (femur). He was at once impressed with the resemblance of this arrangement to stress lines of which he had made extensive studies in his mechanical devices. He made a sketch of the landmarks of the thigh bone, and calculated the stress lines in it, according to the mechanical principles well known to him. In this calculation he took into account the effect of the load of the human body. In brief he devised a structure resembling a crane, with the well-known outline of the thigh bone, which was capable of meeting the required stresses. On comparing this constructed system of lines and planes with the distribution of the bony material in the bones, a complete agreement was found (Fig. 15).

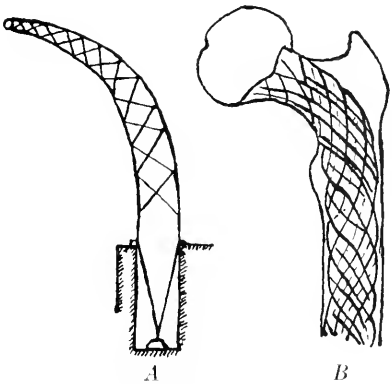

FIG. 15. STRESS LINES IN THE THIGH BONE

Diagram *A* gives an idea of the location of the lines of stress in the head of a crane, diagram *B* those on the surface of the femur.

This stripe formation in bony material is quite comparable to the stripes formed in gelatin under stress. It is assuredly worth noting that we can learn something about the make-up and character of vital structures from these simple experiments with gelatin or egg white. It serves as encouragement to investigate the matter on a somewhat wider scale. A more systematic survey shows that gelatin, or salts crystallizing in it, and various soft and slimy materials, such as starch, when crystallizing under differing conditions, give rise to an enormous number of forms. Some of these forms bear a truly surprising likeness to certain living forms (Figs. 16–22).

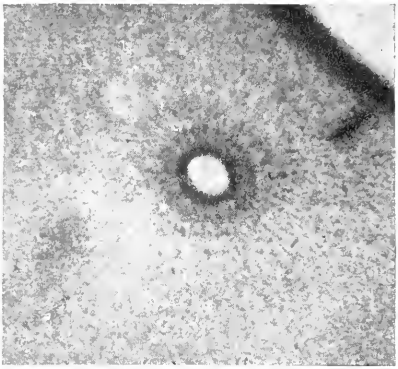

FIG. 16. WHEEL SPOKE ARRANGEMENT AROUND A CONTRACTING AIR BUBBLE IN GELATIN

A radial striation, as shown in the above microphotograph (magnified 450 times), arises in gelatin, if a small air buble is included in it while it is poured as a warm solution on a glass plate. As the gelatin cools, the bubble contracts and consequently exerts a pull in all directions upon the solidified gelatin around it. The result is that a stripe formation arises in the gelatin which radiates from the contracted air bubble in all directions. The origin of this radiation can be easily understood by comparing this figure with Figure 14, in which a linear pull is shown to produce a parallel striation. Naturally, the concentric pull of the contracting air bubble must produce a radial striation. (Bütschli, Atlas XXII.)

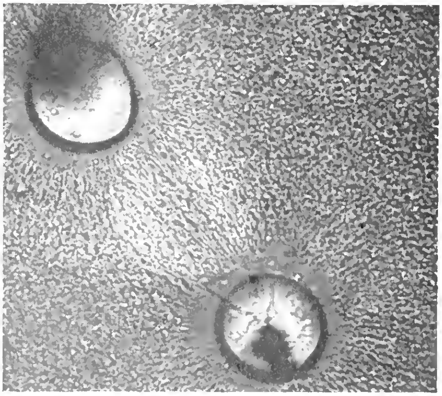

FIG. 17. TWO AIR BUBBLES WITHIN MICROSCOPIC DISTANCE, PRODUCING A "SPINDLE" BETWEEN THEM

If two contracting air bubbles are in close proximity, a curious looking "double aster" arises; the two sets of radial striations now interfere with each other, producing what looks like a spindle. (Magnified 450 times.) Bütschli, Atlas I, 7.

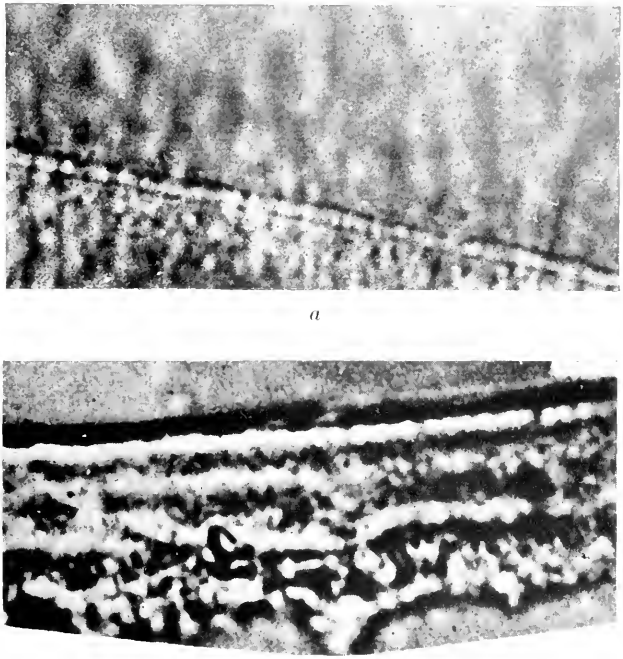

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FIG. 18. SKIN FORMATION ON THE SURFACE OF A STARCH SOLUTION (*a*) AND A CELLULOSE SOLUTION (*b*)

On the surface of a starch, gelatin, or cellulose solutions we can see the formation of a delicate skin consisting of one or more nicely arranged "cell" layers, more compact than the underlying loose "cell" arrangement. A similar surface layer or skin is formed on boiled milk and many other liquids. Its structure as revealed by microscopic examination is much more primitive than that of the real skin of plants, animals or man, yet there is a remote resemblance. (Magnified 3600 times.)

This microphotograph with its extremely delicate structure, as well as those shown in Figs. 13, 14, 16, 17, and 19a, are from O. Bütschli, in his days a professor at the University of Heidelberg, a man who worked with painstaking accuracy. The microphotographs of structures in gelatin, starch, etc., which he left to posterity, are performances which required rare skill, and have never been duplicated. Most of them are done with a magnification near the limit of visibility. The striking feature of these pictures is their resemblance to many microscopic aspects of living tissue.

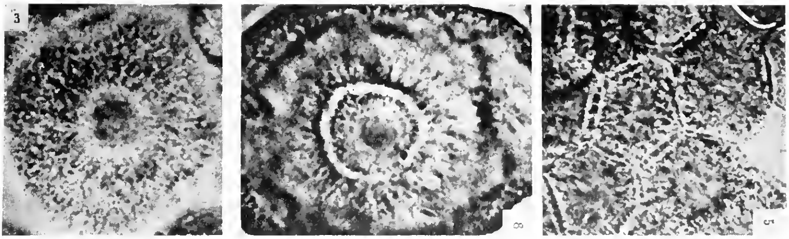


FIG. 19A. MICROSCOPIC STARCH CRYSTALS RESEMBLING CELLS

The microscopic photographs shown here are taken from crystallizing starch; note how the crystals form structures resembling cells, some even remotely resembling living cells with a nucleus. Others exhibit definite lines of separation between the cells. Magnification about 1730 times. (Microphotographs by Bütschli.)

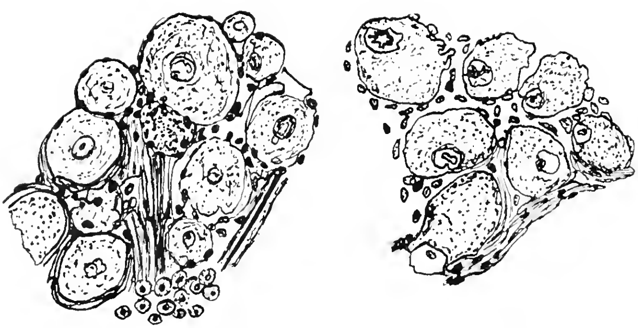


FIG. 19 B. MISCROSCOPIC PICTURES OF NERVE CELLS

Note the resemblance of these cells, containing a nucleus, to the starch crystals shown in the previous figure.

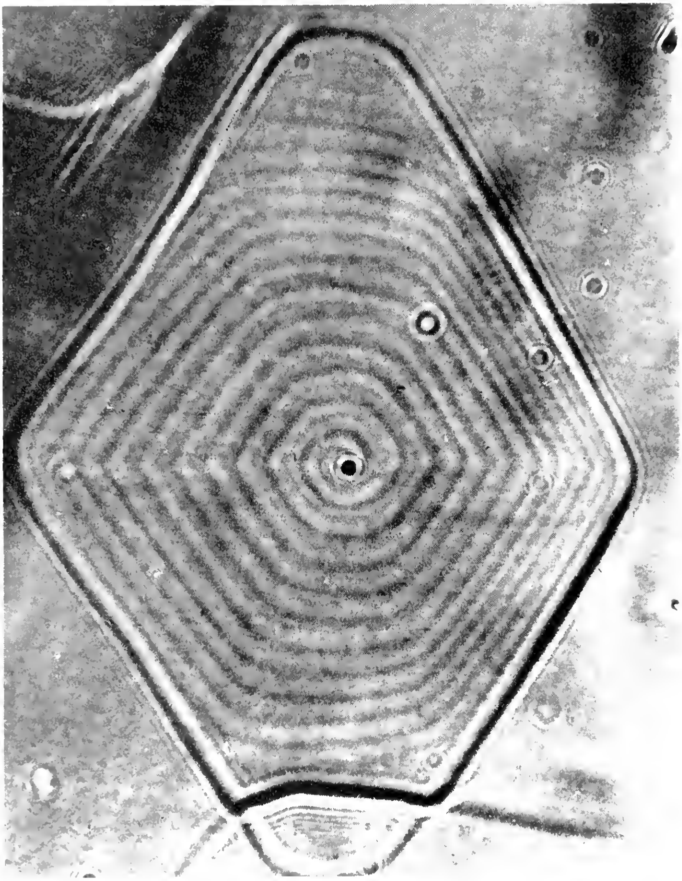


FIG. 20. SPIRAL ORGANIZATION FOUND IN PARAFFIN CRYSTALS

Spiral organization, which is commonly found in plant and animal life, very rarely occurs in non-living crystals. In rare cases the surface of a quartz crystal will show a kind of spiral when it is properly etched. Professor C. M. Heck of the North Carolina State College has recently discovered spirals in abundance and of exceptional beauty in the ordinary paraffin wax when it crystallizes from mineral oil. (Magnified 1200 times.) (Courtesy of Science Service.)

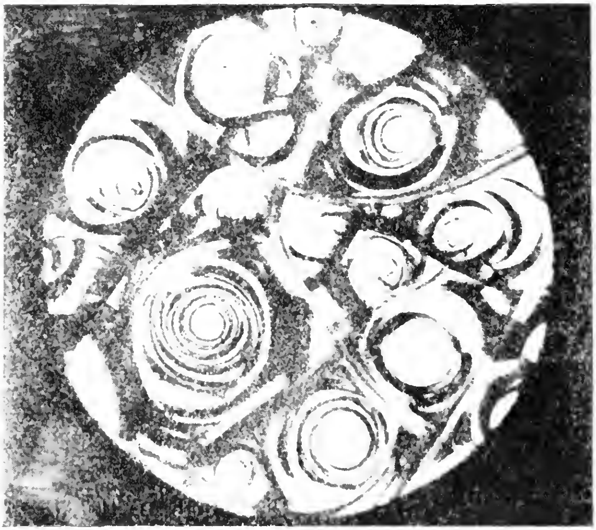


Fig. 21. Artificial Epithelial Pearls

A picture similar to the one shown here appears in cancer of the skin, and is considered of value for diagnosing this disease. The artificial epithelial pearls are obtained by letting a thick layer of gelatin dry up on a plate at moderate heat, then observing the gelatin under slight magnification. (Magnified 60 times.)
(According to Dr. Martin H. Fischer of Cincinnati.)

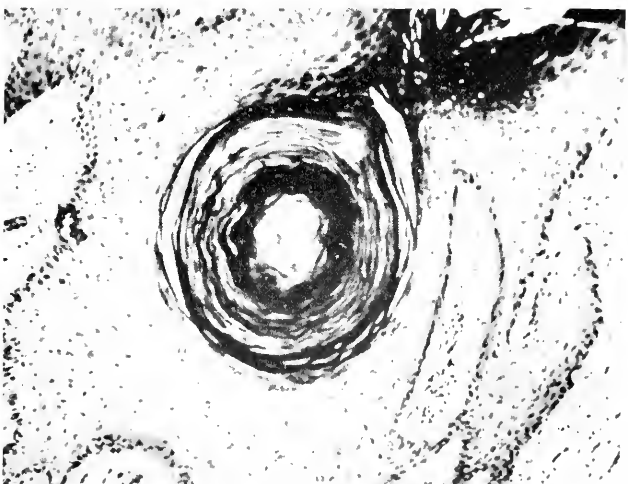


Fig. 22. Real Epithelial Pearl Occurring in Cancer of the Skin

(Magnified 80 times.) (From Boyd, *Text-book of Pathology*, by courtesy of Lea & Febiger, publishers.)

4. THE PROBLEM OF RELATION OF LIVING GROWTH TO CRYSTALLIZATION. CONDITIONS DETERMINING THE SIZE OF GROWING CRYSTALS

We hope to get a "glimpse into the workshop of nature" by studying crystalline forms produced in non-living matter and comparing them with those of the living world. What a diversity of forms of life-like appearance can crystallization produce in lifeless matter!

Now we wish to understand what occurs in living plants or animals. Are their bodies formed by a process related to crystallization? Before answering this question let it be clearly understood that none of these gelatin structures, or the various aggregates of crystals, can be called living. Some of the most essential features of life are not shown at all by any of them: all these structures lack the ability of living plants or animals to build up their bodies from food material which is totally different in composition from the substances of their own bodies. A crystal can grow only in its own solution. Sugar, for instance, will dissolve in water, but in so doing it has not undergone any changes; the sugar water tastes as sweet as the crystalline sugar. If we drive off the water from the sugar solution by gently heating it, the sugar is left behind, and appears again as crystals in the same form as before.

In spite of this profound distinction there is a general similarity between living forms and those of certain crystallized non-living materials. It would seem therefore that a relation of some sort must exist between the growth of a crystal and that of a living thing. The determination of the nature of this relation ought to be looked upon as one of the greatest tasks of science, but its solution has been handicapped by the prejudice that only those substances are crystalline in which crystals are directly visible. It is easy to demonstrate, however, that crystals of any size can be formed, some being so small that they are not visible even through the most powerful microscope. The size to which a crystal can develop depends on how much time we give it to grow; the more time we allow the greater the crystal. One way to obtain large crystals of a salt is to take hot water and to dissolve in it as much salt as possible. Then allow the water very gradually to cool down. While it cools leave a few large undissolved salt crystals in it. The well known alum, often used as a styptic pencil after shaving, is the salt most suitable for this experiment. When an alum solution cools down the alum crystals will slowly increase in size, because cold water cannot hold quite so much alum as warm water. If plenty of time is allowed for this cooling, a sizable crystal will develop. In nature, where thousands of years are allowed for crystallization, crystals of other materials are found to grow still larger, as might be expected, sometimes up to a length and width of many feet.

Let us now force the formation of crystals with greater velocity, by rapidly boiling away more than half of the water of an alum solution, then quickly chilling the remaining solution in a refrigerator. The result will be the formation of a large number of small crystals, which look like powder.

There are ways of forcing the formation of crystals with even greater rapidity, so as to make them still smaller, eventually so small that they drop out of sight. The procedure is to mix two solutions, each containing a different substance such as a soluble sulfate and a soluble barium salt. These two particular solutions, when mixed, produce a third substance which is completely insoluble in water and settles to the bottom as a solid mass (Fig. 23). This settling is retarded if plenty of water is added to these two solutions, since more time is thus allowed for mixing, and the third insoluble solid substance forms more slowly. Under such conditions the third substance appears as visible crystals possibly as a fine-grained crystalline powder. The greater the amount of water added to the two solutions, the larger are the crystals formed.

If on the contrary the two solutions are more concentrated the crystals are smaller. No visible crystals appear at all if the concentration of these two salt solutions is raised to the highest possible level, that is, if more salt than water is used to make up these salt solutions. The solid precip-

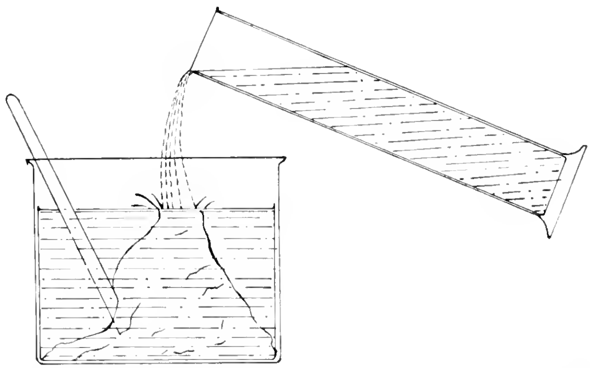


Fig. 23. Rapid Settling Out of Insoluble Material by the Mixing of Two Soluble Salts (a Sulfate and a Barium Salt)

If these two salts are dissolved in a little water and mixed, the insoluble product settles so rapidly that no crystals are formed; if they are mixed in a more dilute solution, crystals are formed: the more dilute the solution, the larger the crystals.

itated substance then forms as a soft jelly-like mass. No microscope is powerful enough to reveal the presence of crystals in this soft mass, yet we may assume that invisible small crystals are in it since crystals do form from more dilute solutions.

5. ARE CRYSTALS PRODUCED BY VITAL GROWTH?

It is manifest, therefore, that the absence of visible crystals in living organisms does not exclude the possibility of the existence of small invisible crystals in them. How can we find out whether or not these are present?

The solution of this problem has been greatly handicapped by the conception that the forces acting in life must be different from those in non-living matter. As early as 1858, a Swiss, Carl Naegeli, pointed out that many of the components of living matter are probably built up of very tiny crystals. Naegeli found some evidence for their crystalline character through the study of the appearance of plant and animal material, if illuminated by a special kind of light, so-called polarized light which forms if ordinary light passes through a plate of transparent lime-spar under certain conditions. There appears a play of colors, which is otherwise seen only if certain crystals are illuminated with this polarized light. Particularly, fibers which have grown in living plants or animals, like silk fibers, cotton fibers, tendons, or muscle fibers, distinctly exhibit such a play of color. Hence it is likely that they have invisibly small crystalline components in them, a fact which tends to show that the process of living growth shows some traits similar to those of crystallization.

By such studies, one of the artificially erected walls of separation between living and dead matter was torn down as early as 1862. The time honored teaching of science had been that the growth of a crystal bears no similarity to living growth, this being explained by vital forces, vital energy, or some other meaningless word. It is only natural therefore, that every possible effort was made to disprove the arguments which indicate the crystallinity of the products of vital growth. Every possible effort was made to prove that the characteristic play in color of plant and animal material can also appear even when no crystals are present at all.

It is always possible for a scientific specialist to find flaws in a theory. So against Naegeli's reasonable theory, arguments were soon advanced. That play of colors which Naegeli regarded as indicative of crystallinity can also be seen if pressure is exerted upon a substance like glass which contains no crystals at all; under pressure the glass is slightly distorted and thus gives rise to the play of colors under polarized light. Naegeli's opponents argued that a stress might arise in fibers during the process of growth, and that the assumption of crystalline particles was therefore unnecessary to explain that play of colors.

But their contention is impossible since it fails to consider the make-up of living fibers which is totally different from that of glass. The fibers consist of an almost liquid mass in which small solid particles are imbedded. These particles are freely movable, being held together only by soft layers between them. Stress exerted upon the substance as a whole leads only to a mutual displacement of the single solid (crystalline) particles against each other; but it cannot distort them.

Naegeli thus had good reason to discard this argument. But his opponents had still other doubts. A weary controversy arose, the final outcome of which was that every one lost interest; the general impression was that hair-splitting arguments were being debated by a small group of scientific specialists. The great issue raised by Naegeli, that is the nature and essence of vital growth, finally fell into oblivion for more than half a century.

6. X-RAYS FURNISH A MEANS OF PROVING THE EXISTENCE OF CRYSTALS IN LIVING MATTER

Fifty years elapsed after Naegeli's early experiments, which had suggested a relationship between crystallinity and living growth. Naegeli died without seeing his epoch-making discoveries recognized. Yet the issue was not completely dead. In the minds of a few it remained as an unsettled question until suddenly in 1912 and the years following, the question stood again in the limelight of the world of science everywhere.

The famous x-rays discovered by Roentgen in 1895 had been employed as a means of investigating crystallinity. In this manner, a new basis had been established for the study of the crystalline state. It became possible to trace crystals of the most diminutive size by means of these rays. Applying this method to various products of living growth, the existence of crystals in them was revealed.

The ideas developed by Naegeli became definitely established facts: science was now in a position to demonstrate a distinct realtionship between the growth of a crystal and the growth in living plants or animals, and even to determine the mutual arrangement of the crystalline components in the living organism in all their details.

Figures 24 and 25 are reproduced here to convey to the reader an impression of the method by which x-rays can be used to trace crystallinity. If a single ray of x-ray light strikes a photographic plate, it leaves a dark spot in much the same manner that any light ray will. The same occurs if a layer of any non-crystalline substance like cellophane or paraffin is interposed between the ray and the plate. But if a whole solid crystal is interposed there, a different picture appears on the plate (Fig. 24). The ray now also leaves on the plate a large black spot with a hazy contour. Around it appears a handsome symmetrical pattern of smaller dark spots, which arise from deviating rays. These rays form when the x-ray passes through the invisibly narrow openings between the molecules or atoms from which the crystal is built. In these fine openings the x-rays are entangled; some of them are held back by interference with each other; other rays in turn intensify each other and thus leave distinct marks on the photographic plate. In the case of ordinary light, we observe a similar alternating extinction and intensification of light rays, if they have passed through fine openings. X-rays have a wave length only one ten-thousandth as long as that of ordinary light. To produce a like result they must pass through infinitesimal openings, so fine that they cannot be made artificially. However, nature itself provides us with such fine openings: they are found in the crystals. The appearance of the dots

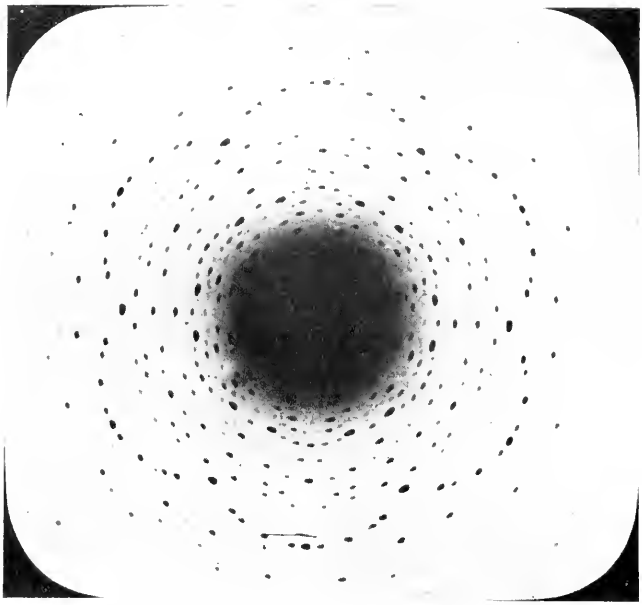


FIG. 24. APPEARANCE OF X-RAYS AFTER PASSING THROUGH A CRYSTAL

The large dark patch in the center is produced by the bulk of the ray which passes straight through the crystals. Surrounding this central ray there appears a large number of smaller dots distributed regularly around it. Their appearance is an unmistakable indication of crystallinity. (Courtesy, Dr. O. Glasser, Cleveland Clinic.)

on the plate indicates that the crystal contains an exceedingly fine grating. The regularity of the pattern formed by these dots points to the symmetry of the infinitesimally fine structure of which the crystal consists.

A similar symmetrical pattern indicates that crystallinity can be produced on the photographic plate by x-rays which have come in contact with organic material such as a cellulose fiber (Figure 25). Its crystalline nature is thus demonstrated.

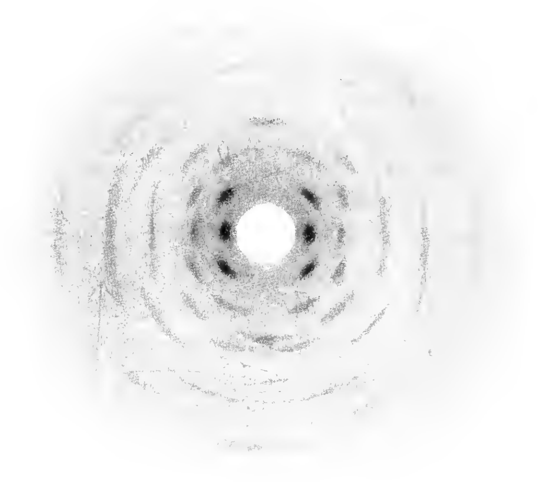


Fig. 25. X-Ray Reflected from a Cellulose Fiber

The appearance of the peculiar dots and dashes, produced through mutual interference of rays which have passed through very fine openings, indicates crystalline character, as demonstrated in the preceding illustration. Here we have a similar effect from x-rays acting upon a cellulose fiber. The black dots appearing here are, therefore, an indication of the crystallinity of this fiber which is a product of vital growth in a plant. (According to Meyer and Mark.)

It may be remarked that in this case the rays are not sent through the fiber (Fig. 25) but are reflected from its surface. The reflected rays alternately re-enforce or extinguish each other in much the same manner as the rays which have passed through a crystal. This reflection technique must be used in the case of a fiber or other organic material on account of the exceedingly small size of the crystalline components in it.

As we have seen, time is an important factor in the formation of a crystal; the more time we allow for growth, the greater the crystal. The same rule holds for the development of the crystalline components in living tissue, even though they never develop beyond diminutive dimensions. A cellulose or silk fiber (which is formed by living silk worms) grows by the slow addition of one diminutive particle after the other, sufficient time being allowed for each particle to adjust itself and take up its proper position in an orderly arrangement which contains diminutive crystalline components.

It is well known that artificial fibers can be produced, for instance those of artificial silk, or rayon, but the process of making them is much cruder. It simply consists in forcing, under pressure, the thick liquid material from which the artificial fiber is made into a hardening solution where the thread thus formed sets. Obviously no time is available in such a process for any particles to take up the proper position. As might be expected, an examination by means of x-rays according to the method described above shows no pattern of dots as in figure 25; no evidence of crystallinity is found in these rayon fibers.

SUMMARY

The first act of our drama has presented to us a large number of diversified forms which resemble some living ones, yet all are built up of growing crystals and consist of inorganic material. The reason for this similarity is that living tissues themselves are made up of diminutive crystalline elements. The building forces are therefore similar in the living and the non-living world; the growth of crystals and plants and animals presents some common features.

In demonstrating this fundamental relation, science has made the first step in our day towards the realization of an old dream of mankind: to determine how the complicated forms of living organisms are built up from invisibly small atoms, linked together according to a definite order, so that finally, from trillions and quadrillions of them, visible structures arise—plants or animals.

The second act which is about to begin presents the problem of life from an entirely different angle.

The Second Approach

LIFE, CARBON'S OUTSTANDING PROPERTY

The Second Approach

LIFE, CARBON'S OUTSTANDING PROPERTY

1. THE RISE OF MODERN CHEMISTRY, THE KEY TO THE MYSTERIES OF LIFE

As we glance over the various relationships and similarities between living growth and the growth of crystals it may appear that there is no distinction between life and lifeless matter at all. Such an assumption is hardly justified. One definite difference is that the material from which living things are built up is of a constantly shifting composition. By some means the surrounding lifeless matter, or the food taken in is transformed into the material of which the living plant or animal consists. As is well known, it is the science of chemistry which is concerned with the study of material changes. Thus chemistry holds the key to the secrets of life. The development of scientific chemistry which began a century ago has indeed enabled us to understand some of the most essential secrets of vital processes. Here are some of the outstanding events in this development.

The curtain rises on a scene in an old German schoolhouse at Darmstadt, in the year 1819. The school year nears its end. The schoolmaster has decided to spend the rest of the hour in asking his pupils about their prospective vocations. Most of them select such time-honored and dignified professions as law and medicine. The quiz ends when the poorest pupil is asked: "Now, Justus Liebig, what do you wish to be?" "A chemist, sir," is his prompt reply. The teacher bursts into loud laughter: "What did you say? A chemist? A worthy occupation for such a fool as you! Meddling with the mud, trying to make gold from it." As the class joins in the teacher's laughter, the period ends.

A short time later the faculty meets to decide on the final grades and promotion of the pupils. They decide to drop Justus Liebig, and his home-room teacher moves to expel him saying that he is a detriment to the school; the motion is passed.

Justus Liebig, however, far from being discouraged by this verdict stuck to his plan to become a chemist. He was disgusted with the antiquated classical studies, as practiced in European schools for centuries. He knew, far better than his teacher, that the thoughtless repetition of meaningless phrases led nowhere; he sought and found new ways to the truth: the experimentation in a chemical laboratory.

But in those days hardly any scientific chemical laboratories existed anywhere in Europe, except in Paris. There the immortal Lavoisier had imbued the old alchemy with a new spirit. He had shown that a burning flame consumed a part of the air, the oxygen, and that it was not merely a volatilization of something contained in the burning substance, as had been postulated by the old phlogiston theory. This knowledge was acquired by introducing scale and weights for the study of chemical problems. Facts known for centuries acquired a new importance after these investigations.

Lavoisier fell a victim of the French Revolution in 1794, but his work was carried on by a large group of pupils. A school of thought and experimentation developed in Paris through which France was undoubtedly dominant in chemistry for half a century, as expressed in a well-known old statement: "Chemistry is a French science founded by Monsieur Lavoisier."

Justus Liebig devoted himself to the study of chemistry at first in Bonn, Germany, but found little satisfaction in studying the obsolete chemical methods taught there. He saw that the right kind of chemical training was available only in Paris. He went there in 1822, only nineteen years of age, assisted by a recommendation from a leading German scientist, Alexander v. Humboldt, to the French Professor of Chemistry, the noted Gay-Lussac. He was admitted to work in Gay-Lussac's private laboratory and soon achieved distinction by a novel and startling discovery concerning the chemical character of fulmic acid, a substance used for initiating explosion of gun powder. His work was published in the papers of foreign scientists of the French Academy, soon also in German, and his fame thus established. Other discoveries followed.

In the meantime several German universities had concluded that a change was desirable in their antiquated methods of teaching chemistry. Seeing the great progress made in France, they desired to adopt the French methods. A man like Liebig, with training in Paris and a successful score of chemical discoveries in his favor, became a much sought candidate. So in 1824, Liebig, only twenty-one years of age, was appointed professor of chemistry at the small University of Giessen, a position he retained for twenty-eight years. Prior to his arrival, Giessen had been an insignificant university; during his activity it acquired world fame as a focus of scientific chemistry. When Liebig finally left in 1852 to accept a call to a bigger university (Munich), Giessen at once dropped back into insignificance.

The success of Liebig's teaching and research at Giessen surpassed every previous record, nor has anything like it been achieved since. He scored a long list of epoch-making chemical discoveries, surpassing his French masters. For instance, according to the French methods, weeks and months were required to analyze a single fat, but Liebig invented a new method by which the same analysis can be done in a few hours by two weighings. According to this method, fat is burned. Water and carbon dioxide are formed, the latter being a gas. Water is driven off as a vapor. Two special apparatuses serve to retain the water vapor and the carbon dioxide gas. The increase of weight of each of these serves to determine the amount of water

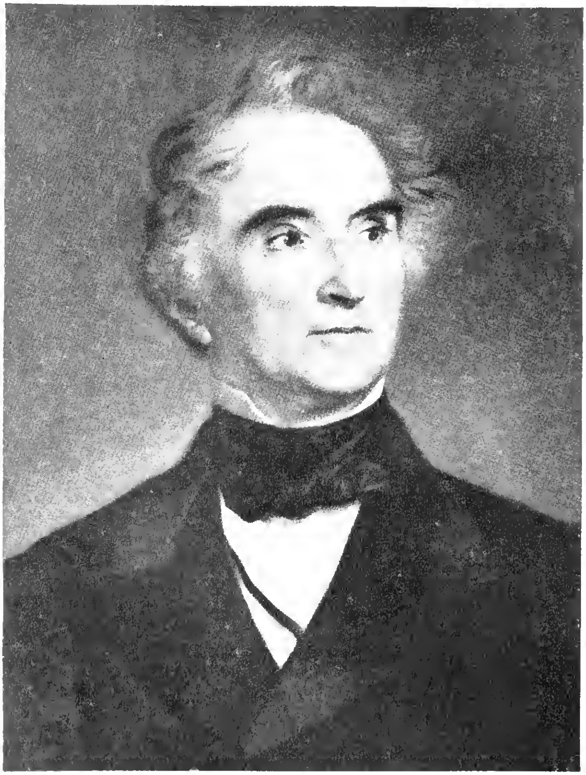


FIG. 26. JUSTUS VON LIEBIG (1803–73)

Professor of Chemistry at the University of Giessen, Germany, 1824–52; noted for his epoch-making chemical discoveries; he founded the science of organic chemistry and organized the first modern chemical research laboratory.

and of carbon dioxide formed. From the figures thus obtained the carbon and the hydrogen content of the fat can be calculated. By this and other new methods, Liebig became the founder of modern organic chemistry, the chemistry of the compounds of carbon.

Even more important than Liebig's researches and discoveries was his success as a teacher. He had an enchanting personality which transferred his enthusiam for chemistry to the large group of pupils who flocked to his laboratory from everywhere. He was endowed with the rare faculty of making his pupils' thoughts his own, of guiding them to independent thinking and research. After some years he was generally considered as the supreme authority on scientific chemistry. His pupils were called to professorships in universities in Germany and other European countries.

In order to appreciate fully Liebig's achievements, it should also be stated that the means at his command were extremely modest. Since prior to his appointment at Giessen, there were no chemical laboratories, he had to content himself with a former military guard-room which was transformed into a laboratory. That guard-room became famous for the enormous number of scientific discoveries emanating from it.

Liebig's activity marks the beginning of the great development of chemical science and its application to industry in Germany and Central Europe in general. Liebig himself had a keen practical sense; he was always prone to apply his results to problems of every day life. By an application of his findings to the problems of agriculture he became the founder of a new school of thought in agricultural chemistry. Liebig also stimulated the interest of the public at large in chemical science. Outstanding among his popular writings are his *Chemische Briefe*, published during the fifth and sixth decades of the past century, first printed in the *Frankfurter Zeitung*, still one of the greatest German daily newspapers.

No better introduction to the problems of scientific chemistry can be given than to quote some passages from these famous writings:

Chemistry comprises the actions of the most hidden natural forces which do not attract the daily attention like light, gravity, or other physical forces. Here are forces which do not act at a distance, their manifestations being perceptible only upon immediate contact of different materials. Thousands of years were necessary to create the knowledge of all the phenomena of which chemistry consisted at the time of Lavoisier. Countless observations had to be made before it became possible to explain the burning of a candle, long before the hidden roads were found which led to the knowledge that the rusting of iron in the air, the bleaching of dyes, the respiration of animals all depend on the same cause as the burning of the candle, namely, a using up of the oxygen of the air.

In order to acquire chemical knowledge such as is available today it was necessary that thousands of men, equipped with all the knowledge of their times and inspired with an untamable and almost furious passion for scientific research, should devote their lives, their property and all their will power to explore the earth untiringly in all directions. It was necessary to bring into contact with each other under the most diversified conditions all known substances and material, organic and inorganic. It was necessary to continue this work throughout fifteen centuries.

A powerful and irresistible inducement impelled men to carry on with unprecedented patience and perserverance this line of work which was not necessary for any imminent need of that time. It was the pursuit of human happiness. A miraculous disposition planted into the minds of the wisest and most experienced men the idea of the existence of a thing hidden in the ground, by the finding of which man acquires possession of all he craves: gold, good health, and a long life. Gold gives power; without good health nothing can be enjoyed and long life takes the place of immortality. These three sublime requisites for human happiness were believed to be combined in the Philosopher's Stone.

The notion of the Philosopher's Stone was, of course, a basic error; but all our views have developed from errors. What we regard as true today may be revealed as an error tomorrow. Any opinion which incites us to work, which stimulates ingenuity and maintains perserverance in work is an advantage for science; for it is work which leads to discoveries.

The most active imagination, the keenest intelligence is unable to devise an idea capable of acting more powerfully and lastingly upon the mind of man than the idea of the Philosopher's Stone. Without this idea chemistry would not exist in its present perfection. In order to call this science into existence and develop it to its present stage in 1500 to 2000 years it would be necessary to create a-new this very idea.

FIG. 27. ROGER-BACON, ALCHEMIST-MONK

Roger-Bacon, 1214–1292, a scholar and alchemist stands almost alone in the 13th century as a prophet of the Renaissance not to come until two centuries later. We see him in this picture working and meditating in a primitive ancient laboratory. The patient labor of such men paved the way for the magnificent development of modern chemistry.
(From an etching by Howard Pyle.)

In order to find out that the Philosopher's Stone did not exist everything accessible to investigation had to be observed and studied. But herein lies the influence of this idea bordering on magic: its power was broken only after science had developed to a certain degree of perfection. Through centuries, whenever doubts arose, whenever the workers wearied of their labors, at the right time a mysterious stranger appeared who convinced some outstanding trustworthy man that the "great magisterium," the Philosopher's Stone, did exist. . . .

Any layman who cares to glance over one single page out of the many thousand pages of a handbook of chemistry must be amazed by the mass of single facts which are recorded there. Almost every word in such a work expresses an experience or a phenomenon. All these experiences did not easily present themselves to the observer; they had to be searched for and investigated with painstaking labor. What would modern chemistry do without sulfuric acid which was discovered by the alchemists one thousand years ago? What would it do without hydrochloric acid, nitric acid, ammonia, or without alkali or the countless metallic compounds, without alcohol, ether, phosphorus, or prussian blue?

It is impossible to imagine the difficulties which the alchemists had to overcome in their work. They were the inventors of tools and processes for the making of their preparations. They were forced to make everything they needed with their own hands.

Among the alchemists there had always been a nucleus of true scientists. Alchemy was the science in which were contained all chemical and technical industries. The achievement of Glauber, Boettger, and Kunkel in this line may well be compared with the greatest discoveries of our century.

On this foundation the great modern science of chemistry has been built. Chemistry has since outgrown the narrow limits in which it was confined a century ago. It has created many industries concerned with the manufacture of thousands of articles in daily use, thus becoming a leading factor in the life of man. Rapidly it is pouring new powers and luxuries into the lap of civilization. A wide and ever growing literature, technical and popular, deals with these developments.

2. THE FUNDAMENTAL LAWS OF SCIENTIFIC CHEMISTRY

As the scene shifts to modern times the Manager of the Performance decides to insert a lesson in elementary chemistry, just a brief one so as not to bore his audience, many of whom may remember these well-known facts from their school days. Consider one of the simplest chemical changes which occurs if iron filings and powdered sulfur are mixed together. Such a mixture remains unchanged if it is not heated. Under a magnifying glass, one can see the yellow particles of sulfur lying next to the grey iron filings. With the help of a magnet, many of the iron filings can be removed from the mixture. Or the sulfur can be extracted by means of a solvent like carbon bisulfide, which will dissolve the sulfur, leaving the iron filings behind. However, if the mixture is heated in one place, it at once flares up to red heat that rapidly spreads over the whole mixture like an explosion. Once this has happened and the mass has cooled down again, it is no longer a simple mixture of iron and sulfur particles, but a chemical compound, iron sulfide. The individual particles of iron have disappeared, and the sulfur cannot be extracted by any solvent, because iron and sulfur have united to form a new substance.

Such a formation of new material through the interaction of two completely different substances is called a chemical reaction. In the case just discussed it is a union of the two elements iron and sulfur. Elements we call them, since they cannot be decomposed by simple means. A union of two elements invariably occurs in definite proportions by weight. In our case each gram of iron filings combines with $\frac{4}{7}$ of a gram of sulfur powder. This means that we have to mix seven parts of iron filings with four parts of sulfur powder if we wish to obtain iron sulfide in pure form free from uncombined sulfur or iron. If we add more sulfur some of it can be extracted after the reaction with a suitable solvent. If we add more iron, it will not combine.

Another example is the union of hydrogen and oxygen, both gases, uniting with each other with explosive violence if mixed and then touched with a spark. Or if hydrogen gas is allowed to stream into oxygen, or into air, it can be ignited and will burn with a very hot flame. In this flame a union of hydrogen and oxygen is formed which is water in the form of vapor. The union invariably occurs in the proportion of one part by weight of hydrogen to eight parts of oxygen.

From these and thousands of other chemical reactions the conclusion is reached that elements invariably combine in a hard and fast ratio. This experience is summed up, and at the same time explained, by the atomic theory which states:

1. Every element is made up of invisibly small particles which remain unbroken in any chemical reaction: the atoms. All of the atoms of a particular element have the same weight.
2. Chemical compounds are formed by the union of atoms of different elements in a simple ratio. When two atoms unite each furnishes its proportion to the total weight.

Although we have mentioned only two examples to illustrate the formation of chemically known compounds, it is easy to imagine how many thousands of other diversified substances have been formed by uniting the atoms of the ninety-four elements. And in all this enormous number of possible combinations the simple atomic relations hold good, with one outstanding exception to which we now turn: the compounds of carbon.

3. THE COMPOUNDS OF CARBON

Carbon compounds are of the greatest importance in life processes. When dealing with them we are, first of all, confronted with the striking observation that their number and variety is enormously greater than that of all other compounds. This observation has gradually come to light in the development of the science of chemistry during the past century: the total number of all the compounds which contain the element carbon is more than ten times that of the number of compounds of all the other elements. A survey of the enormously extended chemical literature of our times shows that about 300,000 carbon compounds have been made so far; but there are fewer than 20,000 that contain any of the other elements, carbon excluded. This relation is certainly not the result of a preference given to the study of the carbon compounds but the expression of an outstanding chemical property possessed by carbon itself. If we fully understand this property, its causes and characteristics, we have made a step forward in the solution of the great problem of life.

The carbon compounds are collectively designated as organic compounds. This term was originated more than a century ago, at which time all these compounds were obtainable only by extraction from the plant or animal body. It has been known long since that carbon compounds can be made artificially. Since that time their number has been increased to the enormous extent described above. It must also be emphasized that all the artificially made compounds of carbon are obtained by methods which have nothing in common with nature's own ways of making such substances.

Let us review the most important high lights of our knowledge concerning the carbon compounds. Most of them contain, other than carbon, only the chemical elements, oxygen, hydrogen, and nitrogen. Some also contain chlorine, bromine, iodine, sulfur, and phosphorus. Metals very rarely share in these compounds.

The most general experience is that the percentage composition of a carbon compound is of little or no importance as far as its properties are concerned, since numerous compounds have precisely the same content of carbon, hydrogen, oxygen and nitrogen, yet one of them may be liquid, the other solid; one may have a pungent odor, the other no odor at all; one may exhibit a brilliant color, the other no color. Many other variations may occur, although the actual amounts of carbon, hydrogen, oxygen, and nitrogen are the same in each compound. The conclusion is that the atoms in the molecules are laid together like bricks in a house, and that the arrangement of the atoms determines the properties of a carbon compound. The same bricks may be laid to turn out either a beautiful colonial mansion or a shabby tenement. Only by varying the structure would it be possible to obtain such an enormous variety of substances—300,000 different compounds, from only four constituents. The carbon atom has the rare property of holding large structures together; only the carbon atom can serve as a building stone in nature for these immensely diversified substances through which life in all its complexity is possible.

In order to appreciate fully this rare property, let us compare all the known compounds which exclusively contain oxygen and hydrogen, with those containing nothing but carbon and hydrogen. There are only two oxygen-hydrogen compounds known.

1. Water, in which hydrogen and oxygen atoms are linked like this:

$$H—O—H$$

2. Hydrogen peroxide in which the linkage is like this:

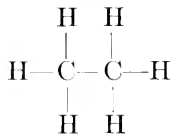
$$H—O—O—H$$

The last one is unstable since a linkage of two oxygen atoms is readily broken. Other compounds such as H—O—O—O—H, or chain systems with more oxygen atoms are impossible.

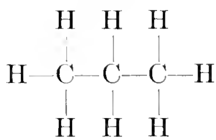
Compare this short list with that of all the known compounds of carbon and hydrogen. So many are known that only a few selected ones can be discussed. The simplest one is methane, one of the gases contained in natural gas; its molecule contains one carbon and four hydrogen atoms arranged as follows:

$$\begin{array}{ccc} & H & \\ & | & \\ H— & C & —H \\ & | & \\ & H & \end{array}$$

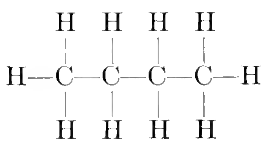
Natural gas contains numerous other gases, among them ethane. Its molecule is made up as follows:



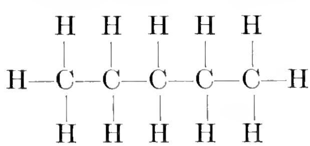
The structure of the molecule of this gas would seem to be analogous to that of hydrogen peroxide, but in contrast to this latter unstable compound, ethane, is perfectly stable. This demonstrates the great strength of carbon to carbon linkage. Even longer carbon chains are possible and quite stable ones. They are known to occur in propane:



in butane:



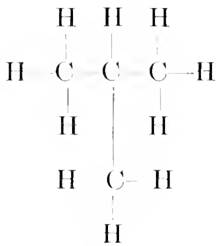
(both of which are gases) and in pentane:



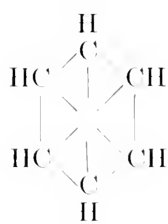
(which is a liquid).

Carbon-hydrogen compounds with still longer chains are also known (all of these are liquid or solid). Each of these structures corresponds to a definite substance. Substances consisting of molecules made up of varying chains up to 27 or more carbon atoms are found in nature, mixed together as petroleum. Gasoline, which is so important for the world on wheels, contains such carbon-chain compounds with only hydrogen attached from pentane (see above) up to decane, a ten-membered chain. Octane, the well known motor test-fuel is one of the series. Solid paraffine which also belongs in this series contains compounds with chains of *21* to *27* carbon atoms.

The diversity of carbon-hydrogen compounds becomes greater due to the existence of ramified chains such as that of iso-butane:



Moreover, carbon atoms can be linked together not only by the simple linkages, as they appear in the carbon-hydrogen compounds mentioned so far, but also by the so-called double links or triple links. Still another possibility is the arrangement of carbon atoms in rings. The most stable ring system is the six-membered ring as it appears in the hydro-carbon benzene, also known as benzol, which has the following arrangement of atoms in its molecule:



Countless other ring structures are known, as for example, one consisting of two six-membered rings, very closely linked together; this arrangement is peculiar to the molecule of naphthalene, a solid substance that forms fine glittering crystals. Substances containing three or more compounded rings are also known.

The six-membered rings are not the only ones known; there are also three, four, and five-membered rings. Moreover ring systems may have attached to them one or more open carbon chains of the kind first described. Any type and length of chain may be attached to any ring system.

Obviously the number of variations is enormous. It is impossible to enumerate here all known carbon-hydrogen compounds, since several thousands are known. If other elements such as oxygen or nitrogen enter these structures the number of known compounds increases to an amazing degree. The discovery of all these substances was accomplished within a century, since the first organic compound, urea, was made by Wöhler in 1828. Beilstein's famous handbook of organic chemistry which registers all known compounds has grown from two thin volumes to twenty-three thick ones, within the last century.

In his search for new carbon compounds the chemist is guided by structural formulas such as those depicted above. With confidence he draws pictures of the atom-built structures. In these structural formulas he picks out weak spots as well as strong spots. In this way he anticipates where a carbonic structure can be broken up into simpler groups, or how molecules can be fitted together.

Never has any theory been so fruitful of results. Back in his laboratory the chemist finds the fragments of which living nature is composed. He puts them together to produce artificially the complicated products of nature. Clever ways must be devised to make the parts unite and to unite them right. Nature's own ways of making these substances are shrouded with deep mystery. The chemist has to find his own ways which are widely different from the natural ones and quite artificial.

In many cases these methods of chemical synthesis consist in simply mixing and heating together the carbon compounds which are to combine, just as iron and sulfur can be heated together to make them combine. Yet in the chemistry of carbon compounds not every two substances will combine if heated together. Through his skill and extensive experience, the chemist knows how to select those that will react upon each other. In this way the study of these carbon compounds has been developed into a highly involved science whose methods are artificial, but whose products are in many instances identical with those produced by life.

4. HOW ARE CARBON COMPOUNDS MADE IN THE LIVING NATURE?

How can we hope to advance further? How can we understand the ways and means by which carbon compounds are made in the living plant or animal?

No one should say that this, the deepest hidden secret of nature, cannot be revealed. Only a century ago the generally accepted teaching was that no compound of plant or animal origin would ever be made by artificial means. How wrong has such a conception proved to be! Why should we now be forced to stop halfway, even if serious difficulties may retard further progress? Some of these difficulties have recently been overcome: we can understand Nature's gentle and efficient methods of making the most complicated carbon compounds: such substances as sugars, cellulose or proteins. Few of them can be made by the forcible laboratory methods in which our research chemists make use of strong acids, heat, and complicated apparatus, working with a quite disproportionate expense. Thus the ordinary cane sugar, selling at a few cents a pound, is literally worth its weight in gold when made artificially in the laboratory. Nature performs such a difficult task with the greatest of ease because it operates by means of traces, of *activating substances,* known as *enzymes* or *ferments,* which can start up the desired chemical changes, even at ordinary temperature. When these activating substances work on carbon compounds they can bring about the most diversified changes on account of the great multiplicity and the complicated make-up of the carbon compounds. The question is not so much whether any chemical changes will occur at all, but precisely in what manner the carbon atoms will be hooked together, or the bonds hooking them together broken and re-arranged. Any new arrangement means a complete change of the substance. In this manner some enzymes perform the most miraculous transformations.

One enzyme, for instance, the green chlorophyl contained in plant leaves, literally transforms the "clear thin air" into sugar, starch, and other solid material from which the plants build up their bodies. Plants take only a part of their body building material from the ground. Most of it comes from the carbon contained in the air as *carbon dioxide,* carbon combined with oxygen. Although only traces of this gaseous carbon compound are contained in the air (about four parts in ten thousand), this diminutive amount is taken from the air by the leaves, and transformed by mere contact with chlorophyl into the solid substances composing the plant body, substances like cellulose, of which wood, one of our best building materials, is largely made up.

The chemical processes involved in this transformation are little understood; not only carbon dioxide enters into them, but also water vapor. The light rays of the sun are indispensable for these processes as well as certain salts taken from the ground; but certainly the carbon dioxide gas of the air is the outstanding raw material since it supplies the indispensable carbon for the organic substances of the plant. This transformation of the highly dilute gaseous carbon dioxide is the most important process for all forms of life, for, the entire animal world feeds on plant material, either directly or indirectly. The bodies of all animals and men are thus built up from the various carbon compounds which are indirectly or directly derived from the plants; and the plants take them from the air.

However, not all of this material goes to build animals. A considerable portion burns up in their bodies; it burns in a slow protracted "fireless" combustion quite different from the burning in red hot flame. The term "burning of food in the body" is used merely because the end products are the same as those of a flame. Carbon is again combined with oxygen and transformed into the gaseous carbon dioxide which is exhaled by the lungs. It is then distributed in the air, blown around by the wind until it hits upon green leaves in the sunshine, where it is transformed again into plant substance, which is eaten and "burned." The cycle of carbon is thus completed.

How does the flameless and slow combustion of food in the animal body operate? Here, as in the case of the transformation of the gaseous carbon dioxide of the air into plant materials, the process can be set into operation only by the activating enzymes. However, the process is not so simple; the food is not all simply burned up directly as in a flame since, simultaneously with this combustion, there occurs the above-mentioned process of transformation of food material into the substance of which the body consists.

One feature stands out clearly if we review the endless chain of transformation of matter in life and its swing back and forth from plant to animal: it is the presence of those powerfully activating ferments or enzymes which keep the transformation going. We may consider it as a great progressive step that we know of the existence of these enzymes. Moreover, our research chemists have extracted some of them from plants or animals and prepared them in pure form. But, we are not in a position to make real enzymes artificially; that task is too difficult for present-day chemistry. Another difficulty arises from the fact that the chemical changes in tissues depend in many instances on the simultaneous presence of several enzymes. In such a case we may consider ourselves successful if we know one of these jointly-operating ferments. In this class belong the well known vitamins, small amounts of which are hidden in the grosser foods. After being taken up with the food they are rapidly used up in the body, and consequently must be refed continually to keep the body economy working. Failing this, the entire body mechanism is deranged and grave disease follows; it often occurred before vitamins were known, for instance the scurvy of sailors from the lack of fresh fruit and vegetables, containing vitamin C.

Another type of "partial" ferments are the hormones. They are made inside the body by the glands of internal secretion and transported by the blood to that part of the body where they have their greatest activating influence. A well known hormone is insulin, the administration of which is the chief treatment for diabetes.

5. THE PROBLEM OF SPONTANEOUS GENERATION OF LIFE

We hope that the knowledge of some of the essential features of life processes will help us to form at least some conception of the origin of life on our earth. Any explanation must, of necessity, be very uncertain in the present state of our knowledge, but we may hope that some clues may be found.

Whence did life on our earth come? How did it originate? Strenuous attempts have been made to answer this question. Up to the middle of the last century the idea of spontaneous generation was prevalent. If plants were suddenly found to grow upon a previously barren soil, it was believed that they were generated from the soil. Carelessly performed experiments added to the confusion. Nutrient media, like gelatin, were seen to cover themselves with rapidly developing germs: the fallacious conclusion was drawn that the gelatin was the source of the bacteria. The generally accepted opinion was, therefore, that life arises readily under a variety of conditions. But in 1860 and the following years, Louis Pasteur (1823–95), in a renowned series of experiments, definitely demonstrated the fallacy of these conclusions. He showed that the best nutrient medium fails to develop any growth, if it is carefully heated (so as to destroy all germs in it) and protected against contamination with new germs after the heating. From these experiments some have drawn the sweeping conclusion that life can never arise from inanimate matter. Thus general opinion swung to the opposite extreme.

It is known that at one time the earth was a red hot mass, incapable of supporting life in any form. Some time, some how, life must have sprung from the inanimate matter left after this fiery mass had cooled down. The desire to deny this unavoidable conclusion is one of the queerest outcomes of modern scientific specialization. In a series of experiments continued over a few years, a scientist sees that in *his* laboratory life is never generated spontaneously. From this experience he concludes that spontaneous generation can never occur. But a laboratory is not comparable with the earth in its entirety. What was impossible during a few years of experimentation might well have happened some time during the billions of years of the earth's age.

In view of the great uncertainty prevailing about this problem, it is worth while to recall the varying opinions about another fundamental question, the transformation of one chemical element into another. During the sixteenth, seventeenth, and eighteenth centuries, such a transformation, especially that of other metals into gold, was believed to be possible, since fraudulent reports about alleged results were in wide circulation. The delusive character of these reports and the methods described therein were at last unmasked with the development of scientific chemistry early in the nineteenth century. At the end of the nineteenth century, the belief in the impossibility of transforming the elements was more widely held than today's belief in the impossibility of the rise of life from non-living matter. For nearly a century, hundreds of able chemists had investigated indefatigably every possibility of transforming elements, and saw no success. So they believed themselves justified in saying that such a transformation would never be accomplished. Yet a very short time later, new methods of investigation were discovered by which it was definitely shown that elements can be transformed by radioactivity in some cases.

In the light of this experience, to say that life cannot arise from non-living matter seems to be hardly more than a creed based on doubtful authority. To prove it, we should exclude by experimentation all possibility of generating artificially anything remotely resembling a living organism. It seems that this has never been undertaken. On the contrary, some experiments point to the possibility of making structures which show at least a remote resemblance to living ones.

6. THE SMALLEST LIVING THING COMPARED WITH THE SMALLEST PARTICLES OF NON-LIVING MATTER

It is almost certain that the first forms of life to appear on the earth were the simplest ones and probably also the smallest ones possible. This idea is in general agreement not only with the conceptions of the theory of evolution but also with the evidence brought forth by geological research, since the oldest fossil remains in the crust of the earth are the simplest and smallest ones.

The question therefore is to be answered: what are the smallest living things? To find the answer we embark on a journey of exploration into the domain of the most diminutive living creatures. Passing in review small worms and primitive one-celled animals whose body diameter averages $\frac{1}{4}$ mm. or $\frac{1}{100}$ of an inch, we arrive at the much smaller bacteria some of which measure only $\frac{1}{2000}$ of a millimeter. But they are real giants as compared with the much smaller filtrable viruses some of which measure only $\frac{1}{20,000}$ of a millimeter. Objects of such diminutive size cannot be seen in any microscope, since $\frac{1}{5000}$ millimeter is about the lowest limit of any directly visible object, no matter how efficient a microscope we use. On account of their diminutive size they will pass through the finest openings in filters. Their approximate size can be estimated from the size of the holes through which they are able to pass.

The reader will ask, how we know of their existence. The answer is that these filterable viruses are disease-producing agents; a few of them, when inoculated into an animal, will multiply at an appalling rate. They can be readily transferred from animal to animal, or from man to man. The most commonly known human diseases caused by them are influenza, small pox, rabies, yellow fever, and trachoma. Each disease is produced, of course, by a different virus. Their entire behavior resembles closely that of the visible germs, the bacteria, which cause other infectious diseases like cholera, typhoid fever, diptheria, and pneumonia. If the bacteria are believed to be alive, the viruses should also be so considered, in spite of their invisibility.

The production of disease is the only sign we have of the presence of a virus. It can be demonstrated by placing material containing viruses on a filter and by showing that the liquid passing the filter remains as an agent to propagate the disease. This finding is in contrast to the observation made with filtrates from liquids containing bacteria. Such a filtrate is not a carrier of a disease, since the bacteria are too large to pass through the filter.

In spite of this evidence some scientists still hesitate to call a filterable virus alive, chiefly on account of its diminutive size. A vague opinion prevails in some quarters that a living thing proper must have "organs" of some sort, which means some visible feature about it: for example, a skin. Not so long ago the requirements for what was really deemed alive were set considerably higher than now. Thus the famous chemist, J. Liebig, held that yeast is not a living thing. He fought a long and bitter controversy on this issue with his renowned contemporary Louis Pasteur, who had a more enlightened insight. The basis for Liebig's erroneous assumption was that the too simple make-up of yeast cells did not conform with his rather fastidious idea of what a living organism ought to be. But his error in this instance has been demonstrated. At present, scientists have become less dogmatic in that respect. So it is perhaps permissible to state that those who refuse to recognize viruses as living may later modify their opinion.

The most important feature, however, about these most minute living things is that their size approaches the size of the smallest known particles of matter in general. It has long been known that no material—alive or not—can be indefinitely divided and subdivided. A limit is reached at a diameter of about $\frac{1}{1,000,000}$ of a millimeter. Thus, no oil can be spread out on a large water surface thinner than this; the thinnest gold leaves are of about the same thickness. Numerous other observations show that no material can be stretched, dissipated, or broken up by any mechanical force into particles below that size. These tiny indivisible particles are the molecules. That they actually exist is shown by the fact that their size is found to be the same if determined by independent methods.

The fractions given above with all their zeros do not readily confer a vivid conception of the size of an indivisible particle. The following comparison may be helpful: there are more molecules in a single drop of water than there are drops of water in the Atlantic Ocean. Another comparison: if each molecule in a glass of water became a grain of sand, the sand produced would cover the entire area of the United States to a depth of 100 feet.

For different materials the size of the smallest particles is, of course, not identical. Those of carbon compounds are larger than those of water, in keeping with the larger size of their atomic structure (see pages 61 and 62).

7. THE VIRUS IN CHEMICALLY PURE FORM AND ITS CRYSTALLIZATION

We have learned from the foregoing descriptions that size alone is no criterion of living or non-living matter. One might draw the dividing line between living and non-living at any chosen level, for instance by pronouncing alive only creatures of the size of a horse or larger. In that event we human beings would not be alive. Unexpected findings should never discourage our patient search for truth. A faithful student of nature will learn more from startling discoveries than from those findings which were partly anticipated. And indeed we arrive at new important conclusions if we follow the fundamental fact that a shapeless mass may consist of a multitude of invisibly small living things.

We may raise the following question: what will occur if any one of these virus materials is freed from all other material mixed with it? That is to say, if the virus is "purified chemically," as it is usually expressed? Most "pure" substances tend to crystallize, if they are solid. Two everyday examples illustrating this are ordinary white cane sugar and table salt, both of which are in the form of small crystals. If we dissolve salt or sugar in a little water, filter and evaporate a part of the water, the salt or sugar will crystallize again and again in "purer" form, since traces of other substances which may have been in it in small amounts will stay in the solution. The cheaper grades of salt or of sugar contain small amounts of other substances; repeated crystallization is the widely used method to remove these other materials.

If virus is a pure material in the same sense as sugar or table salt, should it not be capable of crystallization, even though it is alive? This is a thought of momentous importance: a living entity capable of crystallization! We have previously discussed the occurrence in plants and animals of crystalline elements which can be demonstrated by x-rays. But now we are confronting a different problem; we are not concerned with the question whether each individual virus may or may not be an invisibly small crystal. The question before us is whether a multitude of viruses, if present in bulk, can be induced to form crystals, like the sugar which settles from an evaporating sugar solution.

Certain technical difficulties must be overcome in order to solve this problem by experimentation. The total amount of virus which grows in animal or man when a disease (like small-pox) develops, is quite small as compared with the total weight of the body. Even at the height of a fatal disease, the virus has not so multiplied that the body substance is consumed by it. Crystallization is impossible under such circumstances. Even sugar crystals will not form if the sugar is mixed with a greater amount of other material, as is done in sweetened food like cake or ice cream.

Before crystallization is possible the virus material must be separated from the body materials with which it is mixed. Such a separation is in most cases difficult, but it is relatively easy in certain virus diseases of plants, of which the tobacco mosaic is the best known example. In this disease, which attacks by preference the leaves of tobacco plants, the virus actually multiplies until it has consumed the greater part of the leaf, transforming the substance of the leaf largely into the virus material. From such diseased leaves the tobacco mosaic virus can be obtained in nearly pure form, ready for crystallization.

Even so, the crystallization of this virus is no easy matter, since crystals are not readily formed by any material of this type (protein). The workers of The Rockefeller Institute for Medical Research at Princeton, New Jersey, experimented for many years on the crystallization of similar material. In 1935 one of them, W. M. Stanley, equipped with all the special experience gathered in this line attacked the great problem of crystallizing a virus, and finally succeeded. He isolated from mosaic-diseased plants a crystalline substance possessing all the properties of the virus. The disease producing power and the composition of the crystals obtained from different batches of leaves were identical. Nor did these properties change if the virus material was dissolved and allowed to crystallize out; the substance thus obtained after repeated crystallization was exceedingly active; a minute amount, one hundred-millionth part of a grain, dissolved in a few drops of water and then injected into healthy leaves, sufficed to start a fresh outbreak of the disease which will rapidly consume the entire leaf. Even if the crystallization of the virus substance was repeated ten times, its activity in producing the disease was not diminished.

Definite evidence was thus collected by Stanley to show that the crystals obtained were nothing but virus. If the originally collected virus had contained anything else of importance for its propagation, this would have disappeared in the repeated crystallization, or at least it would have been reduced to a negligible quantity; repeated crystallization would have changed the properties of the material. Since this was not the case, the only conclusion left is that the virus is a chemically pure substance or, to put it in more familiar language, that it consists of only one kind of matter.

Stanley prepared his crystallized virus at first from infected leaves of Turkish tobacco. Later he repeated his experiments starting from "mosaic" infected tomato plants. "Mosaic diseased spinach and phlox plants were next studied and, although the yields were still less than for the tomato plants, it was found possible to isolate the virus protein from these plants," said Stanley in an article published in 1937. In the same article Stanley describes the appearance of the crystals obtained from tobacco mosaic: "The suspension of the crystals has a very characteristic appearance. When stirred it has a satin-like sheen. The crystals are very small and may best be observed by means of a microscope at a magnification of about 400 times. The crystalline protein may be removed by centrifugation or by means of filtration on filter paper. The crystallized proteins obtained in this way had the same properties in every regard, hence were obviously identical." (Figs. 28 and 29.)

All these findings suggest that other types of virus might prove to be similar in nature. In fact, by similar methods, other members of The Rockefeller Institute, Drs. C. Ten Broeck and Th. J. G. Wykoff, have prepared in crystallized form a certain virus causing warty growths in wild rabbits and still another virus which causes an inflammation of the brain, usually in horses. These viruses causing animal disease have been found to be somewhat larger than the viruses of plant diseases, yet are still quite invisible. "All of the facts available at present may be explained reasonably, simply and without effort, on the assumption that the different virus proteins are in fact the different viruses," Stanley concludes.

All these viruses can be killed or rather inactivated by the same poisons that inactivate bacteria. Like other living things, they have a remarkable propensity for changing into different types.

Fig. 28. Crystalline Protein from Tobacco Mosaic

Crystals indicate chemical purity. The chemically pure substance of these crystals is at the same time a living entity. Magnified 400 times. (From W. M. Stanley, *Isolation and Properties of Virus Proteins in Ergebnisse der Physiologie, biologischen Chemie, und experimentellen Pharmakologie*, volume 39.)

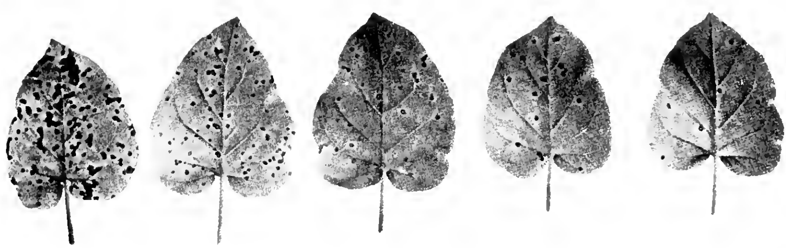


Fig. 29. Diseased Spots on Leaves of a Species of Tobacco Caused by Solutions of Different Strengths of the Virus Protein

(From W. M. Stanley as cited before)

8. LIFE AS THE PROPERTY OF A HIGHLY SPECIALIZED KIND OF MATTER

Life is thus a property of certain types of matter. Which materials, we may ask, can be considered alive? Evidently only those which have that distinctive life quality, the ability to grow and to propagate itself in an environment different from itself. This is indeed a rare property. Such materials as sugar or salt will, in general, not show it. Nor can any crystals be classified as living if they grow only in their own saturated solution. The material must have the power of transforming nutrient material, as the green chlorophyl of plants transforms the gaseous dilute carbon of the air into plant material. But even this is not sufficient; chlorophyl is a part of the living plant, yet it is not a living thing itself, since it can only transform the gaseous carbon dioxide into plant material, not reproduce itself.

Evidently the virus material does have the power of transforming its food material. It is active material, a so-called enzyme but in this case the product of the transformation is the virus material itself. Thus it propagates itself as long as there is available food material like the tobacco leaves on which the tobacco mosaic "feeds." And yet the virus is a chemically pure substance in the same sense as pure cane sugar. How is this possible?

Chemically pure substances can only reproduce by enzyme action. The virus does just this. By its enzymatic action it initiates in its surroundings a chemical reaction which results in the formation of identical viruses, which are also enzymes of the same type. There is positively no reason to deny that a single molecule has the essential properties of a living organism, if it is an enzyme which has the power of producing in a naturally occurring environment chemical reactions that lead to its own multiplication. This means that such an enzyme propagates itself in the same manner as a living organism. In this sense life is a property of matter, but only of a highly specialized kind of matter.

Is it possible to make this kind of matter artificially? Organic chemistry in its present stage of development has not yet advanced that far. It has not even developed to the point of making a real enzyme artificially, to say nothing of making a self-reproducing enzyme like a virus. But we may reasonably hope that chemical science will reach that goal in a remote future. In putting together carbon structures, organic chemistry has succeeded in joining, in a few instances, several hundred carbon atoms. The virus material, however, consists of indivisible molecules, having several hundred thousand carbon atoms tied together. Moreover, the problem is not merely to put together in some way or other as many carbon atoms as possible. A definite set-up must be made. It is impossible yet to say just how this should be done in order to produce a substance which has the desired property of self-regeneration.

The belief that this goal will be reached sometime in the remote future is founded upon the steady development of our knowledge of organic chemistry, upon the continuous increase of the number of known carbon compounds, and particularly upon the development of new methods for making still more of them. But no scientific genius can suddenly produce by magic this final result. It can be done only by painstaking work, continued through centuries. Nor should we forget that the real driving force behind the great development of organic chemistry is primarily the expectation of finding more useful materials: substances which are better dyes, flavors, fabrics, moulding and building material, and above all better drugs. Indeed they are needed.

If the synthesis of life should finally be accomplished, it will probably be discovered that life, which seems so immensely involved and incomprehensible in all its complexity, is nothing more than one of the innumerable properties of the compounds of carbon. Actions and forces of an entirely unknown nature must be discovered before this great truth becomes an acknowledged fact. At present it appears as an assumption but is corroborated by a great deal of evidence; for only the carbon compounds are known to have that diversified character, that faculty of rapid change from one kind of substance to another that makes life possible. Hence, it seems justifiable to suppose that those enzymes which set up chemical changes leading to a production of the enzyme itself, can be nothing other than carbon compounds.

9. HISTORICAL REMARKS ON THE PROBLEM OF ARTIFICIAL GENERATION OF LIFE

The artificial creation of life has always aroused the imagination of thinking men, but is usually regarded as too fantastic for serious consideration. At the age of the Renaissance about 500 years ago, when new and startling discoveries were made, a belief arose that the creation of life might be a comparatively easy matter. Had it not been possible to transform various kinds of matter into something entirely different? Did not sulfuric acid or nitric acid transform a brilliant shiny metal into a salt-like material? Did not heat and carbon produce brilliant shiny metals from the dull ores? Had not "liquid silver" (mercury) been obtained from certain ores in a similar fashion?

The explanations offered 500 years ago for such transformations were confused and contradictory. Thus the pure metals were regarded as compounds of the naturally occurring ores with the mystical "phlogiston," which actually does not exist. In reality the metals are elements. When mercury was obtained from ores, the explanation was that some sort of liquefying agent had been infused into the ore. Why then should it not be possible, it was argued, to imbue lifeless matter with the "breath of life?"

Such arguments, after lengthy discussion, finally took on the character of fairy tales. An example is the story of the magic Dr. Faustus, a fabulous alchemist, who was said to have obtained a small human being, the "homunculus," in a retort in his laboratory. The stigma of the ridiculous was thus attached to the problem, and it disappeared from the domain of science. The Faustus tale reflects the lack of knowledge which prevailed about five centuries ago or earlier. Little was known at that time about the most elementary chemical processes, nothing about the rôle which carbon compounds play in life processes. Nothing was known of enzymes or anything like them. Not one organic substance had yet been made artificially. Nevertheless, the alchemists talked about the artificial production in the laboratory—of man! Nothing less than a complete man, springing from the retort, appeared as an object deserving the effort of research. The idea that man might have evolved from animals was entirely foreign to the scientific thought of 500 years ago. If an alchemist had announced the possibility of making an animal in his retort, he would have been considered as lacking capability, since the prevailing assumption was that small animals were generated directly from the soil every year in the spring time. When we realize the progress made in 500 years, it is not unreasonable to look for a great advance in future centuries.

Our most important progress, of course, is that we know now how little we know, how far we have to go before we arrive at the creation of artificial life. We are not dreaming about the homunculus. We assume that if any living thing is ever made in the laboratory, it will be something tiny, like the self-reproducing enzymes. But it will certainly take a long time before this goal is reached.

We should also realize that the self-regenerating enzymes, known so far, the filterable viruses, can develop only in the tissue of a living plant or animal. Self-regenerating enzymes propagating on non-living matter are as yet unknown, but we may assume that they will be discovered in the future.

10. THE ORIGIN OF LIFE ON THE EARTH

The modes and circumstances through which the first forms of life arose on the earth can be fully understood only when we have learned to make one of those self-producing enzymes by artificial means. We can guess, however, that such an enzyme might have arisen early in the history of the earth, possibly through the help of electric discharges. Experiments have shown that by the passage of electric discharges through gases which contain carbon, a wide variety of solid carbon compounds is formed. Almost any compound of organic chemistry may be formed in this way. The electric spark somehow shakes up the carbon atoms and puts them together again. It is likely, therefore, that spark discharges in nature may have led to the production of a countless multitude of different organic substances.

The earth's surface was once much hotter than it is today. Lightnings were probably of frequent occurrence. More carbon containing gases were contained in the atmosphere than today; the hotter climate favored chemical changes. Thus a considerable amount of organic material was formed. As the earth gradually cooled, water vapor condensed and the first oceans were formed. Much of the organic material formed by lightnings was soluble in water and was gradually washed into the oceans. More and more of it piled up as more was formed. Thus we are led to believe that at one time, a billion or more years ago, the ocean contained a considerable quantity of diversified organic substances though nothing resembling life was present.

Among the countless substances formed by the lightnings, enzymes appeared and still later self-regenerating enzymes. Some of these were also washed into the ocean where inert organic material was already piled up. Eventually enzymatic chemical reactions started in the sea.

Were these reactions the beginning of life? This question is difficult to answer. At that early stage, certainly no life in the usual sense of the word was present, yet conditions prevailed which prepared for the appearance of life. This period is named by geologists the Azoic or lifeless age. At that time were formed the oldest known Sedimentary Rocks, developed from sediments settled at the bottom of the earliest oceans. These rocks come to the surface here and there, exposed after vast ages of concealment, because the rocks that covered them have worn off later.

These ancient rocks contain no remains of life at all, not a trace of it. Yet we find in them graphite, a kind of crystallized carbon, (the material used for manufacturing pencils). This deposit of solid carbon seems to justify our assumption that the first lifeless ocean contained carbon compounds (organic matter). Much of this organic material decomposed and left carbon behind it, just as carbon (coal) has formed from the organic matter of plants which appeared at very much later periods.

We are thus led to the ocean as the cradle of life's beginnings. Others have propounded a different theory. Cromeis and Krumbeis (in *Down to Earth*, Chicago, 1936) express the view that life originated in the soil, since they suppose that it is somehow related to processes of evaporation or erosion. They consider that a concentration of certain materials was necessary for the processes preceding life generation. The sea water offers "too great an opportunity of diffusion" which Cromeis and Krumbein regard as unfavorable. The writers, however, admit that when any life-line is traced into its simplest ancestral types, the trail invariably leads to the ocean. Thus they confirm our hypothesis.

11. THE SLOW DEVELOPMENT OF LIFE IN ITS EARLIEST BEGINNINGS; ITS FURTHER COURSE

We may assume that that early stage when enzymes were acting upon lifeless organic matter extended over an enormous period of time. For we know that enzymes can function only in a limited range of temperature and each enzyme can attack only a few substances. Millions of years must have passed before some of the enzymes formed by lightnings encountered a substance which they could attack. Probably it was a still longer time before self-regenerating enzymes met the proper substances in an environment suitable for interaction. Moreover, many enzymes are fragile substances and disappear unless they are regenerated. There was certainly no streamlined efficiency in the earliest functioning of enzymes, preparatory to the generation of life.

We may assume that enzymatic chemical reactions tentatively appeared here and there and again disappeared. Finally self-regenerating enzymes came to stay and they grew and developed probably in the lap of the ocean where the temperature, the supply of reactive material, and other conditions were most stable. Gradually conditions and organisms appeared which resembled more and more closely what we nowadays call life. Millions of years of preparation were thus necessary, as it seems, before real life in its most primitive form appeared on the earth.

Since we know that the evolution of life has taken millions of years, it is hardly reasonable to suppose that its creation occurred in a flash. Yet our assumption of a very gradual development of the preparatory processes is a thought which never seems to have occurred to men who meditate about such problems. It is, of course, not surprising that all the ancient histories of creation describe the origin of life as an act of short duration. But even some of the modern scientific theories take it for granted that life suddenly appeared on the earth, although they assume that at first only primitive cells were there. Such an assumption is made by the widely accepted theory of panspermia according to which life was propagated from germ cells scattered through the universe. This theory is that life and evolution depend on the dropping of such germ cells upon a planet like the earth at a time when conditions are favorable for germination. The germ cells are assumed to be carried from planet to planet and from solar system to solar system by so-called radiation pressure, which is a propelling force exerted by the rays of the sun or of other celestial bodies. In a laboratory experiment this pressure can be demonstrated by the propelling of dust particles. An influential propounder of this hypothesis was the late Svante Arrhenius of Sweden (1859–1927), a noted physicist and Nobel prize winner. (See his book, *Worlds in the Making.*) He assumed that life could never have arisen anew. But as we have seen such an assumption is hardly warranted. Arrhenius states his opinion in that book that "life is eternal like time and space." This is hard to comprehend, since life must have arisen somewhere if the earth was incapable of producing it.

The panspermic theory is nevertheless widely accepted. Emphasis is laid on the often-demonstrated fact that cells of various types withstand the lowest known temperature, hence can stay alive in the extremely cold interstellar space of the universe. Quite recently Dr. A. Goetz of the California Institute of Technology has again demonstrated this extraordinary resistance of cells against cold, particularly yeast cells. His finding was announced in numerous daily papers all over the United States, on April 12, 1938, as evidence for the assumption that life might have reached the earth from another planet. We may just as well assume that life arose first on the earth and then was transferred to other planets. But if it is true that life first arose outside the earth, the question of its origin presents the same problem; the scene is merely shifted.

It also seems difficult to comprehend why cells of any type should be considered the beginning of life Cells are structures of much greater size than any self-regenerating enzyme or filterable virus, and it seems more likely that the first cells came after the self-regenerating enzymes.

It is quite possible to form an idea about the development of cells from self-regenerating enzymes. As modern research chemists have found, the behavior of enzymes and particularly the crystallizable viruses is readily modified by variation of the conditions; for instance, by subjecting them to moderate heat. (Temperature high enough to boil water destroys all enzymes.) One may assume that certain types of the earliest self-regenerating enzymes were modified in such a manner that the product of their action was not only the enzyme itself but also some other non-enzymatic or inactive material. This material may have surrounded the enzyme, thereby protecting it from various deleterious influences.

A substance like starch may have been one of these protecting materials. The formation of a primitive cell from starch thus formed is not surprising since we have seen that ordinary starch forms crystals resembling cells (Figure 19a). In the subsequent development, more and more of this material may have been formed, thus leading to the development of more and more involved organisms.

In the center of living cells proper, numerous molecules of enzymes are found, mostly in the so-called nucleus, as "genes." Each cell contains millions of enzyme molecules, all imbedded in the protecting inactive material around them. Many million cells, in turn, are needed to make up an animal or plant. On account of the incompleteness of our knowledge, we can only visualize the development of the present existing plants or animals in a hazy outline.

It should be clear, however, that the mere putting together of millions of molecules of self-regenerating enzymes does not make a cell. We might just as well say that a pile of apples makes an apple tree. Nor would the putting together of millions of cells ever create an animal. Every living thing has developed as a distinct entity; it needs all its own diversified material for maintenance, not only the enzymes, but countless other materials which protect or hold together or facilitate communication in the entire organism. The understanding of the mode of action of all these other components is even more difficult than a thorough understanding of the action of enzymes.

Many details of our explanations of the origin of life remain obscure, yet we feel that we have made a step forward in our understanding of life. Its amazing variability and diversity now appears less enigmatic. We realize that there cannot be one single self-regenerating enzyme but hundreds or perhaps thousands of them, each giving rise to a peculiar type of chemical change. Some of these are capable of initiating an evolution of living plants and others that of animals. In this manner we are led to understand the great diversity of the living world.

There is also no reason to assume that the formation of the self-regenerating enzyme is limited to the earliest periods of the earth. Some of them may have formed only a relatively short time ago—a few thousand years, or even a few hundred. Such an assumption would explain the simultaneous existence of highly developed and primitive animals (or plants) as we actually see them on our earth. On this suggestive theory, man may derive from the earliest self-regenerating enzyme, perhaps a billion years ago; whereas primitive organisms like bacteria arise from comparatively recent formations. Of course the possibility also remains that some primitive forms of life have persisted over a long period of time without undergoing any evolutionary development.

12. LIFE ON OTHER PLANETS

Great interest has also centered about the question whether plants, animals, and particularly men, can and do exist on other planets in the universe. Astronomy, after extensive studies, has calculated that forty billion suns are contained in the Milky Way. Some of them may have planets as our sun has. Planets may be, of course, in any condition, either very hot or very cold, or consisting mostly of vapors; and they may be of almost any size. It is possible that some may closely resemble the earth. Men would be able to live on such planets, if it were possible to transfer them there.

Does this mean that men are actually living there? It is idle to guess. But from what knowledge we have gained thus far, it is reasonable to conclude that the forces of nature are not tied down to any definite scheme. On the earth, on a limited space, under definite conditions, life has branched out very widely; it has reached numerous diversified peaks so that we are impressed with the truly boundless wealth of forms of which nature is capable. Under the conditions on this earth, the warm-blooded vertebrates won the race. Man became dominant; his hands became free to use tools; his brain developed to enable him to invent and to use tools.

But the make-up of plants and animals is determined not only by their present achievements and accomplishments, but also by the history of their kind. If past conditions had been different, if, for instance, a different type of plant had existed, our teeth would be different. If, in the development of the earth, the ocean had broken over certain ridges, our ancestors would have been forced to adapt themselves to different conditions. This would have changed the trend of evolution. Countless causes, interconnected in an obscure manner, have contributed to the evolution of man in his present form.

It seems doubtful that, on any other planet circling any of those forty billion suns, the train of events of evolution has been duplicated in exactly the same manner as on the earth. Consequently the lines of development of plants and animals must have taken different courses. If nature has evolved some other living being, with a developed brain, this living being need not necessarily resemble man.

SUMMARY

The great problems here discussed have at all times been the cynosure of human interest. Yet no solution has been found for them. During the ages many a man's brain has worn itself out in useless pondering over mankind's most bewildering question, "what is life and where did it come from?"

Now it seems that we may at least look forward to a future possibility of solving the problem. In dim outline, a new vision appears, which science reveals to those restless minds who are the true pioneers of progress. Science has now penetrated much farther into the realm of the lowest living things, representative types of which are the filterable viruses. These invisibly small creatures are about the size of indivisible particles of matter, the molecules. Yet they can act upon other organic matter to attack and change it, the end-product of the change being the enzymes themselves. Thus a strictly chemical process leads to the multiplication of something which exhibits some properties of living matter, yet appears also as a substance. We believe that, through matter of this type, life originated on this earth. Cells, even the most primitive ones, developed from this material at a much later period.

A Survey of Oparin's book: The Origin of Life

After the manuscript of this book had gone to press, the epoch-making work of A. I. Oparin, "The Origin of Life," appeared in its English translation by S. Morgulis of Omaha, Nebraska, published by the Macmillan Company of New York in May 1938. The publishers of this book have kindly agreed with the proposition of this writer to insert here a review of Oparin's work which so closely touches upon the subject here discussed.

There is a close resemblance of Oparin's views on the origin of life, with those here evolved. His idea like ours is that life did not arise like a spark igniting a flame, but that a period of time of unimaginable length must have elapsed before anything remotely resembling a real living organism made its first appearance on the sterile surface of this globe. Oparin elaborates this idea very clearly. In an admirable historical exposé, which goes as far back as the ancient and medieval philosophers, he compares it with the hitherto prevailing views on the origin of life. He discusses extensively the views of the naturalists of the 17th, 18th and 19th centuries prior to Pasteur, most of whom believed in the spontaneous origin of life in its well developed forms. Such ridiculous tales as the origin of mice or grasshoppers from the ground or of birds from the fruits of trees are reported in Oparin's book in detail.

As equally irrational, Oparin rejects the futile attempts of the post-Pasteurian period to prove that life should be "eternal"; in other words, that it should have been transferred from planet to planet in the sense of the panspermic theory of S. Arrhenius, which we have discussed. It may be mentioned that Arrhenius was not the originator of this idea since Lord Kelvin postulated the "eternity" of life as early as 1871. He, like others after him, (Preyer, Richter, for example) assumed the existence of an "eternal" principle which was handed on from organism to organism—if necessary through the empty space of the universe from one solar system to another. Without this principle, life was assumed to be impossible.

As Oparin very appropriately points out this idea is strictly vitalistic in its character. It attempts to erect an impassable barrier between the living and the non-living world, and in this respect does not differ from the pre-Pasteurian views of life's creation by means of some supernatural force.

As we discussed before, Arrhenius had attempted to find evidence for the physical possibility of the scattering of life germs throughout the universe. He had also tried to minimize the numerous dangers to which these wayfaring germs must of necessity be subjected in the interstellar space with temperatures near the absolute zero ($-273°C.$) and with its ultraviolet radiation of unchecked violence. As Oparin emphasizes this radiation should kill off any viable germ almost instantly since much feebler radiations generated by artificial means are used as powerful disinfectants. Arrhenius had found excuses for all these objections; thus, for example, he maintained that in the alleged absence of water vapor in the interstellar space, the ultraviolet rays would fail to act. However, recent investigations have demonstrated the existence of a shorter and more powerful interstellar radiation. These rays have wave lengths shorter even than the X-rays. They bring about not only chemical changes but also attack and decompose the atoms which remain unchanged in ordinary chemical reactions. This radiation violently attacks all particles of matter as, for example, meteorites which are not surrounded by a protecting atmosphere like our earth. Profound changes take place: by the breaking up of atoms, new elements are formed: iron is changed to aluminum or to magnesium and helium, etc. It is quite evident that any organic substance would be rapidly decomposed and the wayfaring germs, if any should be there, would be rapidly killed off. These irrefutable facts are the doom of the theory of panspermia.

In contrast to all these contradictory assumptions, Oparin builds up a rational new theory. He postulates that a long process of evolution of lifeless organic matter preceded the development of the first simplest living organism. He takes the standpoint that all living things are merely a very late result in the general evolution of matter, particularly of the evolution of carbon and the carbon compounds. Thus, Oparin draws the same conclusions which this writer tentatively developed in 1933, namely, that "life is just one of the countless properties of the compounds of carbon" (Compare R. Beutner, *Physical Chemistry of Living Tissues and Life Processes.*)

Plenty of lifeless organic matter, similar to that of which living things are nowadays formed, must have been present at the surface of the earth prior to the appearance of life itself, as Oparin points out. Where did this lifeless organic matter come from? Oparin answers this question by determining the fate of carbon, the life-producing element. What changes did carbon undergo from the earliest time of the existence of our planet?

Our earth was formed from the sun as a consequence of a cosmic catastrophe of a type which is of extremely rare occurrence. Another sun of equal or larger size must have passed by our sun close enough to exert gravitational influence. A huge tidal wave of the liquid white-hot matter of the sun was drawn out from it. This tidal wave was pulled further and further away from the sun as that celestial body approached our sun closer and closer. But that second sun later passed by and continued its travel into space in another direction. The tidal wave which had become separated from the sun formed a long red-hot nebula which, like a huge band, hung out into space. This must have occurred from two to three billion years ago. From this mass the planets circling our sun were formed gradually by a process of condensation, (according to this theory—developed by J. Jeans, a Russian astronomer and quoted by Oparin). Thus, from a part of the hot gaseous mass separated from the sun, our earth was formed. Carbon passed into it along with other elements from the sun.

As the earth cooled down, carbon was one of the first elements to condense in solid form owing to its extremely high boiling point. Heavy metals—particularly iron—likewise condensed and formed the solid nucleus of our earth. Even at present the interior of our planet consists largely of red-hot, molten iron mixed with some other metals. Carbon must have interacted chemically with these heavy metals. Just as sulfur combines chemically with iron (page 57) so also carbon may combine with metals, particularly with iron to form so-called "carbides."

The earth was still red hot at that time and was surrounded not by an atmosphere of oxygen and nitrogen, as at present, but by overheated steam vapor. No liquid water was able to form on account of the high temperature. Oparin assumes, with good reason, that this overheated steam vapor interacted chemically with the carbon-metal compounds whereby enormous amounts of hydrocarbons were formed. (These are substances like methane, etc. chemically related to mineral oils—see page 61). He assumes that the hot molten mass of metal and metal carbides was covered with a thin layer of igneous rock which at times would rupture so as to bring the water vapor surrounding the earth into contact with carbides and allow the formation of hydrocarbons. The probability of this formation of hydrocarbons is strongly supported by the fact that Jupiter, the largest planet of our solar system, with its low surface temperature of $-135°C.$, is surrounded by an atmosphere of methane (CH_4), the simplest hydrocarbon, according to the latest investigations. Besides, ammonia (NH_3) is contained in its atmosphere. The same is true for the other large planets. Enormous oceans consisting of the higher hydrocarbons, like ethylene, etc., which are liquid at $-135°C.$, have been traced on these planets. Similarly a wholesale formation of hydrocarbons might have occurred on our earth, as Oparin states.

Later with the continually dropping surface temperature other carbon compounds were formed, such as alcohols sugars and organic acids through interaction chemically with water vapor. Besides water vapor, the atmosphere of the earliest earth contained large amounts of ammonia (NH_3) and this also interacted with the primary carbon compounds to form nitrogenous carbon compounds, amino-acids the progenitors of proteins, the most important materials contained in living organisms. According to these plausible assumptions of Oparin, a great variety and quantity of different lifeless organic materials must have been present by the time our planet cooled to the point where water in liquid form appeared on its surface.

We have attempted to explain the formation of lifeless organic matter before life itself was produced by the action of electrical discharges, but it must be admitted that Oparin's suggestions are much more plausible explanations of the formation of organic matter *in enormous quantities*, such as the large deposits of hydrocarbons as are now found in the form of mineral oil. Concerning the natural mineral oil deposits existing at present on the earth, some authorities believe that these have been formed in the same manner as postulated by Oparin, namely, from water and metal-carbides.

Electric discharges might well be considered, however, as a contributory factor. Their action would have been to produce an even greater variety of organic substances, so many that finally, after millions of years, self-regenerating enzymes appeared in a suitable medium of organic materials. It may be remarked that Dr. F. Haber, a noted chemist and Nobel prize laureate, under whose guidance this writer began his studies some thirty years ago, had performed numerous experiments in which electrical discharges were sent through carbon-containing gases like methane, carbon dioxide, with the aim of obtaining, in this fashion, sugars or other valuable materials; but he completely failed in this respect. Although some sugar was formed, a practically unlimited number of various other substances were also formed; in fact, a mixture of hundreds of different materials which the most skilful chemist was unable to separate. Haber thus came to the conclusion that by means of electrical discharges, through carbon-containing gases, practically "any substance known to organic chemistry" can be formed.

Is it not reasonable to assume that in the natural course of events electric discharges passing through the carboniferous atmosphere of the early earth during millions of years must have given rise to a still greater variety of substances until finally those rare and delicate materials appeared which are enzymes capable of reproducing themselves? These we regarded as the predecessors of life. The assumption that sparks can eventually form self-regenerating enzymes would seem to be even more probable if the early earth had plenty of hydrocarbons in its atmosphere. And if the earliest ocean was loaded with lifeless organic matter, it would seem that somehow, somewhere, these spark-generated enzymes must have found an environment suitable for their multiplication.

Another important point which Oparin clearly emphasizes is that the abundant formation of organic substances, like sugars and proteins, in the early oceans was possible only because of the complete absence of life in them. In our days this formation of organic matter would be impossible since the countless microorganisms which are present everywhere would rapidly devour it. Complete absence of life was therefore the prerequisite condition to give the lifeless organic matter an opportunity to develop into the most primitive living things during millions of years. Naturally all forms of development intermediary between the simplest lifeless organic substances and the simple living things have been wiped from the earth, having served long ago as food for the higher developed forms of life.

So far it would seem that Oparin's investigations tend to supplement and clarify our ideas about the gradual evolution of life from lifeless matter. Naturally there are also some divergences of opinion concerning the detailed mechanism of the origin of life from lifeless matter. In this respect, Oparin does not attribute any importance to the self-regenerating enzymes or to any form of life consisting of single molecules. He stresses the fact that all the filtrable viruses, which are the self-regenerating enzymes best known so far, can grow only in living plants and animals. Their cultivation on artificial nutritive media has *not* been definitely proven although it has been reported by some experimenters. Doubt still prevails whether any mono-molecular form of life is capable of developing outside of a host-organism. For this reason Oparin does not seem to believe in the possibility that self-regenerating enzymes could have been the first forms of life to appear.

Oparin even goes so far as to state that he cannot conceive of an organism which is completely dispersed in its surrounding medium. The term "completely dispersed" has practically the same meaning as "consisting of only one molecule or molecular aggregate" (so-called "micella").

This is just what Stanley of the Rockefeller Institute and his group have recently demonstrated by their cyrstallization experiments with the tobacco mosaic viruses and other viruses as described above (see page 74). Since Oparin's book (in Russian) was published in 1936, and written probably a year earlier, it is likely that he had not yet heard of Stanley's work at that time.

It would also seem that the impossibility for any monomolecular form of life to develop on a non-living medium has not yet been proven. We should realize that we can observe only those mono-molecular forms of life which are disease-producing: the filtrable viruses. There is no reason to assume that they are the only ones which exist.

We must be satisfied with our limited knowledge in this line: we know that a "living molecule" is possible; hence, the failure to cultivate filtrable viruses cannot be an objection to the assumption that mono-molecular forms of life were the first ones to appear on our earth.

Oparin assumes that the first forms of life to appear were much larger. Concerning their formation, he has worked out an ingenious hypothesis, the essential features of which can be briefly summarized as follows. The organic substances present in the lifeless early ocean—like proteins, etc.—were present there as "colloidal solutions" very much like a protein solution in water in which molecular aggregates ("micellae") are evenly distributed. Oparin assumes further that by an interaction of various colloids, a segregation of liquid jelly-like masses occurred, tending to concentrate the organic matter in certain points. This was not an irregular precipitation, but rather a segregation resembling a crystallization with the colloidal "micellae" arranged in a regular fashion; this must have been the case since regularity of arrangement of the smallest particles is typical of any living thing. Such colloidal droplets of matter, so-called "coazervates" as he terms them, should have gradually evolved into living organisms. Each coazervate has not only an individual structure of its own, Oparin assumes, but it is also capable of resorbing matter; hence it grows and finally multiplies by cell division. Of course for this absorption and growth to occur it is necessary to assume the formation of enzymes in these "coazervate" droplets. The question of how the enzymes were formed remains unanswered in Oparin's theory.

Obviously, the essential feature of Oparin's hypothesis is that structural units with a remote resemblance to living organisms were *first* formed from the organic matter of the early ocean and that subsequently enzymes formed in them so as to enable them to assimilate substances from their environment. In this manner some of the "coazervates" eventually developed into living organisms.

Our opinion, on the contrary, was that the life-producing enzymes were the first to appear, through the action of electric discharges, without any structure around them—as self-regenerating enzymes. Later only, a structure was built up around them, as we assumed. The entire difference between the two opposing views is therefore only concerned with the order of the essential events which preceded the appearance of life.

Differences of opinion are bound to occur when such obscure problems as the origin of life are under discussion. In general, experience frequently shows that opposing views are actually compatible with each other. Perhaps we may assume that this is also the case here. Why should not some living organisms have been formed according to Oparin's assumption and others according to our hypothesis? Nature is never tied down to any definite scheme. Concerning the origin of life, it would seem justified to accept not only two divergent views but also invite other investigators to try to find still further hypotheses on a rational basis.

Undoubtedly, Oparin's work deserves the highest recognition due to his admirable attempt to explain the origin of life as just one of the phases in the fate of carbon on our earth. First there was the white-hot carbon vapor, then came the carbides, then the carbon-hydrogen compounds; later, after the earth had cooled, carbon had an opportunity to display its extraordinary faculty to form an almost endless variety of different substances; thus, finally, structural arrangements like the coazervate droplets and enzymes were formed which gradually developed into living organisms.

Oparin attempts to trace as accurately as possible, the character of all the different chemical changes during this history of carbon. On the early earth with no oxygen in the atmosphere, no "cellular respiration" but only fermentation was possible whereby carbon dioxide was given off into the atmosphere. Subsequently, the enzyme chlorophyl in the green plant cells appeared and free oxygen was given off into the atmosphere. There is actual evidence available that this was a very much later development since to this day fermentative processes occur in all plants side by side with the "assimilation" of carbon dioxide, which latter process liberates atmospheric oxygen. Animal life which depends on respiration in an oxygen-containing atmosphere made its first appearance only after all these previous developments were well under way; it relied chiefly on the great energy output resulting from processes of cellular combustion. And what a long way it had to go before it arrived at its present high stage! It is impossible to describe here all the chemical details which Oparin traces as he maps out his gorgeous history of carbon, terminating in life.

In concluding, Oparin can justly claim that he has opened a new outlook to "the colossal problem" of investigating the stages of the evolution of life as being chemically separate entities: the differently-shaped living organisms being merely the expressions of different chemical processes occurring among the endlessly varying carbon compounds.

Oparin finally expresses his view that the artificial synthesis of living things is "very remote" but not unattainable along the road which he outlined. We may point out that we had reached the same conclusions starting from somewhat different viewpoints, and can emphasize again that we agree with Oparin in all his essential ideas concerning the origin of life.

Another postscript remark should be added concerning the statement on page 70 "that particles smaller than 1/5000 of a millimeter are not directly visible in a microscope." We know of devices which enable us to recognize the existence of still smaller objects such as Zsigmondy's ultramicroscope or the recently constructed electronic microscope, but these devices do not operate with directly visible light.

The Third Approach

THE IMPORTANCE OF SALT AND WATER FOR LIFE AND GROWTH

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1. THE OCEAN, THE CRADLE OF LIFE

We have attempted to visualize the supposedly lifeless age preceding life generation, when non-living organic matter began to interact with enzymes. Such reactions can occur only if the carbon compounds and the enzymes acting upon them are dissolved in water. Thus we are forced to assume that those chemical reactions which we regard as fore-runners of vital processes must have occurred in lakes or in oceans, probably in the latter since only in large bodies of water would the conditions have been sufficiently uniform to continue undisturbed over the millions of years required for the development of the first cells, through the deposition of inactive non-enzymatic organic matter around the self-regenerating enzymes. From these materials, the first cells were shaped by the forces of crystallization which, we have shown in our First Approach, exist in all living things. And because only in the oceans would there have been the constancy of temperature and salt concentration so necessary for the protection of these delicate beginnings of life, we are naturally led to consider the ocean as the cradle of life on our earth.

Since that early time life has developed at an ever-increasing rate. At present, with a history of about a billion years on record, it has developed to enormous diversity and strength. Living organisms crowd the surface of our globe. Many of them long since gave up their ocean habitat, but they still require water and salt to exist. This fundamental condition of their origin has never changed in spite of all that has happened within those odd billion years of their existence. As common experience teaches, water and salt are indispensable for any form of life. All living things are bathed in a watery fluid. They either live in it or contain within themselves a water solution with some salt in it to bathe all their vital organs. Viewed from this angle the great puzzle of life takes on a novel aspect.

Further evidence to substantiate the view that oceans are the cradle of life is found in the fact that they display a greater diversity of plant and animal life than do lakes, rivers, or the dry land. We find in the sea, particularly, certain primitive animals which have hardly any blood or tissue-juices, but are perfused everywhere by the sea-water. An example is the common jelly fish, which resembles loose pieces of transparent flesh. Such animals depend entirely upon the sea-water for their existence. They cannot live in rivers or lakes or after the waves have thrown them on the beach.

But more independent types of life evolved during millions of years, while many forms appeared, and again disappeared, unable to maintain and propagate themselves. Little by little the outer skin enveloping the organism became denser. A better protection was afforded, but the tissues inside were thus shut off from the sea water, which had removed waste products and also brought dissolved air to every cell of the animal's body.

So thick-skinned organisms survived only if they developed organs which provided for an intake of air (gills or lungs); organs which provided for carrying around the dissolved air to all cells (a beating heart and blood vessels); and finally, organs for removing waste from the liquid circulating inside the organism (kidneys or organs like them).

Just how all these complicated organs developed is quite incomprehensible at the present stage of our knowledge, but we ought to remember that the ways and means available for development are infinitely more plentiful than we can imagine.

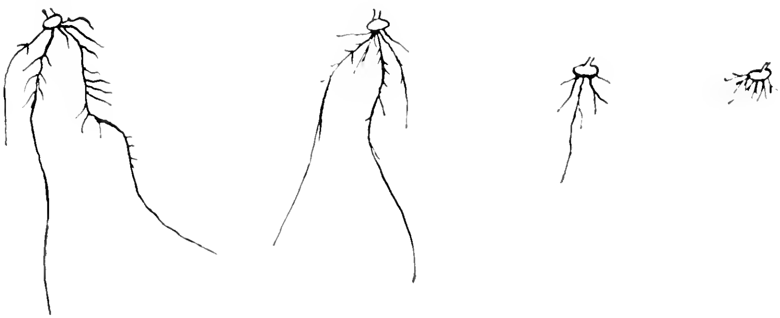
2. OUR BLOOD AS THE DESCENDANT OF THE ANCIENT OCEAN

Following this train of thought, we are led to assume that the internal circulating fluid—the blood of higher animals—was developed from the water of the ocean. Is there evidence to corroborate this view?

The following experiments are helpful because they demonstrate the indispensibility of all the various salts the ocean contains. As an object of experimentation, we select one of the more highly developed fishes, a so-called bony fish, *Fundulus Heteroclitus.* This fish has a dense skin which completely shuts off all the interior tissues of its body from the surrounding water. It has gills for respiration, a beating heart, a circulating blood, and organs for digestion and excretion. It can live either in the ocean or in a river, and frequently changes from one to the other. In the laboratory, this fish can even be placed in distilled (chemically pure) water, without suffering damage.

Very surprising things occur if we place this fish in an artificially prepared solution of pure salts. The ocean water contains several different kinds of salts. Among them is ordinary table-salt (sodium-chloride), which makes up approximately 3.5% of the sea water; the other salts are present only in negligible quantities: about 0.2% each. These minor constituents are the so-called lime salts, and potassium and magnesium salts. One might suppose that a fish which can live in ocean water or in distilled water should also be able to live in a simple table-salt solution. This, however, is not the case at all; all fish die very quickly in such a solution, particularly if the salt content about equals that of the ocean. These striking observations were first made by Jacques Loeb (1859–1924), biologist of the Rockefeller Institute, who indefatigably investigated the cause of this strange phenomenon and greatly helped to clarify it.

Loeb's investigations have shown that the purer the salt solution the more harmful it is to the fish. Most harmful of all is a solution of carefully purified sodium chloride in pure distilled water. If we add to the sodium chloride just one of the numerous other salts present in the ocean in small quantities, the fish lives much longer.



A *B* *C* *D*

FIG. 30. GROWTH OF THE ROOTS OF WHEAT IN SALT SOLUTIONS OF VARYING COMPOSITION
(Natural size)

A. "Complete" salt solution containing all the different saline components of the ocean in the same relative amounts as in the sea.
B. Solution containing only table salt (sodium chloride) and lime salt.
C. Lime salt solution only.
D. Table salt solution only.

A seed can develop only in solution which contains all the oceanic salts. A solution with only one of its components is definitely harmful.
This experiment shows that all the various salts which are contained in the ocean are necessary for the development of life in any form, even up to the present day.

The chemically pure table-salt solution is detrimental, not only to fish, but likewise to any other living creatures, including plants. Wheat germs germinate poorly in a pure salt solution, whereas they develop abundantly in a solution containing all the salts of the ocean or at least some of them (Fig. 30). Moreover the common food of men and animals contains salt but never pure salt; common table salt is not chemically pure sodium chloride, and many of the minor salts mentioned, particularly the lime salts, are contained in most food. Thus both milk and cheese are rich in lime salts; most vegetables contain potassium salts, and bread contains both.

Further investigations have revealed the cause of the deleterious action of pure salt. It can be proved that the outer skin of sea animals, if placed in pure salt solution, loses its natural density. It rapidly swells and begins to disintegrate; if this occurs in the gills of a fish, the fish must suffocate because water cannot pass through the engorged and occluded gills. In a similar manner, men suffocate after inhalation of large amounts of acid vapors or other irritating gases that disintegrate and swell up the tender membranes surrounding the air cells of the lungs; the air cells are engorged by the vapors. Lime salts are naturally-occurring salts which keep cells dense. But some salts, which never occur in the ocean, also act in this way.

(It has also been possible to make artificial membranes from a fat-and-water mixture. These membranes become permeable in pure salt solution just as does the skin of animals. In these artificial skins, the cause of the increased permeability can be studied and determined. It is due to a separation of the oil and water constituents of the artificial membranes, (according to experiments of G. H. A. Clowes).

Thus we see that life depends on all the salts contained in the ocean, including those which are present only in small amounts. If it is true that our blood has developed from the ocean, we should expect to find in it, also, all the salts of the sea. An analysis of the blood salts shows that this is the case. We find among them all those minor constituents which ocean water contains. Yet there are some discrepancies as follows:

First: the relative amount of the several salts is not exactly alike, although there is a preponderance of sodium chloride in both.

Second: the total salt content of the blood is only about 0.9 per cent; in the ocean, however, it is 3.5 per cent.

The last deviation is not at all surprising; on the contrary it seems to corroborate our assumption. For, our blood is certainly not derived from the modern ocean but from the ancient ocean that existed hundreds of millions of years ago, when our ancestors left it to adapt themselves to life on the land. We have to consider that the salt which is now dissolved in the ocean has been extracted from the surface layers of the earth by rivers. This process of extraction still goes forward. In the remote past, the salt concentration of the ocean must have been appreciably lower. It was then that the first animals left the ocean and adapted themselves to conditions on land. They have preserved the low salt concentration of the early ocean, in which, probably, the relative amount of the salts differed from that in the modern ocean. Furthermore, the surface of the earth, and hence the ocean, was then probably warmer than it is now. The warm blood of the body may be looked upon as another inheritance which has been kept at an even level, reminding us of the oceanic existence of our very remote aquatic forebears.

It seems therefore that even man, "the crown of evolution," carries within himself a small part of that original ocean, low in salt content and of a higher temperature, as it was at the time of man's earliest ancestors. Times have certainly changed a great deal since then, yet the old ocean still persists in us. Its salt concentration and temperature is constantly kept at the same level by the regulating action of our internal organs, particularly by the kidneys. Not only is the total content thus kept constant but also the concentration of each of the several salts of the ancient ocean.

3. WATER RETENTION AND WATER EXCHANGE IN THE TISSUES OF OUR BODY

The salt solution of oceanic inheritance permeates all cells and tissues of man and the higher animals. A part of it is contained inside the diminutive cells, of which all tissues are built; another portion is held between the cells; and still another portion circulates in large channels which extend like pipes through the body. The outstanding system of this type is that in which the blood circulates. Blood is a special type of oceanic salt solution; along with the various salts it also contains a large amount of dissolved nutrient matter (protein, fat and sugar) and the well-known red blood cells which contain the red dye, hemoglobin. While the blood is passing through the lungs the hemoglobin forms a loose combination with the oxygen of the air; this oxygen is then given off to all the internal organs of the body. In this manner vital processes of combustion (see page 66) are kept going all over the body. The blood is propelled in the arteries and veins by the pumping action of the heart which alternately contracts and expands. Another system of circulation exists in the brain and spinal cord and is filled with the cerebro-spinal fluid, a clear colorless salt solution of strictly oceanic type. A liquid system serving for drainage is the urinary system which consists of the kidney, the ureter, the bladder, and urethra.

Three fourths of the human body thus consists of oceanic salt solution. Closely examining living organisms, we find that there are definite partitions in the form of thin skins or membranes which separate the various channels through which the body fluids pass, or the cells and organs which contain fluids. And yet these fluids with their salt content have some communication with each other, so that water can readily pass, usually in either direction.

Nowhere in the body do we find stagnation of the body fluid; water is constantly taken as food or drink and then excreted through the natural channels; the blood is incessantly driven around; body fluid passes into the blood or vice versa; the oceanic salt solution in our body is in constant motion. Before we can hope to understand the mode of working of the vital organs of our body we have to know the laws which regulate the water exchange in it.

The most casual survey shows that the rôle which water plays in the body economy is very complicated. The following example may serve to illustrate this point. In most cases of starvation or wasting diseases, such as cancer or tuberculosis, large amounts of water are lost along with the solid body building material. In other cases, of similar ailments however, a retention and a piling up of large amounts of water may occur (Fig. 31). This is known as edema or anasarca. Cases of hunger edema are usual in the great famines which at times visit Russia, China, or India. While most of the unfortunate victims of starvation resemble walking skeletons, some of them develop enormously distended arms, legs and abdomens. Why does the water escape from the body in one case, while in another, water is piled up?

This question can be answered if we understand the complicated mechanism through which water may enter or leave the organism. Nothing is gained by inventing new descriptive terms to explain this mechanism; instead we should start with simple experiments on non-living models. We can construct what we may call an artificial cell, a contrivance capable of attracting or giving off water under conditions similar to those existing in living tissues.

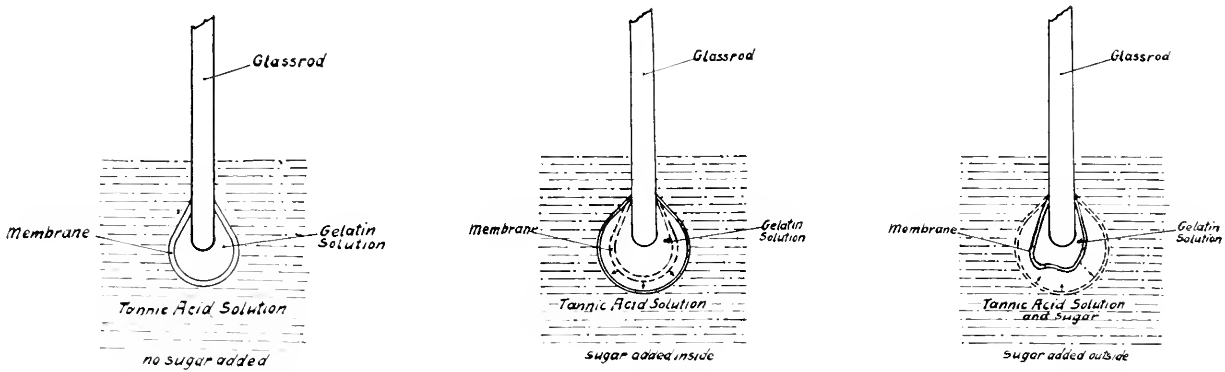
Here is the method of preparing such an artificial cell: A solution of gelatin is made and a drop taken out of this solution with a glass rod. The drop remains hanging at the end of the rod, and is exposed to the air for several hours. It is then dipped into a 5% solution of tannic acid. In about ten minutes a thin iridescent solid film forms at the surface of the drop. This solid film forms because gelatin is rendered insoluble when tannic acid is added to it. If tannic acid is mixed with gelatin, all of the gelatin becomes insoluble. But in the set-up here described, only the surface layer of the gelatin solution comes into contact with the

FIG. 31. OLD PICTURE OF A PATIENT SUFFERING FROM HEART DISEASE EXHIBITING ENORMOUS SWELLING OF THE ABDOMEN

The picture distinctly shows the enormous accumulation of water in the abdominal cavity of a sufferer of heart or kidney disease in the terminal stage.

tannic acid solution; the surface alone becomes insoluble, forming a solid film (Fig. 32a).

The most important property of this film is that it permits water to pass, but prevents the passage of salt, sugar, or similar dissolved materials. Such a film is therefore called



a. *b.* *c.*

FIG. 32. AN EXPERIMENT ON TRAUBE'S ARTIFICIAL GELATIN-TANNIC ACID CELL

(*a*) A drop of gelatin is attached to the glass rod and is immersed into a solution of tannic acid. A film forms at the surface of the gelatin drop which allows water to pass, but not dissolved substances.

(*b*) If a considerable amount of salt or sugar is added to the gelatin, the drop will swell, since the salt or sugar attracts water, forcing it to flow through the film into the gelatin drop. The drop acts as though it were puffed up like a balloon into which air is blown. This expanding force of a salt or a sugar solution is called the osmotic pressure.

(*c*) If the sugar or salt is added to the tannic acid, the drop will shrink, since water is now withdrawn from the gelatin drop into the solution surrounding it.

a semi-permeable membrane. Owing to this semi-permeability the gelatin drop swells if salt or sugar is added to it (Fig. 32b). The salt inside attracts water and draws it through the membrane, since the salt itself cannot pass through the film. But if salt or sugar is added to the tannic acid on the outside, the drop will shrivel, because now the salt draws water from the inside of the drop through the membrane (Fig. 32c). We see, therefore, that the flow of water through the semi-permeable membrane occurs *towards the dissolved substance*. These results can also be expressed in a different way. We may say the swelling is due to a pressure exerted by the salt solution, if this is inside. Such a cell may be compared to a rubber balloon which is puffed up by blowing air into it. But this analogy is incomplete since the rubber balloon which is puffed up certainly does not gain weight; as it is stretched it gets thinner. In this regard the artificial cell behaves differently; the iridescent film on the gelatin in tannic acid solution does not get thinner. More of it is being formed, owing to the expansion of gelatin which offers a greater surface to the tannic acid solution, allowing this solution to act upon a greater quantity of the gelatin. Hence the film actually grows by stretching. If similar conditions prevail in living tissue, we should expect that living cells will also grow under the expanding influence of certain substances in the fluids inside the cells.

4. THE SWELLING AND SHRINKING OF LIVING CELLS

Doubt may arise whether there is true similarity between a living cell and the artificial cell made of gelatin and tannic acid. We need definite evidence that similar conditions occur in living tissue. Does a living cell shrivel or swell under the influence of salt in the same fashion as our artificial cell? This question is readily answered by observing red blood cells. The blood cells are actually tiny bags surrounded by an elastic film. The inside is mostly liquid and in this liquid are various salts and other dissolved substances including the red blood pigment, hemoglobin. These cells float in blood liquid, which contains dissolved salts in the same concentration as that inside the cells. The blood cell may therefore be compared to an artificial cell in which salt is added both to the gelatin and to the tannic acid, with the result that the effects inside and outside equalize.

What will happen if we remove a number of blood cells from their natural environment and place them in distilled water? We may predict that, the pressure of the salts inside must expand the cell, since the pressure acting on the outside has been removed. An experiment shows that such an expansion actually occurs; indeed more than mere swelling occurs: the cell bursts, quite like an over-inflated rubber balloon. This bursting can be best observed under the microscope, since the blood cell is of small size, less than $\frac{1}{100}$ millimeter. But if a large number of blood cells burst in water, the hemoglobin imparts to the water a distinctive red color and renders it translucent like red wine. (Normally blood is not translucent.) This is known as laking of blood or hemolysis.

On the other hand, if we add more than 1% of salt to the solution in which the blood cells are floating, then the blood cells shrink, owing to the excess pressure on the outside. A simple experiment makes this shrinking obvious; if we centrifuge a given volume of red blood cells, the cells fall to the bottom of the centrifuged fluid. After centrifuging we add concentrated salt solution and centrifuge again. The volume of the cells is now considerably smaller.

This pressure exerted by the salts on thin films is one of the most widely recognized forces acting in the living world. It is termed the osmotic pressure. The swelling or shrinking of living or artificial cells under its influence is called osmosis.

The expanding action of osmotic pressure can be observed also in the cells of a muscle. If a freshly excised muscle of a frog is placed in distilled water, it swells; in concentrated salt solution, it shrivels. The muscle therefore seems to consist of cells surrounded, like the red blood cell, by a semi-permeable film. A closer observation shows that the muscle does not consist entirely of such osmotic cells, but also of fibers which support them. A similar support of the tender osmotic cells is found in growing plants. In a *Tradescantia*

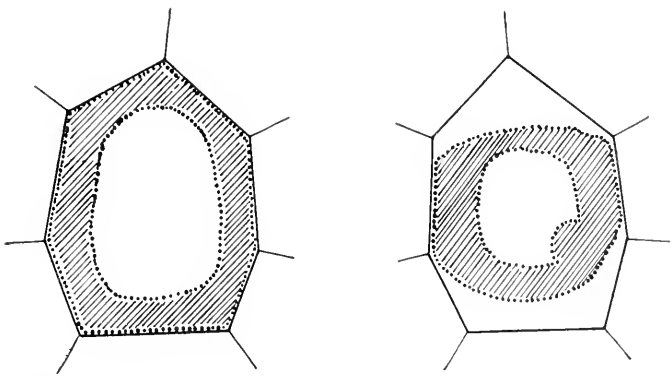


FIG. 33. DIAGRAM ILLUSTRATING THE EFFECT OF OSMOSIS ON SPIDERWORT CELLS (TRADESCANTIA)

In spiderwort cells only a part of the cell will shrink if placed in a concentrated solution. The tender semi-permeable film is imbedded in a supporting framework of cellulose fibers; the latter remain unchanged in any solution.

(spiderwort) cell, for instance, the osmotic cell is held in a rigid framework (Fig. 33). Place this cell in a concentrated salt or sugar solution and the innermost portion will shrink as indicated on the diagram. The surrounding cellulose fibers remain unchanged. The conclusion is, therefore, that only the inner part of this plant cell is surrounded by a film which lets water pass.

It seems likely that the expanding forces of osmotic pressure must also be of importance for the natural growth of plants and perhaps also of some animals. In the plants, the enzyme chlorophyl, the green dye of the leaves, transforms the gaseous carbon dioxide of the air into solid material as we have seen; a part of this solid material is probably soluble sugar. Cells form around it in some fashion, perhaps similar to our artificial cell. A cell thus formed must swell through the action of osmotic forces; in this manner it contributes to the growth of the plant.

All these observations demonstrate the analogy of real living cells and the artificial cells made of gelatin. And there is more than a superficial similarity. Even the mode of origin of living cells seems to be related to that of the artificial cells. Just as the gelatin drop immersed in tannic acid solution is able to envelop itself in the thin film of the tender semi-permeable membrane, so also certain material obtained from living plants, when immersed in water, readily surrounds itself with a semi-permeable membrane.

A suitable material for demonstrating this membrane formation is contained in the delicate root hairs of the water plant, *Hydrocharis*. If we place these delicate root hairs in a drop of a colored watery solution on a glass slide and press them with a cover glass, the contents flow out, forming oil-like droplets; some of these in turn enclose water droplets. Each droplet surrounds itself with a film which is semi-permeable, as demonstrated by the shrinking of these drops in concentrated salt or sugar solution (Fig. 34).

In other cases, the new formation of a membrane can be seen directly, for instance around the squeezed-out content of the egg cells of such low marine animals as the sea-urchin (*Arbacia*). In general the material obtained from young and growing cells readily surrounds itself with a film capable of regeneration. Of course these oil drops squeezed from cells cannot be regarded as real cells, but we can form at least an idea about the manner in which living cells originate.

On the other hand there are cells in which an enveloping membrane is not formed automatically. These cells are surrounded by a membrane, but if it is broken, it fails to regenerate, and the cells disintegrate. To this type belong the red blood cells. If their membrane is broken the red hemoglobin in the cell flows out; no repair is possible. One

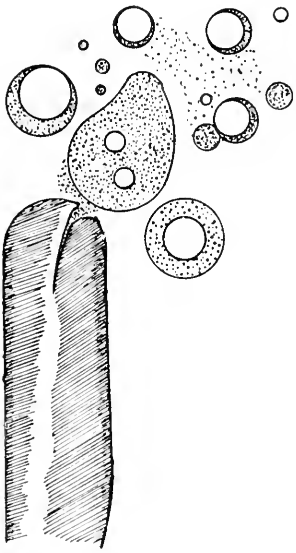


FIG. 34. MICROSCOPIC VIEW OF A ROOT HAIR OF HYDROCHARIS AND OIL DROPS SQUEEZED FROM IT

Droplets squeezed from the tender root hair of Hydrocharis, on contact with water in which they float, immediately surround themselves with a semi-permeable membrane as demonstrated by the fact that they shrink in concentrated salt solutions and swell dilute ones, just as the artificial cell made of gelatin shown in Figure 32. (Magnified 150 times.)

may assume that this cell membrane was also originally formed by contact of two substances, probably in the bone-marrow where all blood cells originate. The blood into which the cells pass later is not capable of generating the membrane when in contact with the contents of the blood cell; consequently, regeneration of the blood cells in the blood itself does not occur.

A great deal of experimentation has been carried out in numerous research laboratories in order to determine the make-up of the thin envelope (semi-permeable membrane) of the red blood cell. A chemical analysis is impossible since the envelope is so extremely thin that it is hardly visible. Only indirectly has some information about its character been obtained, by determining the kind of material which will penetrate it. To do this we observe whether or not the blood cells break up in various solutions. We have already seen that in a 1% salt solution the cell does not break up, owing to the counterbalancing of the internal pressure of the salt. This shows that the salt does not penetrate. But if we place blood cells in a mixture of alcohol and water, they break up and we know then that the alcohol penetrates into the cell. Alcohol lacks that essential property, non-penetration, which is indispensable for osmotic pressure. The pressure inside the cells is not counterbalanced and so they burst.

Similar tests can be performed with a variety of substances. Ultimately we find that penetrating substances are mostly those which dissolve in fat or oil, and since solubility of the membrane obviously facilitates penetration, we conclude that the cell membrane is some sort of fatty material. Further experiments, however, show that fat solubility is not the only condition required for penetration.

Many problems concerning the nature of this film remain unsettled, but science is on the way. The discovery of osmotic pressure has established a working method which may be used for thousands of experiments enabling us to penetrate further and further into the secrets of the make-up and functioning of the more complicated living organisms which have evolved during millions of years, from enzymatic reactions in the ocean.

The fundamental knowledge of the rôle of salt and water is of practical importance in medicine and surgery. For the flushing of extensive wounds, particularly in surgical operations, a liquid is needed which will not damage the tissues. Water will not do for this purpose; it would break up the blood cells and cause a swelling of the other body cells. Rapid injections into the veins of large amounts of distilled water are deadly, because of the shock produced by wholesale destruction of blood and other body cells. A solution, known as Ringer's solution is used; it contains all the salts ordinarily present in the blood, including those present in small amounts.

5. THE AMAZING SIZE OF THE OSMOTIC PRESSURE AND ITS MEASUREMENT

The expanding force of growing plants is very great; the delicate root tips of growing plants are strong enough to burst heavy iron pipes. The thin tips of the growing root first project into one or more of the crevices of the iron pipe. As these root tips expand by growing, the heavy tube cracks in two.

Can we explain such a force as a result of the "osmotic pressure"? How great is this pressure? Can it, like the steam pressure of a boiler, be measured by a manometer?

Such a measurement is indeed possible, and actually shows that a heavy pressure is exerted by osmosis. Many technical difficulties, however, must be overcome. It would appear that a set-up with an artificial cell—such as described in Figure 32—is not suitable for this purpose. Instead of stretching the semi-permeable membrane we must now use the expanding force of the osmotic pressure to work upon a pressure gauge. To this end the membrane must somehow be reinforced. Nature itself shows us that the very delicate semi-permeable membrane can be rendered more resistant by imbedding it in a supporting framework as in the case of the *Tradescantia* cell (Fig. 33).

For the purpose of measurements, we imbed the semi-permeable membrane in a cup of porous clay (Fig. 35). This cup is not semi-permeable as it stands. A solution of sugar passes through it, since the pores in the cup are too big to hold back the sugar. But we can plug these pores by forming in them a semi-permeable membrane, through precipitation. To this end we allow two different solutions which interact with each other to penetrate the cup, one from the inside, the other from the outside. The detailed technique of this procedure is described in the legend of Figure 35. We mount the cup as shown in that figure, fill it with a sugar solution, and immerse it in water. A manometer attached to it measures the water-attracting force of the solution—in other words, the osmotic pressure. We find that the osmotic pressure is very great and can well understand how it cracks iron pipes. The osmotic pressure of a 4 per cent cane sugar solution is nearly equal to that of a water column standing in a tube 100 feet high. For higher sugar concentrations it is correspondingly higher.

Owing to the magnitude of the osmotic pressure it is very difficult to carry out such measurements. If the set-up has the slightest leak, the sugar solution will pass through it instead of pushing up the mercury column. If the whole apparatus is tight, the osmotic pressure of the sugar solution equals that registered by the mercury column. If, on the other hand, the pressure of the manometer is increased by the addition of more mercury to the mercury column, water will be driven out from the sugar solution against the osmotic pressure.

6. HISTORICAL REMARKS: THE LIFE OF MORITZ TRAUBE AND THE FURTHER DEVELOPMENT OF THE WORK ON OSMOSIS

We have made a great step forward by observing the expanding forces of osmotic pressure and its influence upon vital growth, as well as upon water exchange between sap

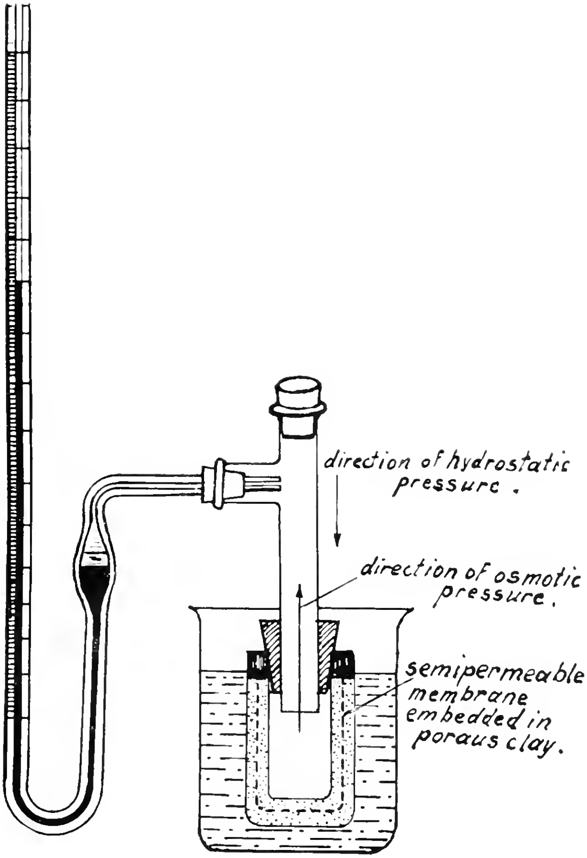


FIG. 35. DIAGRAM OF SET-UP FOR MEASURING OSMOTIC PRESSURE

With an apparatus of this type we can demonstrate the extraordinary force of the osmotic pressure. A porous cup with clogged pores is the essential part of this set-up. The pores are clogged with an insoluble substance, copper ferrocyanide, which is generated in the pores by pouring a copper sulfate solution into a moistened porous cup and immersing the cup, with the solution in it, in a yellow prussiate solution. The two solutions diffuse into the clay from opposite sides and produce a semi-permeable membrane in the inner layers of the clay where they meet.

The top of the cup is then fitted to a glas tube attached to a manometer. The entire inside of the cup and the conneeting tube is filled with sugar solution. The cup is immersed in a larger beaker containing pure water. Water will now be drawn into the cup and the manometer will rise as shown in the figure.

and cells. We see something of the secret driving forces responsible for the development of plants and animals. Osmotic pressure is only one of the acting forces, but an important one. It was the first to be explained in terms of purely physical forces, and thus stripped of the mystical obscurity prevalent in oldtime biology. (Other vital forces are those related to crystallization, see pages 15 to 46.)

One may suppose that the man who initiated this great new line of investigation on osmotic forces was a well known professor in a famous university, but he was nothing of the kind. He was a simple chemist, Moritz Traube, who lived in Germany from 1818 to 1876. He published his discoveries on the expanding and shrinking of artificial cells and the osmotic pressure in 1864, 1866, and 1867.

He and a few others saw the importance of these forces in explaining the life phenomena of plants and animals. Yet his epoch-making work never brought him much recognition. The leading chemists of his day declared his work to be outside the realm of pure chemistry. Most of the biologists refused cooperation, because Traube lacked preliminary training in botany and zoology, sciences which busied themselves exclusively with a description of the form of plants and animals. The result was that the man who presented to science this far-reaching discovery never obtained any academic position. He became a wine merchant in a small German town and pursued his research in his spare time in a primitive laboratory in his home.

Moritz Traube's fate resembles that of another pioneer in a related line: Carl Naegeli, 1817–91, the discoverer of crystalline constituents in living structures who also failed to obtain that recognition which he deserved. As in Naegeli's case, Traube's work was recognized only after his death.

The first promoter of Traube's ideas was an able and progressive young botanist, W. Pfeffer, 1845–1920, who, in 1877 and later studied the osmotic pressure in plants. It was he who first recognized the magnitude of this pressure in plant cells. He also saw that such a pressure can be measured in an osmometer of the type described in Figure 35.

Through Pfeffer's work, Traube's basic ideas were received and recognized in the official sciences. From that time on work along this line has gradually spread. At present, it is discussed from many diversified points of view.

7. THE FLUID RETENTION IN THE HUMAN BODY IN STARVATION AND WHAT CAUSES IT

Let us return to our original problem, the perplexing question of why the human body swells in some cases of starvation and shrivels in others. We can indeed be proud if this question can now be answered through the knowledge acquired on our journey of exploration into the borderland between living and non-living matter, where we followed the trail blazed by the discoveries of Moritz Traube.

Blood flows from the heart through the arteries, then through the numerous narrow-gauge capillary tubes, and finally back through the veins into the heart. The blood vessels and the heart form a closed system surrounded by a membrane everywhere. Blood can escape from this closed system only where the coat of the vessel is very thin, as in the capillaries. Fluid can break out here; not merely water, but also the salts dissolved in the blood. However organic matter, particularly the dissolved protein, cannot easily escape through the thin capillary walls. (Fig. 36.)

Since the heart through its contractions exerts a pressure upon the blood, one might guess that fluid would be pushed through the thin capillary wall, run into loose spaces of the body, such as exist under the skin, and cause tissues to swell, as is the case in certain diseases. What force keeps the fluid in the capillaries?

We again consider the principles of osmosis. Any dissolved substances in the blood which cannot pass through the thin walls of the capillaries will attract fluid into them, and the blood contains such substances: the proteins. The proteins draw fluid toward the capillaries while the pressure exerted by the heart tends to push fluid out of them. As a result, in the normal body these two opposing forces counterbalance each other.

However, if the dissolved proteins of the blood are lacking, there is no counterbalancing effect. The blood pressure pushes fluid into the loose spaces of the body, causing swelling of the ankles, the eyelids, the abdomen or elsewhere.

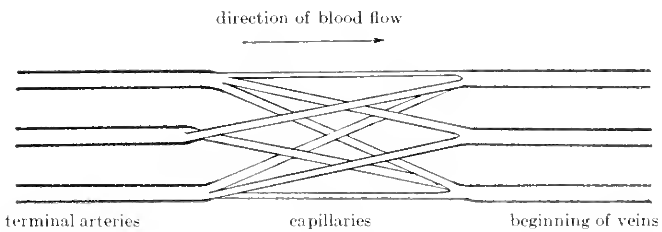


Fig. 36. Diagram of Arteries, Capillaries, and Veins

The contractions of the heart force blood through the capillaries which lie between in the tissue everywhere. Their walls are so thin that fluid readily passes through them. But the blood passing through the capillaries contains more dissolved substances than the fluid which surrounds the capillaries. Consequently fluid will be drawn into the capillaries, thus counteracting the tendency of the blood pressure to drive out fluid. After passing the capillaries, the blood is collected by the much wider veins which run mostly on the surface of the body and carry the blood back to the heart.

We now understand why a swelling may occur after starvation or wasting diseases (see page 110 and figure 31). Our food is the source of those proteins in the blood which, by their attraction of water through the capillaries, oppose the effect of blood pressure. These proteins are continuously used up in life processes, and must be replenished from the food intake through the intestinal tract. If the food supply fails, the blood proteins must soon run low Consequently, not enough proteins are left to keep the blood fluid from leaking through the capillaries anywhere in the body, and hunger edema (swelling) sets in.

But many cases of starvation do not exhibit this swelling. Obviously in starvation, the solid building material is likewise wasted, and the functioning of all vital organs is greatly impaired. The heart soon fails, since it needs a continuous supply of nourishment, more so than any other organ. In most cases of starvation the heart begins to fail before the blood proteins run low, and becomes too feeble to exert enough pressure to press any liquid out through the walls of the capillaries. In such cases the victims of starvation will die before the swelling develops. Hunger edema can develop only if the blood proteins begin to disappear when the heart still beats strong enough to exert a blood pressure sufficient to drive liquid through the capillary walls. It is thus shown that the swelling or shrinking of our body in starvation can be reasonably explained.

Blood proteins are low, not only in starvation, but also in those diseases of the kidney in which the proteins pass through the kidneys instead of being retained in the blood. Food intake cannot always make up for such losses and swelling appears, first in certain loose parts of the body, for instance the spaces below the eyes, where the skin easily gives way. Here is a condition which shows how an understanding of the disease points to a cure. More proteins must be eaten by the patient who uses proteins rapidly. As is well known, milk, meat and eggs are the foods that supply proteins most abundantly. It has been possible to improve some such cases by a richer diet.

However, some patients may have digestive trouble which handicaps their increased food intake. Can such sufferers be helped? Why not inject proteins directly into the veins of the patient? Proteins such as milk or egg-white are immediately fatal to the human body if injected into the veins. There is, though, the possibility of injecting into the veins certain other slimy materials which do not penetrate through the walls of the capillaries, such as acacia, a gum of plant origin. If this is injected in a suitable solution into the veins of patients with edema due to kidney disease, the edema is markedly relieved, as one might expect. This treatment has only recently been adopted and seems to be quite promising.

Again we see that one of those phases of life that we can imitate in the laboratory, osmosis, plays an important rôle even in the function of an organism as highly specialized as the human body.

8. THE ARTIFICIAL OSMOTIC STRUCTURE

Every serious student of vital processes feels keenly the difficulties under which he struggles in his study of life. Abundant evidence is available to demonstrate evolution in the living world. But since we cannot perform experiments which require millions of years, we are at a loss to demonstrate experimentally just what the process of evolution was.

Attempts to reveal the origin of life, are also handicapped, this time by our incomplete knowledge of chemistry. Although 300,000 compounds of carbon have been made, the chemical make-up of the most important substances of the living world, the enzymes, is shrouded in mystery.

As to the rôle of salt and water, we can observe the expanding forces, which they produce, through the osmotic pressure in Traube's simple bag-like artificial cell; but such a make-shift rivals in no way the complexity of the living cell. Yet there are simple means of using the osmotic forces to yield something which has at least a remote resemblance to plants and animals.

Without preliminary explanations, here is a description of a practical method of obtaining more life-like structures through osmotic growth: we take a 1 per cent solution of copper sulfate (a salt) and place in it a solid crystal of yellow prussiate of potash (a salt known in chemistry as potassium ferrocyanide). A surprising development sets in within a few minutes. A plant-like structure develops from the piece of yellow prussiate. It remotely resembles a cactus, showing fine branches and twig-like ramifications (Fig. 37).

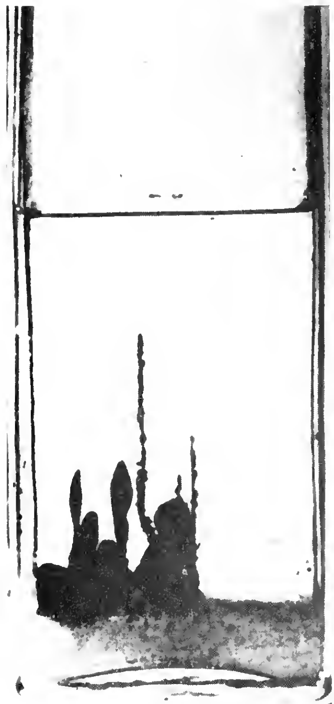


FIG. 37. ARTIFICIAL PLANT-LIKE STRUCTURE GROWING FROM YELLOW PRUSSIATE OF POTASH IN A DILUTE COPPER SULFATE SOLUTION

The process which leads to the formation of this structure is diagrammatically explained in Figure 38, diagrams *1* to *4*. We see how the piece of yellow prussiate dissolves, forming a solution around itself. Observe the second diagram. It interacts at once with the copper sulfate of the solution in the test tube, forming a new material of brown color, chemically known as copper ferrocyanide, which is insoluble and gelatinous. This brown material forms an envelope around the entire prussiate, both the dissolved and the undissolved. This envelope is a semi-permeable membrane of the same type as the one surrounding the gelatin-tannic acid cell of Traube, page 112. It allows only water to pass, none of the dissolved salts. In the solution surrounding the crystal, the yellow prussiate is dissolved up to 28 per cent, this being the concentration of a saturated solution of that salt. During the first minute or so, the envelope is a nearly rounded bag, containing a solution of the prussiate and in addition some as yet undissolved prussiate. More and more of the latter is dissolved by water rushing inside the membrane, forming and maintaining a 28% solution, while the original 1% copper solution is still outside. The osmotic pressure inside thus greatly exceeds the small opposing osmotic pressure of the copper salt outside. More water rushes into the cell and continues to expand it at a visible rate. More salt goes into solution as more water is drawn into the envelope. The result is that the envelope no longer maintains the simple round shape. It assumes a complicated form resembling the growth of a plant. Observe the second and third diagrams of Figure 38.

A similar structure can be produced under reversed conditions by preparing a dilute solution of yellow prussiate into which a crystal of copper sulfate is dropped. But since this copper salt is only sparingly soluble, it is better to use mixtures of solid cane sugar and copper sulfate, moulding this mixture into a pill which is dropped into the prussiate solution. The sugar is helpful on account of its greater solubility, which promotes expansion and subsequent growth. Figure 39 is a photograph of a structure which develops by following this procedure. Its appearance resembles a plant with leaves and ramified branches.

Artificial structures develop from numerous other inter-

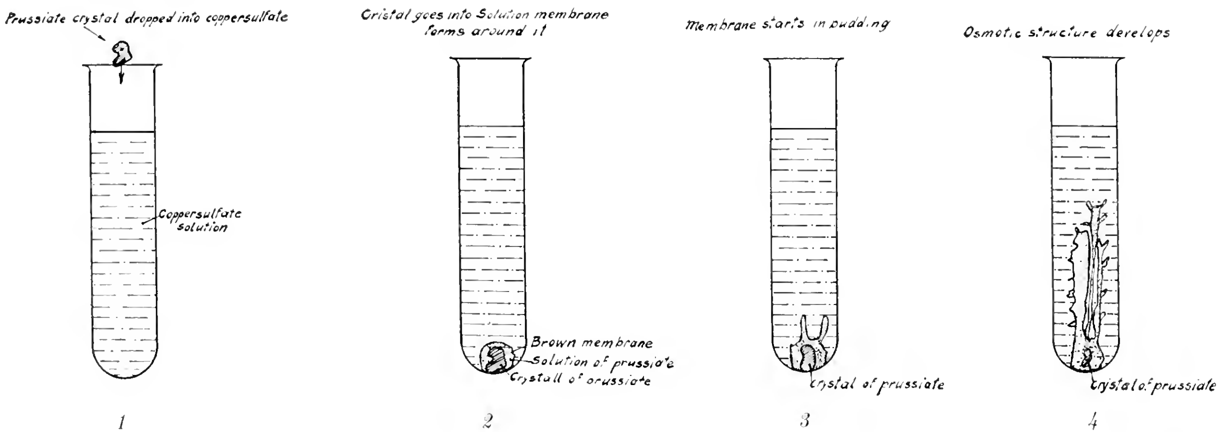


FIG. 38. MODE OF DEVELOPMENT OF AN ARTIFICIAL PLANT FROM A CRYSTAL OF YELLOW PRUSSIATE IN A COPPER SALT SOLUTION

Diagram 1: A 1 per cent copper sulfate solution is contained in a test tube into which a crystal of yellow prussiate is dropped.

Diagram 2: After it has arrived at the bottom, a part of the crystal goes into solution; the solution thus formed around the crystal immediately walls itself off with a brown membrane through the chemical interaction with the copper sulfate solution.

Diagram 3: The bag thus formed expands on account of its higher salt content, since the yellow prussiate is very soluble and more and more of it goes into solution; the expansion does not occur in a regular circular form but sprouts into what looks like twigs or leaves.

Diagram 4: The sprouting continues as the crystal of prussiate gradually dissolves. A "plant" develops.

acting salts, the combination of copper salt and yellow prussiate being only one example. Outstanding for the diversity and beauty of the structures it produces is the combination of ordinary waterglass with any of the various heavy metal salts. Waterglass, chemically known as sodium silicate, is a thick slimy solution which is commonly used for preserving eggs. Into this solution we place small

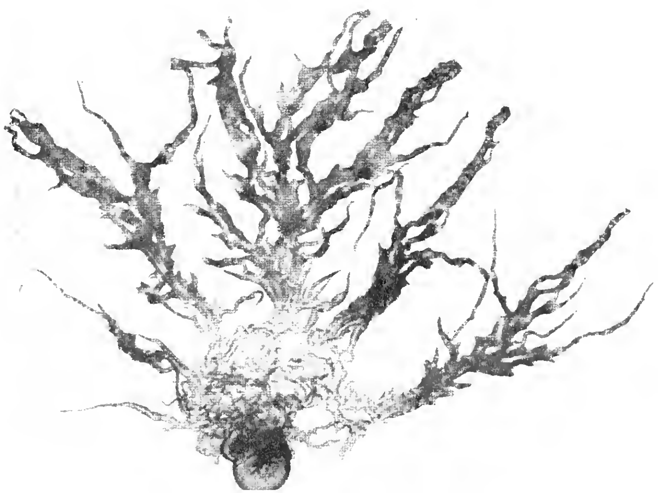


FIG. 39. AN ARTIFICIAL STRUCTURE GROWN FROM A "SEED" WHICH IS COMPOSED OF SUGAR AND COPPER SALT

The "seed" is placed in a dilute solution of prussiate where it sprouts, owing to the osmotic pressure of the sugar as it goes into solution. The procedure is therefore the reverse of that described in Figure 37.

pieces of different salts made from various metals, such as copper, iron, nickel, cobalt, magnesium, and calcium. All these different metallic salts form insoluble, slimy substances, capable of acting as a membrane, as soon as they come into contact with the waterglass. Really beautiful plants will grow, some of them having strikingly life-like flowers and buds of varying colors (Figs. 40 to 46).

Fig. 40

Figs. 40 to 45. A Variety of Artificially Produced Structures

They give us some idea of the immense variety of forms that can be produced through the action of osmotic pressure. The text explains how slender stems sprout if a considerable pressure exists inside of an envelope. Frequently after such stems have reached a considerable height, they spread out into what look like buds. These buds probably form through a thinning out of the membrane. This occurs after the stem has grown to a certain height, and hence the supply of the membrane-forming material is running low because of the distance from the bottom to the top of the structure. No life process or any other mysterious life force is involved in the formation of these structures, which are purely inorganic.

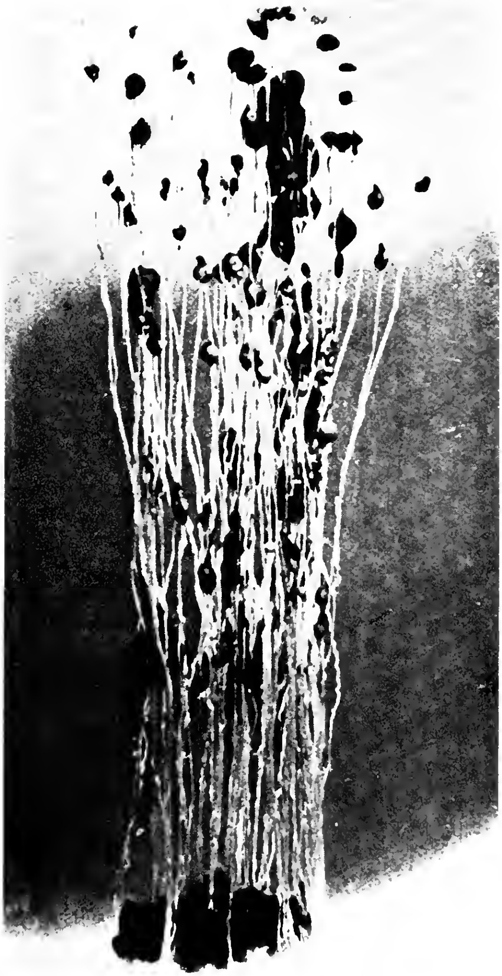


FIG. 41 (see legend on page 131)

FIG. 42 (see legend on page 131)

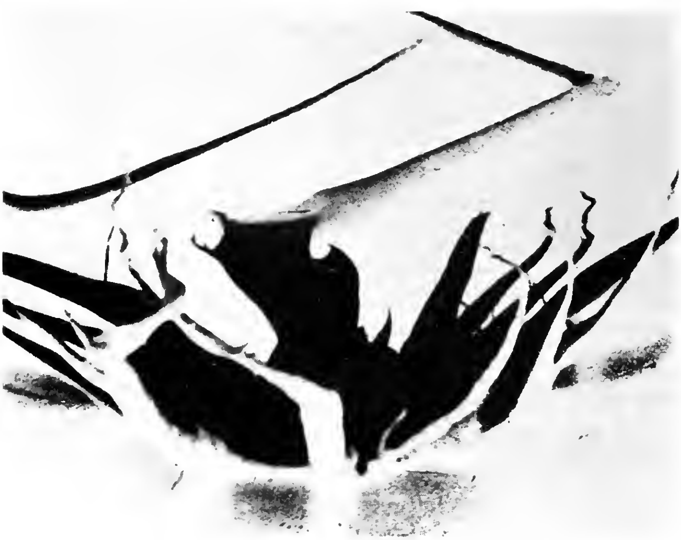


FIG. 43 (see legend on page 131)

FIG. 44 (see legend on page 131)

FIG. 45 (see legend on page 131)

Cobalt salts, for instance, if placed in waterglass, germinate into slender blue stems which develop pink buds at the top. Iron salts produce striking structures with slender budded stems that shoot up in a few seconds.

This technique was developed by Dr. Stephane Leduc of Nantes, France who has studied and photographed a large number of such artificial osmotic structures. He certainly deserves recognition for demonstrating what amazing forms can be produced artificially by osmotic forces. The pictures taken by St. Leduc here reproduced (Figs. 40–45) give only a faint notion of the wealth and variety of forms which he produced in the laboratories and of their close resemblance to genuine vital growth.

9. THE IMITATION OF THE FORM OF CERTAIN PLANTS AND ANIMALS BY ARTIFICIAL OSMOTIC STRUCTURES; INFLUENCE OF GRAVITY UPON ARTIFICIAL GROWTH

Artificial mushrooms, unbelievably similar in appearance to natural ones, will grow in a solution of soda inseminated with pieces of lime salts. On top of this soda solution we carefully superimpose a layer of distilled water in such a way that the distilled water floats upon the heavier soda solution without mixing with it. As the pieces of lime salt begin to grow in the soda solution, they first form what looks like the stem of a mushroom. As soon as this stem has risen to the level of the superimposed water layer, it spreads and forms what looks like a hood. Since the superimposed water layer contains very little of the dissolved materials, the difference in osmotic pressure between the inside and the outside of the stem is much greater when the growth rises into the water. This explains the spreading and the formation of the hood. (This is the technique of Stephane Leduc (Fig. 46).)

The resemblance of these structures to real mushrooms is so striking that, according to Leduc, botanists have mistaken them for real ones. The stems of the osmotic mushrooms are formed by bundles of fine hollow fibers. The upper surfaces of the hoods are smooth or covered with fine scales, while their lower surfaces present traces of vertical gills. Sometimes these gills are intersected with concentric lines. Natural mushrooms—although formed by a different type of growth—are built up in a somewhat similar

FIG. 46. ARTIFICIAL MUSHROOMS

Copy of a picture taken by Stephane Leduc of his famous artificial mushrooms, which although made entirely of mineral matter, have been mistaken for real mushrooms by expert botanists. (Natural size.)

manner, since their stems are also made up of fibers which are bundled together and continue to extend into the hood.

Leduc has succeeded also in imitating certain other living forms by his artificial structures. Some of these are:

1. Vermiform structures (Fig. 47).
2. Structures resembling actinosphaerium which is a one-celled animal with slender outgrowths (pseudopodia) (Figs. 48 and 49).
3. Structures resembling growing nerve fibers (Figs. 50 and 51).

A

B

FIG. 47. VERMIFORM STRUCTURES

Other miracles of artificial osmotic growth, resembling worms or worm-like plant structures. These are also Leduc's products, as are most of the previously reproduced figures.

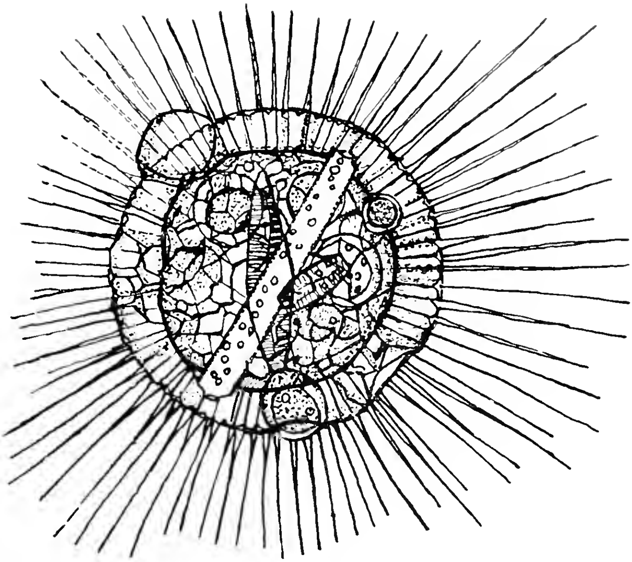


FIG. 48. DRAWING OF AN ACTINOSPHAERIUM ACCORDING TO MICROSCOPIC OBSERVATION

Actinosphaerium eichhornii is a one-celled animal, usually about 1 mm. in diameter, which frequently occurs among the leaves of water plants and feeds on still smaller animals. It sends forth large numbers of stiff projections, as do certain other primitive animals. These creatures hold a middle place between plants and animals. (Magnified 100 times.)

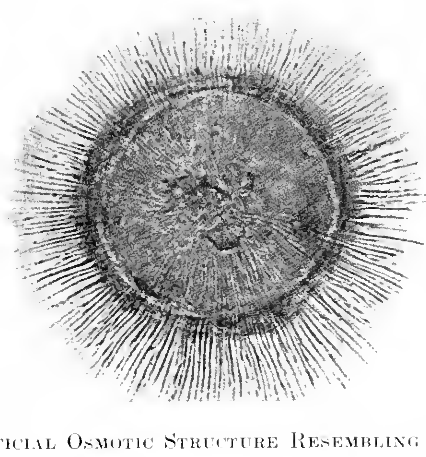


FIG. 49. ARTIFICIAL OSMOTIC STRUCTURE RESEMBLING ACTINOSPHAERIUM

The resemblance of this structure is so striking that no further comment is necessary. (Natural size.) (According to Leduc.)

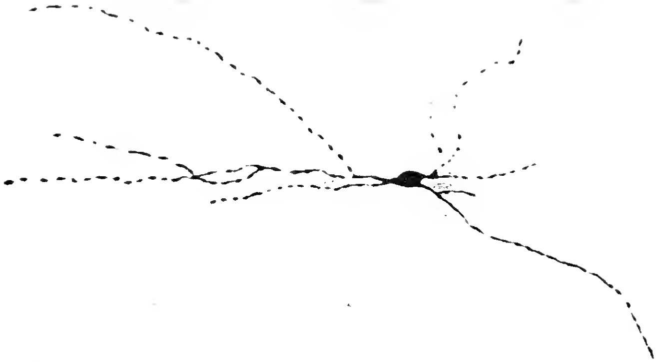


Fig. 50. Ganglion Cell with Nerve Fibers Growing from It

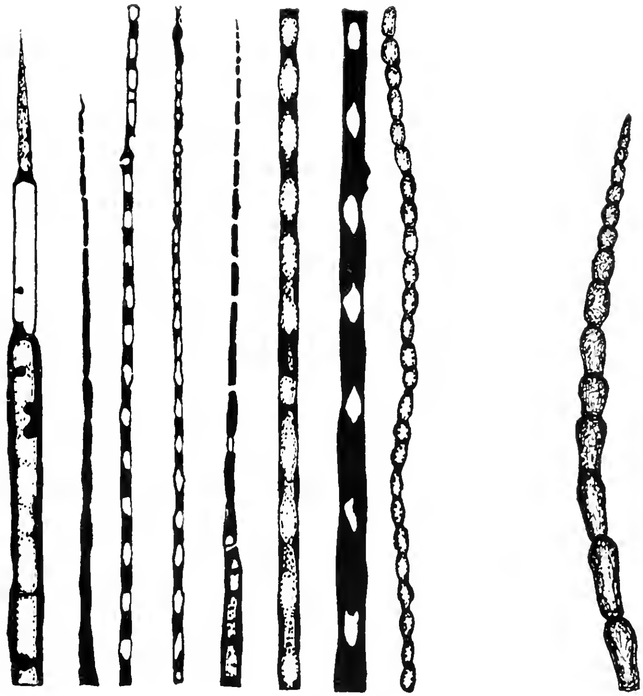
Ganglion cells are the most important components of the nervous system of men and animals. The entire brain of man is composed of billions of similar cells. They differ from other body cells in their capacity to grow very long nerve-fibers that transmit impulses through the human body and thus make possible the movement and functioning of its diversified parts.

Fig. 51. Artificial Cell with Long Projections

It is almost unbelievable that such a make-shift as an osmotic cell should be capable of growing fibers resembling the nerve cells sprouting from a ganglion, as closely as is shown in this figure. This is another achievement of Stephane Leduc.

Unfortunately Leduc does not reveal in his writings the details of the procedures by which he has obtained these various forms.

The artificial structures resemble real plants also in their



A *B*

FIG. 52 *A*. OSMOTIC STRUCTURES GROWING IN DIFFERENT MEDIA, UNDER MODERATE MAGNIFICATION (25 TIMES)

FIG. 52 *B*. REOPAX NODULOSA (AN ALGA!)

Note the striking resemblance of the unicellular animal in 52 *B* to the artificial structure furthest to the right in 52 *A*.

cellular make-up, although the resemblance is only partial. All living tissue consists of a multitude of diminutive cells, visible under the microscope. If artificial structures are scrutinized microscopically they also reveal cells of a sort, although not equivalent to real living cells; observe Figure 52.

By a different technique, we can obtain freely floating artificial cells. (See Figure 53, a microscopic picture of these cells, reproduced here with the courtesy of their originator, Dr. A. L. Herrera of Mexico.)

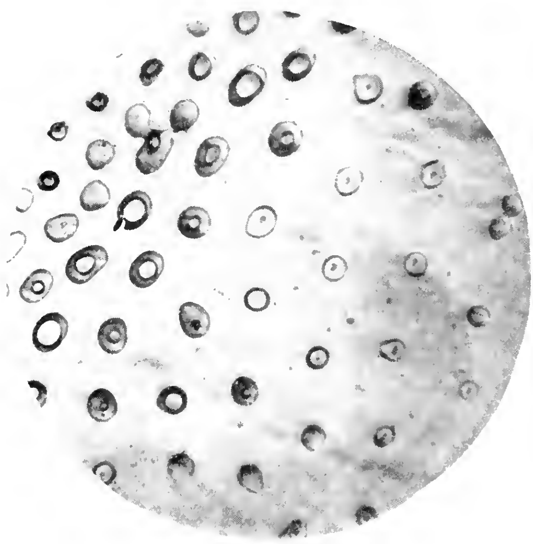


FIG. 53. ARTIFICIAL CELLS WITH NUCLEUS PRODUCED IN SEA WATER

These artificial cells are made by forcing a solution which precipitates lime salts into the sea water through the narrow pores of a porous cup. The precipitation occurs in the form of microscopic globules which have a droplet of water in their center. Herrera believes that this droplet remotely resembles the "nucleus" of living cells, but it may also be compared to a so-called "vacuole."

It seems interesting that cells can be produced in sea water in which, according to our assumption, the first cells actually were formed. However, since these seaborn artificial cells consist entirely of inorganic material, their similarity to living cells may perhaps be accidental.

Moreover, their mode of origin is highly artificial. It is difficult to see, even by the farthest stretch of the imagination, how living cells could possibly have originated in a similar manner. It is important, however, to know that even entirely artificial methods yield cells with such a striking resemblance to certain living cells.

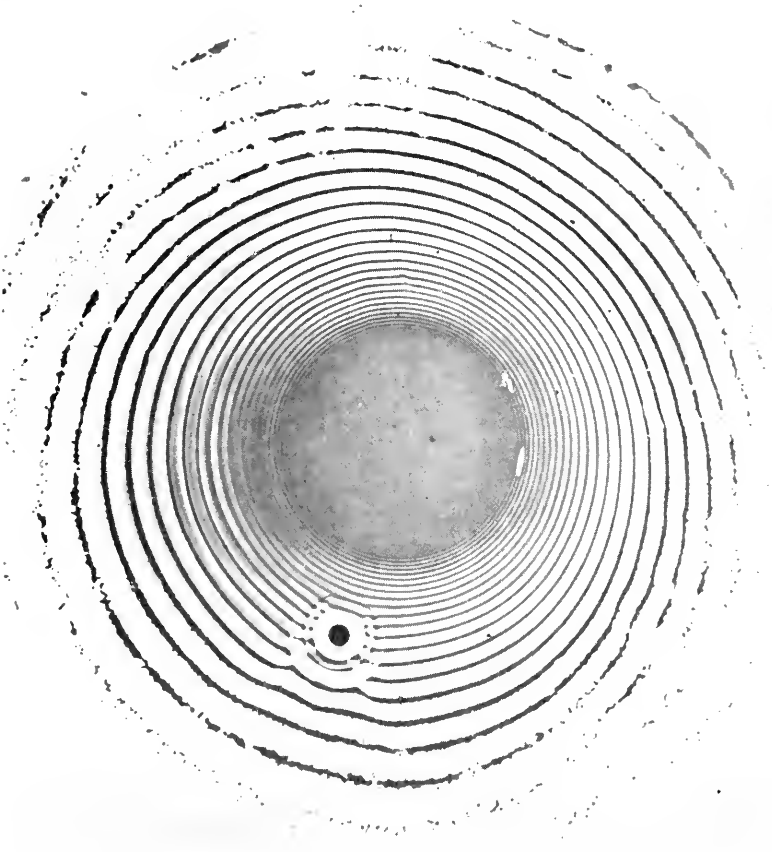


Fig. 54. Artificial Striated Structure (Liesegang Rings)
(Natural size)

"Liesegang Rings" are obtained by the simple slow mixing of two solutions which interact with the formation of an insoluble substance. We add gelatin to one of these solutions and pour it in a flat disk. After it has set to a jelly, we place a drop of the second solution in the center of this jelly. Without any further manipulation or interference a structure is developed such as photographed here in natural size. In this instance the jelly contains ammonium chromate, the solution placed upon this in the center is a soluble silver salt. Numerous other substances of suitable kind can be used to form such structures.

(Compare text on pages 145 and 146.)

a b

FIG. 55. (*a*). PARALLEL STRIATIONS PRODUCED BY THE INTERACTION OF TWO SUBSTANCES

$\frac{1}{2}$ natural size

(*b*). LEAVES OF A CACTUS PLANT WITH SIMILAR STRIATIONS

The striations in 55 *a* are produced as described in Fig. 54, with only this difference: of the two interacting substances, one is contained in a jelly in a test tube, and the other is poured on atop of this jelly. The striations are formed automatically in the jelly in consecutive layers thus producing a parallel striation of great regularity and beauty.

Figure 55 *b* is inserted here for comparison. It is a photograph of a cactus plant which likewise exhibits a parallel striation of great regularity. This striation seems to be the result of similar physical forces which produce the striation in the test tube experiment on the left, even though this experiment is performed only with simple inorganic salts.

The microscopic study of artificial structures frequently reveals parallel striations of the developing branches or fibers, as is distinctly seen in the vermiform structure of Figure 47a. Such a stripe formation has no direct relation to the expanding osmotic forces. It can best be studied by a special technique developed by R. E. Liesegang in 1896.

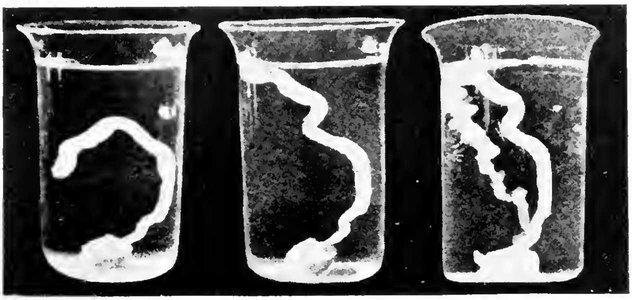


FIG. 56. WORM-LIKE STRUCTURES GROWING IN ALL DIRECTIONS
(One-half natural size)

Here is a series of photographs taken consecutively at short intervals, showing how a sprouting artificial growth can develop in all directions, first up, then horizontally, and finally downward; see first photograph. After it had developed so far, it broke at its uppermost point and the section growing down was carried upward because the solution in which it grew was much heavier than the structure itself. But the growth was again continued persistently downward as shown in the last of the series. This shows that gravity is not an indispensable factor in the development of these structures. Osmotic pressure overcomes the action of gravity in a striking manner. It is quite evident that in this experiment, the direction in which the artificial growth develops is determined solely by osmotic forces and not by gravity.

Details of this technique and the strikingly beautiful striations obtained by it are given in Figure 54 with its legend. (Turn back to page 143; see also Fig. 55.)

Regularly striped structures are frequently found in living tissues of plants and animals. Thus the lime salts, of which the solid bones of our body are built, are laid down around the blood vessels running through the bones (Haversian canals) in regularly striated layers. Other well known examples are the beautiful structures appearing on the wings of butterflies, and also the regular stripes appearing on many leaves. Formerly many complicated assumptions were made to explain the origin of such stripes; for instance,

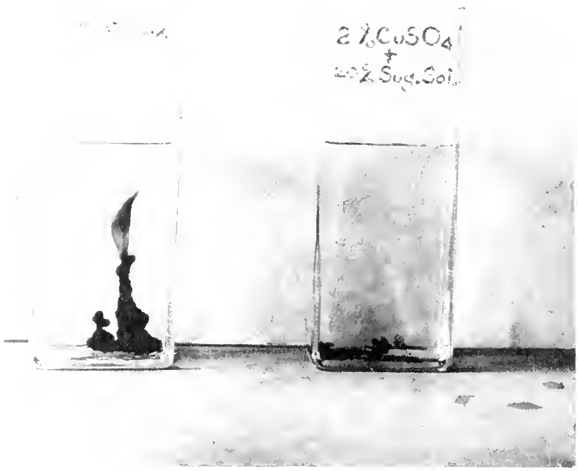


Fig. 57. Inhibition of the Development of an Artificial Structure if Growing in a Highly Concentrated Solution

These two containers were filled with a dilute copper salt solution but the one on the right side had also 20 per cent of ordinary sugar added to it. Pieces of yellow prussiate were placed in both at the same time. The photograph shows that no development occurred in the solution to which sugar had been added. Obviously the sugar exerted an osmotic counter-pressure preventing the development of an osmotic structure.

This is another demonstration that osmotic forces are the important factors in the development of these structures. If gravity were a factor, the sugar would increase the development since, on account of the heavier weight of the sugar solution, it would have allowed the structure to float up. (One-half natural size.)

a periodic supply of food material. No such assumption is needed. Striking periodic stripe formation can be made artificially when all the factors involved are kept constant, or at least do not undergo periodic variations timed with the formation of the stripes. This important fact is definitely proved by Liesegang's discovery of periodic stripe formation.

We have so far assumed that the development of the artificial structures described is due to the expanding influence of the osmotic pressure. Some scientists have propounded an opposing view to the effect that gravity should be considered the important factor. This would mean that the development of these structures depends upon their floating in the solution in which they form. But such a view is strikingly contradicted by experiments. Certain artificial structures will grow in all directions without regard to the action of gravity (Fig. 56). The same fact is proved by the observation that a counteracting osmotic pressure can suppress the growth (Fig. 57).

10. MOVEMENTS OF NATURAL AND ARTIFICIAL PLANTS. ARTIFICIAL STRUCTURES GROWING OUTSIDE SOLUTIONS

Even more striking are the movements of these artificial plants and their similarity to the slow movements of real plants. As is well known, most plants, particularly their flowers, grow towards the light. Light is the real life force of plants; it is indispensable for the converting of the gaseous carbon dioxide of the air into the solid material of the plant body. Does a plant possess some sort of intelligence, as it seeks the light by growing towards it?

This idea seems to be disproved by the fact that some artificial structures also grow to the light, even though they do not need it at all for building up their bodies. No one would ascribe to these structures anything like an intelligence or an instinct. Simple physical conditions are recognized as the cause of the bending toward the light. The enveloping membrane of their stems is rendered somewhat softer and more flexible where it is hit by the light rays. It thus bends over to the illuminated side because of its greater flexibility on this side. It seems likely that a similar process causes the bending of real plants toward the light.

Here is a description of how to observe the bending of artificial structures toward the light. Prepare a 5 per cent solution of a lime salt, calcium chloride, pour it into a square

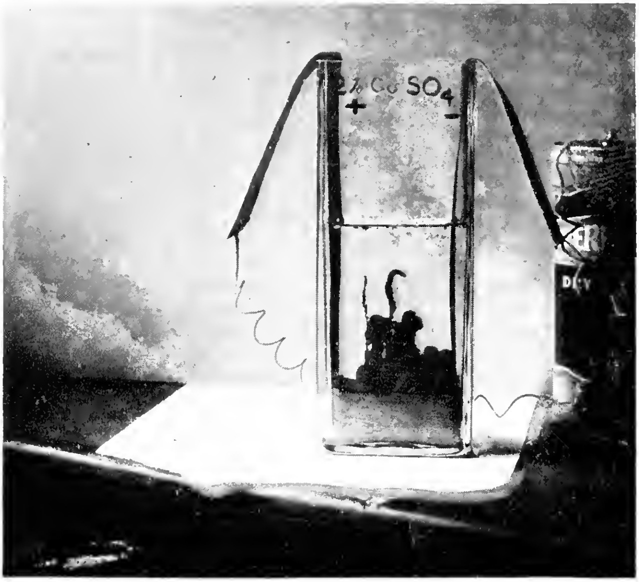


FIG. 58. BENDING OF AN OSMOTIC STRUCTURE TOWARDS THE NEGATIVE POLE AS AN ELECTRICAL CURRENT IS PASSED THROUGH THE SOLUTION

The structure first developed upward. After current was sent through the solution, it bent toward the negative pole.

glass container, and place crystals of soda in it. Light is allowed to shine on one side of the container. The same experiment is performed in a container which is entirely covered by a tin cap. Delicate tubes of calcium carbonate grow in both containers. In the illuminated container they creep up only on the illuminated side, or grow up a fraction of an inch and then bend toward the light. In the shaded container the tubes grow up straight. (After G. Quincke's publications in *Annalen der Physik*, 1902.)

Thus we find that the forces of nature act in the living as in the non-living world. In life we are often unable to recognize their character. But this is hardly a reason for assuming that there are vital forces different in kind from those of the inanimate world.

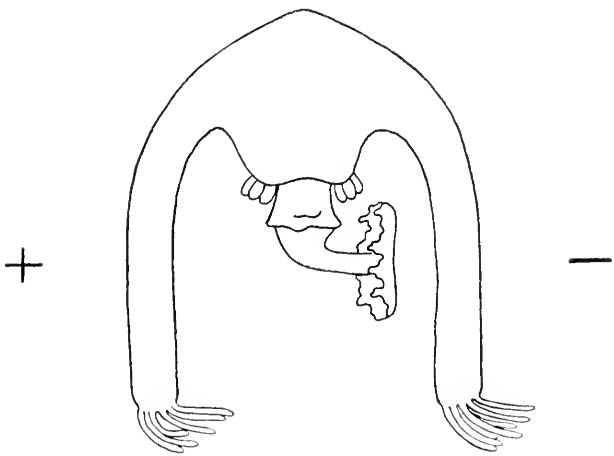


FIG. 59. BENDING OF A JELLYFISH TOWARDS NEGATIVE POLE IF AN ELECTRICAL CURRENT IS PASSED THROUGH THE SOLUTION

The resemblance of this bending to the one shown in Figure 58 is obvious.

The same point is demonstrated by the tendency of certain plants and some of the lower animals to bend if an electrical current is passed through them, along the lines of the current. The same is equally true of artificial structures when an electric current passes through them. (Figs. 58 and 59.) It is reasonable to believe that similar physical phenomena are active causes in both cases.

The artificial structures described so far are all grown in water or in watery solutions and resemble water plants in their appearance. It is also possible to grow similar structures outside solutions. To this end a rather large "seed," consisting of a lime salt, is placed in a shallow dish, containing a solution of a suitable substance, such as soda or waterglass, which will form an insoluble slimy material through chemical interaction when in contact with the lime salt. Like a plant growing from the soil, the upper part of this osmotic structure rises above the liquid.

11. WHAT WE CAN LEARN FROM THE EXPERIMENTS WITH ARTIFICIAL STRUCTURES

In spite of many striking life-like features, none of these artificial structures is a living entity. They all lack the power of propagation. Moreover they are too brittle to maintain themselves for any considerable time.

And yet we may learn a great deal from these perishable artificial structures. In a striking manner they reveal the widespread action of the formative forces which nature has at its command. The entire development of the living world is the result of these forces; its immense diversity is quite comprehensible. The artificial structures are products of a crude and simple technique, yet present a complicated appearance. It seems reasonable to conclude that the much more complicated processes which occur in the living world must lead to much more complex organisms; and that is what we actually see. The secret of life is thus unfolded a little.

Just as a new type of material is formed when living plants and animals grow and develop, so also these artificial structures form new matter from the surrounding solution. This means that chemical reactions occur in them. But these chemical reactions are entirely different in type from those in real life where enzymes are acting. In spite of this difference, similarities have been found because the expanding forces of osmotic pressure are acting in both cases upon a growing membrane. Such a membrane is formed through chemical reactions that are *somehow organized;* the materials that interact do not mix with each other but keep separate, so that they build up a new kind of material, the membrane. Under the action of osmotic forces this membrane assumes plant-like forms.

We ask ourselves then: is it reasonable to suppose that only inorganic reactions, such as those occurring in the artificial structures here described, can be arranged under conditions of organization? Should we not conclude that many of the thousands of known chemical reactions can also be found to occur as organized ones, if the research is continued far enough? This line of thought leads us to the conclusion that a whole world of artificial structures might be possible. We have become acquainted with only the simplest ones.

The inorganic artificial structures described can never be developed to living organisms, but we may hope that future discoveries may lead to the production of more perfect artificial structures. Even more highly developed artificial structures would probably not yet be "living," but they would resemble living organisms so closely that we would no longer feel sure about the sharp boundary line which now seems to separate animate and inanimate. Living organisms would then appear to us merely as limiting cases that occur in nature, owing to several peculiar coincidences which we now collectively call self-preservation and reproduction.

It may take ages to realize such a possibility. Difficulties of an entirely unforeseen nature may retard further progress. Even if the difficulties are greater than now supposed, this new outlook inspires the student of nature with hope for the further development of science.

SUMMARY

Salt and water are a part of life itself. We see their expanding forces in simple artificial cells made of gelatin, in real living cells, and particularly in the artificial osmotic structures which are inorganic and yet counterfeit life amazingly well. We see why and how our own blood has been developed in early evolution from the ocean, which is the cradle of life. New facts thus elucidate the nature of growth, but mainly growth in the plant kingdom. In the fourth and last act, now to follow, observations will be presented through which we shall try to understand the mechanism of motion in the animal world.

The Fourth Approach

THE ANIMAL A MACHINE

The Fourth Approach

THE ANIMAL A MACHINE

1. ENERGY OUTPUT AND MECHANISM OF ACTION

Living animals are often compared to machines. Such a comparison suggests itself to the people of a machine age such as ours. It is customary nowadays to inquire how many miles per gallon the new Ford will do. In times past no one thought of asking how many miles per pound of oats the good old horse would make. Some modern slanderers have spoken of the horse as an oats motor, and science has already attacked the suggested problem.

The customary scientific approach is to perform measurements on single muscles. If a muscle works, it burns glucose, a special kind of sugar—just as an automobile motor burns gasoline. To determine the efficiency of the "muscle-machine" scientists preferably experiment on muscles dissected from frogs or other cold-blooded animals. These muscles contract even after they have been removed from a living animal. A contraction occurs when an electric current is passed through the muscle, or when it is pinched, or suddenly heated, or touched with an irritant chemical. The muscle is held at one end and attached to a weight at the other. By contraction, it lifts the weight. The amount of sugar burned while lifting the weight can be determined by chemical analysis and the efficiency thus calculated. Expert scientists have perfected such measurements to an almost incredible degree. They have won thereby high scientific awards, since this line of work seems to have a strong appeal. It is generally taken for granted that we only need to collect data concerning the "living machine" in order to understand its mode of action.

It is difficult to see, however, how this expectation can be realized. What information can we possibly hope to obtain from a determination of the energy output of the muscle—or of any machine? Suppose we determine with the utmost accuracy the mileage per gallon for a motor car: could we ever hope to learn the mode of functioning of the motor in this way? Obviously not. There is as little hope of knowing the functioning of a muscle by determining its energy output.

But even the examination of the motor will not enable anybody to understand how it works. We know of course that the successive explosions of the gasoline vapors furnish the driving force. Suppose, however, that an automobile motor fell into the hands of a savage who does not know that gasoline is needed to run the motor, and who is ignorant of the importance of explosions of gasoline vapors. What could such a savage learn about the working of the motor, by taking it apart, by noting all of its parts and their mutual relation? Even if he did this with considerable skill, it would not enable him to grasp its purpose and working.

The fact is that we are just as ignorant of a muscle as that savage is of the automobile motor. We can take a muscle apart and observe all the structures of which it is composed, as numerous scientists have done with the utmost care for more than a century. With the greatest ingenuity they have worked out methods to render visible all details of a muscle under the microscope. But all the knowledge thus accumulated does *not* furnish us with any clue as to the working mechanism of the muscle-machine. We shall never arrive at a profound knowledge of a machine if we limit our studies to a description of the component parts. We must be able to make that machine with our hands. In addition we should make a variety both of simple and of complex machines of the type in question. In the case of the gasoline motor, the simplest type would be a plain box with a spark plug in it. We can observe that the lid will blow off if we pour hot gasoline into the box, allow it to vaporize, and send a spark from an induction coil through the spark plug. The explosion, we know, occurs because gasoline burns in the air. In a mixture of gasoline vapors and air, there must be a very rapid spreading of the flame, in other words, an explosion. By experimenting with such simple devices we find the basis of the underlying action and can understand how continuous motion can be produced by a series of explosions set off by a timing device in rapid consecutive order. We can grasp the importance of the entire complicated mechanism of an appropriately constructed gasoline motor.

Do we know anything as definite about the mechanism of muscular contractions? We certainly do not, but the comparison with the motor shows us the cause of our ignorance: our lack of knowledge is to be blamed on our inability to make muscles, or flesh, artificially.

2. AMOEBA AND ITS MOVEMENT

Since it is impossible to make a real muscle artificially, and thus to study the mechanism of its action, we have to find some other way to free ourselves from our ignorance. We have to start the investigations on a simpler type of living thing. As such we select those small animals which consist of one single cell, the so-called protozoa, the lowest type of animal. They constitute the major portion of the fauna in midocean, but are found also on land, in ponds and rivers; in short, everywhere.

The simplest of these primitive creatures are the Amoebae, one of which is the Amoeba Proteus. This animal can be found by searching, with the aid of a microscope, in the water of stagnant pools. It is only $\frac{1}{4}$ of a millimeter in diameter, glassy looking and irregularly shaped, invisible to the naked eye. Even with a microscope it is not easy to distinguish it from microscopic bits of non-living matter such as sand particles, which are likewise glassy looking. Because it constantly changes its shape, an Amoeba can be discriminated from these particles. This change is effected by projections pushed out from the soft mass of which the Amoeba consists; the projections are called pseudopodia. They undergo the most diversified alterations of size and shape. At times they may be withdrawn, while other processes are slowly pushed out at other places. (Fig. 60.)

At the same time careful watching shows that the Amoeba is also changing its position, although this is done with extreme slowness. It moves by a kind of streaming motion. A projection forms itself on one side, and the entire substance of the Amoeba gradually streams into it. A fresh projection appears toward the same side; the streaming movement is repeated. The Amoeba moves along very slowly, so slowly in fact that it takes close watching to detect it. (Fig. 61.)

The essential feature of the movement of Amoeba is a streaming of its internal liquid substance. No continued locomotion can be observed unless accompanied by this streaming, the main streams being invariably in the direction in which the Amoeba is moving. Wherever pseudopodia are formed, the mass in the center of the pseudopodium rapidly flows forward. It then turns back at the periphery, but flows at a much slower rate. On account of the greater rapidity of the forward movement, the pseudopodium extends.

Judging from the nature of the movements, we are obliged to infer that the substance of which Amoeba is composed must be soft and semi-fluid. Yet it preserves a sharp contour; consequently, it must be either immiscible in water, or surrounded by a membrane or skin. Further observations show that there is a membrane since the outer portion

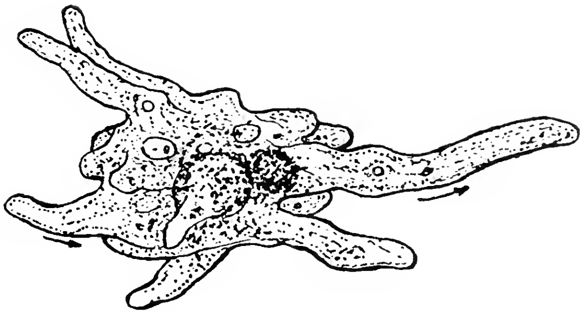


FIG. 60. AMOEBA PROTEUS FLOATING IN WATER

This is a one-celled animal consisting of a soft, almost liquid, material which changes its form continuously. As indicated in the figure by arrows, some of the protrusions of the animal, termed pseudopodia, retract while others are extended. (Magnified 200 times.)

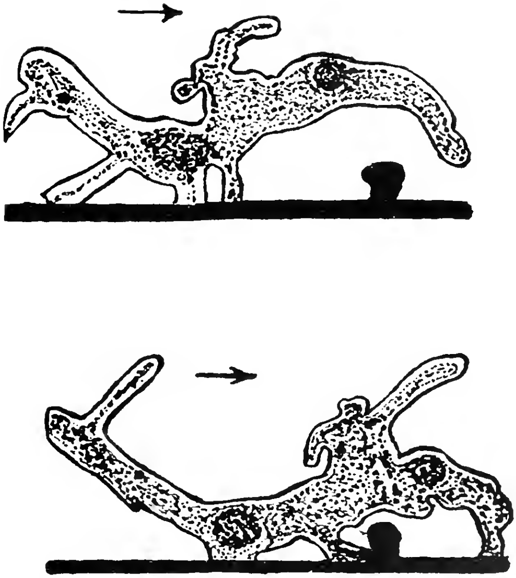


FIG. 61. AMOEBA MOVING FORWARD IN THE DIRECTION OF ARROW

The entire liquid body content of the amoeba streams forward as it moves on. The pseudopodia in front are extended while those in the rear are retracted. As the figure shows, the animal is thus enabled to overcome small obstalces by throwing the pseudopodia across these obstacles.

of the Amoeba is clearly distinguishable, by its glassy transparent appearance, from the internal portion which is granular.

Watching the Amoeba for some time, we observe that the streaming of its liquid content brings into the interior

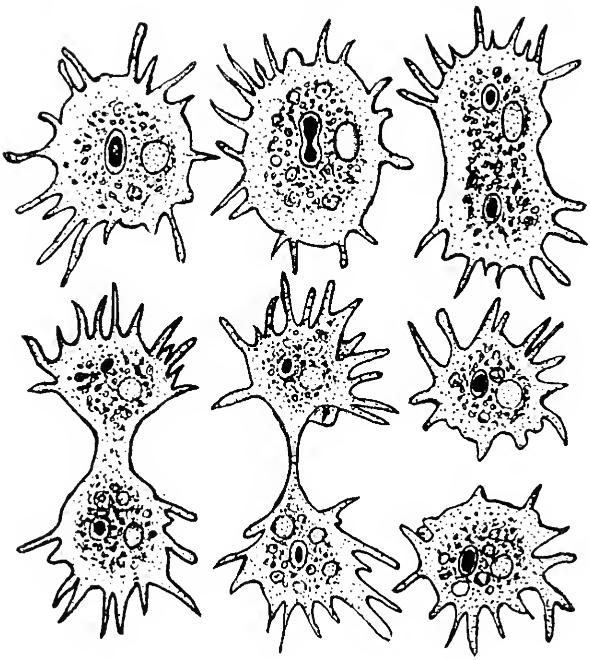


FIG. 62. THE SUCCESSIVE STAGES IN THE DIVISION OF AN AMOEBA

This sketch relates to another type of amoeba, polypodia. It shows how the amoeba gradually divides into two, the light spot indicating the location of the contractile vacuole, the dark spot that of the nucleus. The division begins with the nucleus. The remaining soft substance divides into two after two separate nuclei have formed at opposite ends.

certain particles of an organic nature, which are the potential food for the animal. A process, pseudopodium, of the Amoeba is pressed against such a particle of food, which becomes sunk in its soft substance and gradually passes into the interior. Here it is surrounded by a drop of watery fluid, and by degrees disappears. It is digested which means transformed into the body substance of the Amoeba by the enzymes present. Along with this digestible matter, useless inorganic matter is occasionally taken, but this remains unchanged and is soon thrown out again.

The digested matter which thus disappears obviously mixes with the liquid matter of the Amoeba and adds to its bulk. When food is abundant and the bulk of the animal has considerably increased, another striking change appears; a fissure appears at the outer border of the Amoeba, dividing it into two parts. This fissure grows inwards, the two parts separate more and more, until finally the separation becomes complete, and we have two distinct Amoebae from the division of the one. This is an example of a "cell division"; it represents the primitive mode of propagation of these one-celled animals. (Fig. 62.)

3. AMOEBOID MOVEMENT OF OIL-DROPS

In former centuries, an animal as primitive as the Amoeba would hardly have been looked upon as alive, since it altogether lacks such differentiated organs as muscles for moving, a stomach and intestine for digestion, and genital organs for reproduction, which are elaborately developed in the higher animals. The Amoeba performs all these functions—and still looks like a simple oil-drop.

The question presents itself whether any plain oil-drop is capable of producing similar movements. An answer would obviously enable us to judge whether forces of the non-living world determine the behavior of the Amoeba.

Experience shows that a simple oil-drop does act like Amoeba; it can perform movements which resemble those of the animal in almost every detail, even some of the complicated processes, such as digestion and extrusion (excretion). We may observe an oil-drop of any description: olive oil, cotton-seed oil, rape-seed oil, oil of clove, or any other plant oil. The oil-drop is placed in water, to which

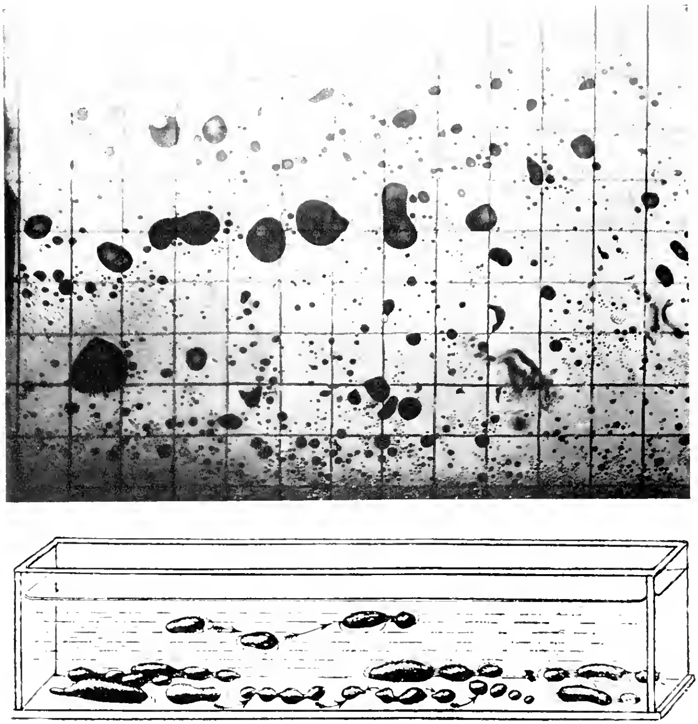


FIG. 63 A. MOVING OIL-DROPS SHOWING AMOEBA-LIKE MOVEMENT

This picture and the next were obtained through the courtesy of A. L. Herrera of Mexico City. The oil is a mixture of one part of olive oil with four parts of gasoline; it floats in a water solution containing 6 per cent soda. The photograph shows the distortion of the droplets by protrusions, giving some of them an ovoid or dumb-bell shape.

should be added some other substance which tends to interact with the oil-drop or to dissolve it.

Figure 63 shows the movements of oil-drops of this kind. The photograph on top is a "flash" from which we recognize the elongated and distorted shape of the moving drops.

The diagrams below indicate the type of movement. The writer is much indebted to Dr. A. L. Herrera of Mexico who very kindly sent him these pictures. The water in which

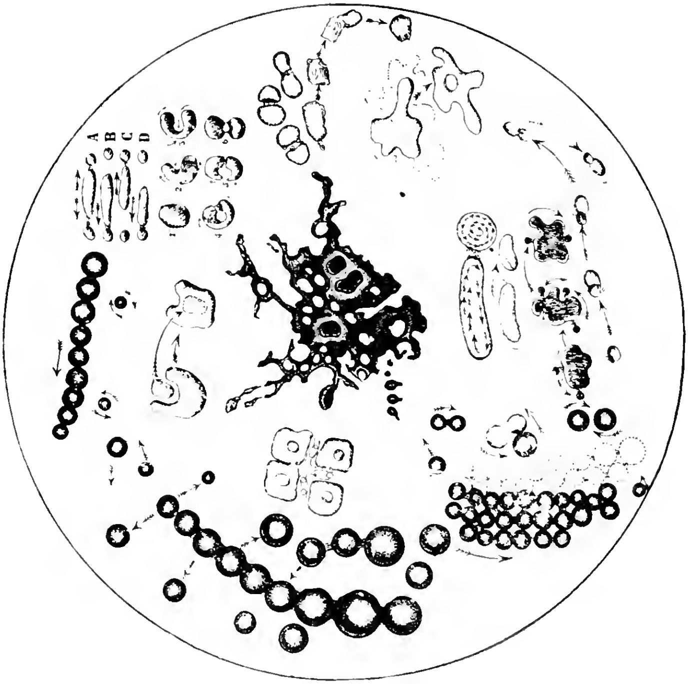


FIG. 63 B. A DIAGRAM DEPICTING THE MOVEMENT OF OIL-DROPS

Herrera was so impressed with the life-like movements of these oil-drops and particularly the mutual suction which they exert upon each other that he has given them a name reminiscent of the animal kingdom, colpoids. (One-half natural size.)

the drops move contains soda which is the necessary addition tending to interact with the oil chemically.

Dr. H. S. Jennings, Professor of Zoology at Johns Hopkins University of Baltimore, has studied moving oil-drops by means of a similar technique in which he uses olive oil floating in glycerin; he adds alcohol as the substance which interacts with the oil or tends to dissolve it. From his vivid description of his experiments we quote the following:

A drop of oil is mounted on an ordinary glass slide in a mixture of three parts of glycerin with one part of 96 per cent alcohol and covered with a cover glass. The oil and alcohol are miscible, so that a little alcohol is continually passing into the drop of oil, a little of the oil into the alcohol." [The glycerin acts as a neutral medium to prevent a too rapid interaction of the oil and the alcohol.] Such a drop of oil will change its form, send out "pseudopodia," and creep about much as "amoeba" does. At first it may be circular, then a long projection will be sent out on the one side, the entire drop may elongate and progress as a whole in that direction. Currents may be formed within it, "pseudopodia" may extend in several directions at once; at times, the drop may divide—as also happens in Amoeba. Altogether, the drop of oil imitates with some degree of closeness the behavior of Amoeba.

That a local chemical change taking place within the Amoeba, (producing thus a new substance in a certain area), might cause the formation of a pseudopodium, and movement in a certain direction may be illustrated by introducing some chemically different substance into a certain region of the drop of oil. A very satisfactory method is to inject a little 70 per cent alcohol into the drop near one side. Take up a small drop of the alcohol in a pipette drawn to a very fine point; introduce this beneath the coverglass and into the drop, and press out a very little of the alcohol into the drop, removing the pipette at once. If this is skilfully done, and not too much alcohol is added, the drop will at once send out a "pseudopodium" on the side nearest which the alcohol was introduced, and often follows this up by moving in that direction. Of course, if the alcohol (or any other substance having less surface tension than the oil) could have been produced through a chemical change within the oil, the resulting movement would be the same.

From these experiments on oil drops, it appears that the protrusion which resembles a pseudopodium of the Amoeba is the result of what is termed a lowering of surface tension.

What is meant by surface tension? It is a force tending to contract surfaces. But what is meant by "force," anyway? Well, the much used term "force" is just an expression designating the cause of any action.

The action with which we have to deal here is simply the rounding up of the oil to a nearly globe-shaped drop. We may say the drop of oil is acting as though it were constricted by a force acting equally all around the drop, the "surface tension." Now, the magnitude of this force is diminished, if an interacting substance, such as alcohol, is contained in the oil. If the alcohol is injected into the oil-drop on one side, as described by Jennings, the diminution of the contracting force must lead to a distortion of the regular round shape of the drop. The contracting force surrounding most of the surface of the drop will, of necessity, squeeze out the oil at any place where the surface tension is lowered. We see, therefore, how the formation of "pseudopodia" in the oil-drop comes about.

If the alcohol is not injected into the oil-drop but added to the surrounding liquid, it will penetrate into the drop, but at one point more than at the neighboring point, thus causing a lowering of surface tension on one side and giving rise to amoeboid movement.

Why should we assume that a different sort of force acts in the Amoeba? There is no reason for such an assumption, but in order to demonstrate this point beyond doubt, we shall compare the movements of the oil-drop and of the Amoeba with respect to many different details, as follows:

A. *Internal Streaming*

As described, the protrusion of pseudopodia in Amoeba is accompanied by an internal streaming motion (a rapid forward streaming in the center and a slower returning near the margin). Exactly the same type of streaming is observed in an oil-drop. (Fig. 64, turn to next page.)

B. *The Tortuous Path*

As the Amoeba slowly moves in the water by protrusion of pseudopodia, its path is very tortuous, since the direction of these protruding extensions varies from second to second. Exactly the same is true for the oil-drop. This feature can best be demonstrated with a drop of a heavy oil, or oil-like substance, for instance chloroform. A drop of this heavy liquid, when placed in a container of water, will drop to the bottom and stay there. An experiment is performed by first coating a glass container on the inside with shellac, allowing this lacquer to dry well, then filling the beaker with water and finally placing a drop of chloroform in it.

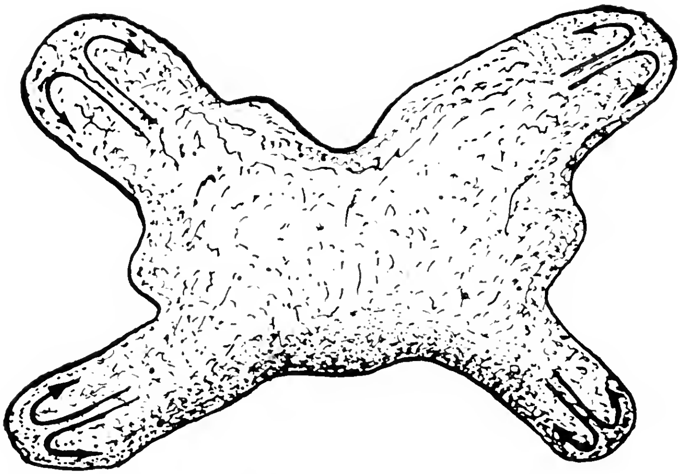


FIG. 64. INTERNAL STREAMING IN AN OIL-DROP AS PROTRUSIONS ARE FORMED

Exactly as in the Amoeba, the oil streams rapidly forward in the center of the protrusion then the stream turns around at the periphery, flowing at a slow rate. (Magnified 5 times.)

Such a drop will at once begin to creep around; like the Amoeba it will extend a "pseudopodium" first in one direction: this attaches itself to the shellac and pulls the drop behind it. Another protrusion of the drop appears elsewhere, attaches itself and pulls the drop in another direction. Along the pathway of the drop the shellac is being partly dissolved, so the pathway shows as a broad light band on a darker background. (Fig. 65.)

FIG. 65. TORTUOUS PATH OF A DROP OF HEAVY OIL (CHLOROFORM) ON A SHELLAC PLATE

Such an oil drop moves around in much the same manner as an amoeba through the extension of protrusions; compare figure 61. In the Amoeba the direction in which these pseudopodia are extended is frequently varied. Consequently, the pathway over which the animal travels is a very tortuous one. The same is true for the pathway of a moving oil drop as shown in this figure. The pathway is rendered visible through the dissolution of some of the shellac of the underlying shellacked plate. (One-half natural size.)

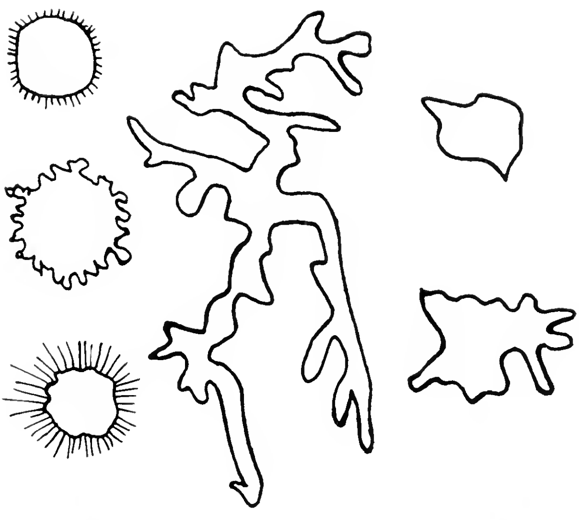


FIG. 66. DIAGRAMS OF THE VARIOUS AMOEBA-LIKE FORMS WHICH CAN BE PRODUCED BY OIL-DROPS

The shape of the oil drop depends on the kind of oil used and on the addition of various substances to the watery solution in which the drop is floating. Almost any outline of one-celled animals can thus be imitated by artificial methods. (Natural size.)

C. The Shape of Pseudopodia

There are many different species of Amoeba. One of their marks of distinction is the form of their pseudopodia. Some animals have extremely slender ones, so that they resemble delicate hairs, of which a large number surrounds the Amoeba everywhere; other animals have broad pseudopodia which, when protruding, seem to distort the entire animal.

Experiments with oil-drops show that their protrusions can likewise be produced in any form, by using various kinds of oil and different additions to the surrounding water. Figure 66 shows how the oil drop can be distorted, or caused to send out protrusions in the most diversified manner.

In the oil-drop the varying shape is the result of the chemical composition of the oil, or of the surrounding watery solution. It is very likely that a similar factor accounts for the shapes of the various species of Amoeba.

D. The Selection of Food

In the selection of its food, the Amoeba also shows a most striking resemblance to an oil-drop, incredible as this may seem. H. S. Jennings, Professor of Zoology at Johns Hopkins University describes this resemblance very clearly:

> One of the most striking phenomena in the behaviour of Amoeba is its power of selecting substances which shall serve as food. Amoeba takes its food simply by sending out pseudopodia, flowing around and enveloping small bodies. But it by no means takes these at random; sand, decayed plant tissue, bits of wood, dirt, etc., are as a rule rejected, while small living plant and animal cells, diatoms, infusoria, are enveloped, carried away and digested. It thus shows a distinct choice in the substances which it takes into itself, and the power of choice has often been considered evidence of a rather highly developed mind.
>
> Before accepting this conclusion for Amoeba, it will be wise to test this matter of the power of choice for other fluids. A drop of chloroform is a good subject for experimentation. With a medicine dropper a drop of chloroform may be placed in the bottom of a watch-glass of water, and then with fine tweezers we may offer it various substances to test its power of

choice. The whole proceeding may seem at first thought very absurd, but the results are striking.

We may first offer the drop of chloroform a fragment of glass; this is held with the tweezers against the surface of the drop. It is not accepted. We push the glass against the drop, but the latter withdraws its surface from it as far as possible. We force the bit of glass into the drop of chloroform and let go of it. It is at once thrown out with energy. We try a small piece of wood in the same way; it is rejected as decidedly as was the glass. We may now try a hard piece of gum shellac. This is accepted eagerly, one had almost said. Hardly has an angle of the piece of shellac touched the surface of the drop, when the latter literally reaches out, envelops the shellac and draws it into itself. If we take hold of the piece of shellac again with the forceps and draw it away, the chloroform drop stretches out after it, and lets go of it only with the greatest apparent reluctance. If allowed to retain the bit of shellac, it proceeds slowly to dissolve it,—just as the Amoeba proceeds to digest the substance which it has taken within itself. A second and a third piece of shellac will be accepted with the same avidity as the first.

Other substances may be offered to the chloroform drop. Glass, sand, dirt, wood, grass, gum arabic, and chlorate of potash, for example, are rejected; shellac, paraffin, styrax, hard Canada balsam, and various other substances are accepted.

It thus appears that a drop of chloroform exercises choice in determining what substances will be taken into itself, fully as decidedly as Amoeba does. The same is true of other fluids, of whatever sort. We must then throw out completely the power of choice of food as any test of mental power or even of life. Amoeba merely shares this power with all other masses of fluid. It is a suggestive fact, and one which has possibly a deep significance, that the chloroform drop (or other fluids) tends to take into itself especially such substances as will dissolve within it, or have a chemical affinity for it, just as Amoeba tends to take within itself substances which it can digest.

E. The Intake of Long Pieces of Food

The intake of long pieces of food larger than itself is another striking feature of Amoeba. Can the oil-drop perform such a seemingly difficult task? Professor Jennings' colorful description answers this question:

The method by which Amoeba takes a small particle of food is very similar to that by which the chloroform drop takes within itself a bit of gum shellac. The protoplasm simply flows over and envelops the food particle. But at times the problem presented to the Amoeba, if food is to be obtained, is much more difficult. Sometimes the food available is in the form of a long thread of alga, many times the length of the Amoeba. How is such an awkward piece of material to be managed? There seem to be only two possibilities for getting such a long thread into a short Amoeba. One is to cut it into lengths, the other to coil it up. Amoeba has no teeth for cutting up the thread, so it adopts the plan of coiling it. Individuals engaged in this process are sometimes found among the specimens studied in the laboratory.

The Amoeba first settles itself upon the filament somewhere in its length, and envelops a portion of it. It stretches out a slight distance along the

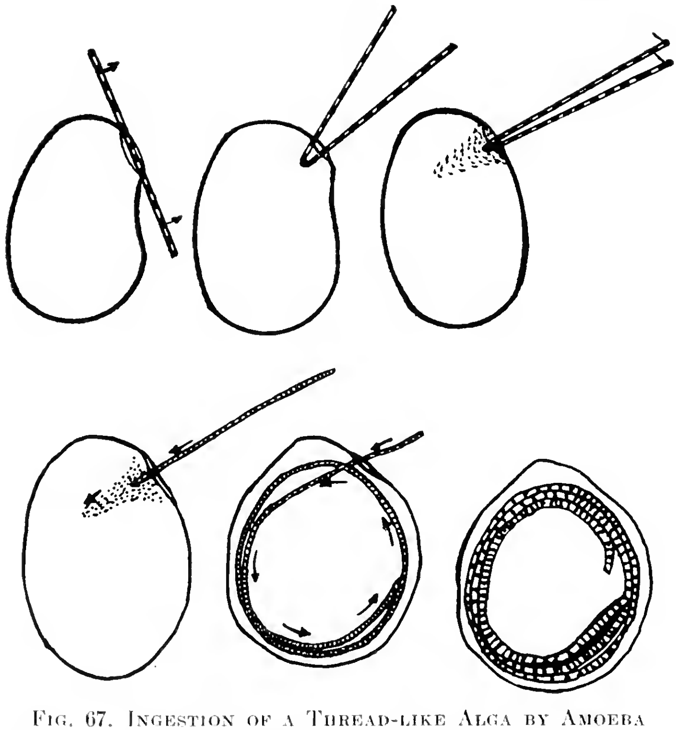


FIG. 67. INGESTION OF A THREAD-LIKE ALGA BY AMOEBA

The tiny lump of protoplasm, the so-called Amoeba, handles a long thread of alga many times its own length in the manner indicated on the diagram. (Magnified 50 times.)

thread, then bends over, of course bending the filament at the same time. The bending is continued until there is a loop formed within the Amoeba. The animal now continues to stretch out along the two ends and to bend them over, till the loop is doubled, tripled, and a coil is in process of formation. This is continued until the entire filament is rolled up into a neat little coil within the Amoeba, where it is digested. (Fig. 67.)

What are we to say to such a clever solution of a somewhat difficult problem as we have here? Must we not admit to Amoeba the power of grasping a situation and intelligently adapting means to end or overcome difficulties—qualities which we are accustomed to consider as characteristic of minds in a high degree of development?

It will be well in this case, as in others, to test inorganic fluids before deciding what is to be thought of this matter. Suppose we present a similar problem to our chloroform drop; how will it meet the situation?

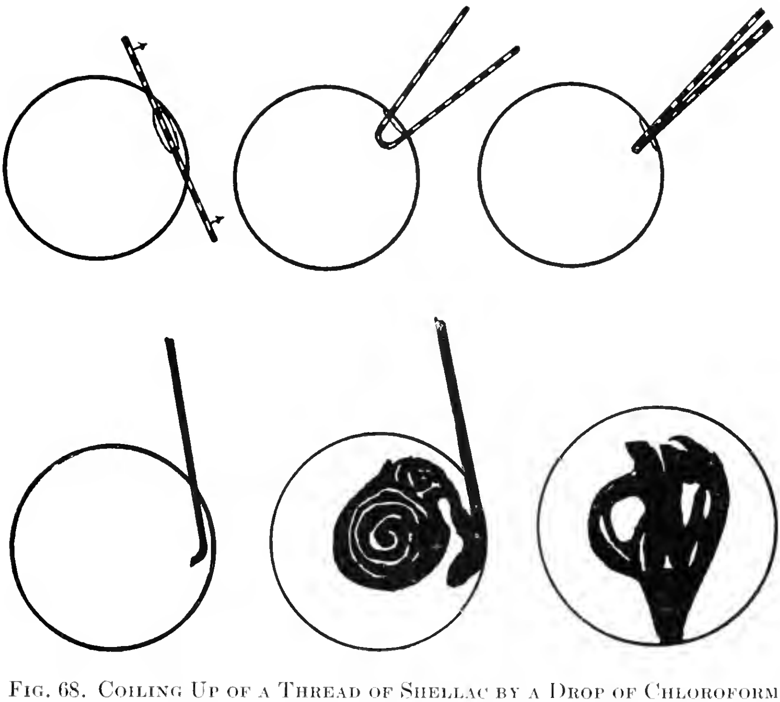


Fig. 68. Coiling Up of a Thread of Shellac by a Drop of Chloroform under Water

This diagram shows that the chloroform drop rivals the Amoeba. (Magnified 5 times.)

We may try the experiment as before, with a drop of chloroform at the bottom of a watch-glass of water. As the chloroform drop accepts hard shellac, we may present it with a bit of shellac drawn out into a long, fine thread, of length many times the diameter of the chloroform drop (Fig. 68).

The chloroform envelops the filament in some portion of its length, just as Amoeba did. Then it stretches out in both directions along the thread, exactly as was done by Amoeba. This is most striking when a drop of chloroform floating on the surface of the water is used, though the experiment is otherwise much more difficult to perform under these circumstances. Thereupon the thread bends, exactly as with Amoeba. The process now continues, precisely parallel with what occurs in the case of Amoeba and the alga thread, until the shellac thread is coiled up within the chloroform drop, like a filament of an alga within an Amoeba. . . .

(Chloroform is a liquid which is heavier than water and does not mix with it. Hence it usually sinks to the bottom of water. Small droplets of chloroform, however, may float on top, being held there by surface tension.)

F. Defecation

It seems almost ridiculous to speak of defecation in the Amoeba, which is not much more than a drop without any body openings. What is meant here is the expelling from the body of the Amoeba of certain indigestible particles, for instance of sand, which were embedded in soft plant food which the animal had taken. The Amoeba first takes up all it can and expels the sand later.

It would seem that an oil-drop is incapable of imitating this procedure, for one could hardly expect the oil-drop to defecate. And yet it is done. To demonstrate this point we proceed as follows: A tiny thread of glass is coated with shellac. Upon touching it with the chloroform drop, the drop will "devour" it. The coated glass thread is kept inside the drop until the shellac coat is dissolved. As soon as this is done, the drop "defecates" or expels this naked bit of glass, but retains the shellac. (According to an experiment described by a German Scientist, L. Rhumbler.)

G. Shells of Sand or Glass Fragments

Another striking feature capable of imitation is the formation of shells of sand around certain other primitive animals, which Professor Jennings describes (Cp. Figs. 69 and 70):

As is well known, Difflugia, one of the close relatives of Amoeba, lives in a shell formed of sand grains, diatom shells, and other small particles

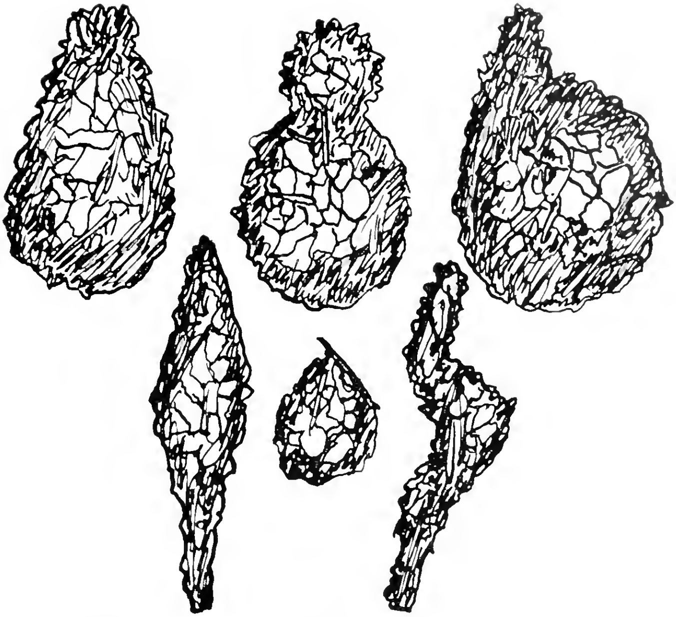


FIG. 69. CHLOROFORM DROPS SURROUNDED BY A SHELL OF GLASS FRAGMENTS

The sketch indicates now the glass fragments tightly surround and enclose the chloroform which also has taken on various irregular elongated shapes. (Magnified 5 times.)

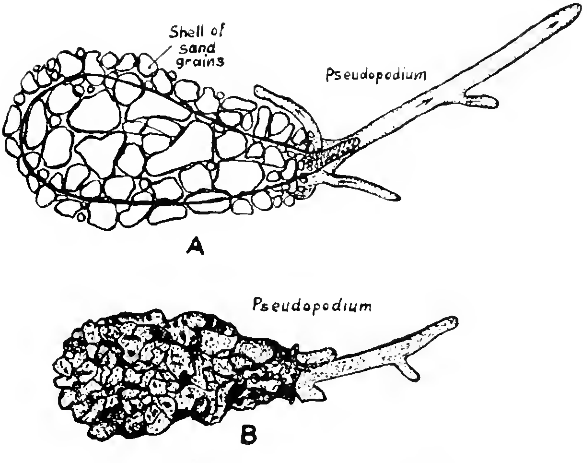


FIG. 70. DIFFLUGIA PYRIFORMIS

For comparison with the chloroform here is a diagrammatic (*a*) and a surface view (*b*) of one of the most common species of Difflugia. (Magnified 100 times.) (From Hegner, *Invertebrate Zoology*, New York, 1933.)

cemented together. These particles are fitted together accurately in a single layer, so that no crevices can be discovered. How are these delicate houses built? It would seem that the process must require much care, skill, and intelligence, to select the proper pieces and put them together with such nicety that the shell is but a single layer thick, and yet no gaps are left.

But the drop of chloroform is not to be outdone, and under the proper conditions will produce a shell not inferior to that of Difflugia. This may be shown very simply. Chloroform is rubbed up with fragments of glass in a mortar until the glass is reduced to the finest dust. Then, with a pipette drawn out to a small point, drops of this mixture of chloroform and glass dust are injected into water. At once the grains of glass come to the surface of the drops so formed and arrange themselves there in a single layer, without chinks or crevices, exactly as in the shell of Difflugia. The chloroform drop is covered with a shell of a delicacy and beauty equal to that of Difflugia, and almost indistinguishable in texture from it. Some of these artificial shells, if unexpectedly found with the microscope, would certainly be taken for those of Difflugia. . . In place of chloroform, linseed oil or other oil may be used. They must be injected into 70 per cent alcohol, since the oil would float upon water. The process is exactly the same as when chloroform is used.

4. OIL-DROPS EXTRACTED FROM THE BRAIN OF FRESHLY KILLED ANIMALS

All these experiments demonstrate the close approximation of the behavior of the most primitive animals and a simple oil-drop. Who would suppose that the mysteries of life are capable of such simple explanation? Where is the vital force if an oil-drop can move about, select its food, devour it, and organize itself in very much the same manner as the simplest animal?

Apparently forces similar to those acting in plain oil-drops are responsible for the movement of Amoeba. But what forces act in the more highly developed animals? The working of a muscle cannot be so readily matched by the behavior of an oil-drop. Must we resort to an assumption of vital forces in this case?

Obviously the application of the term, vital force, is arbitrary. Before the similarity of the oil-drop to the Amoeba was recognized, all the movements of Amoeba seemed to be the result of a vital force. Nowadays there is no necessity for such an assumption, but vital force is still thought to play a part in unexplained phenomena, such as the contraction of a muscle. Does it not seem more reasonable to admit our ignorance and to make serious attempts to develop experimentation to a higher level?

The very fact that the experiments described can be performed with *any* kind of oil indicates that they must be deficient in some respect. The liquid matter of an Amoeba is certainly different from any simple oil. One point of distinction is that in the Amoeba—as in all living things—chemical changes are continually occurring. In the course of these changes substances are being formed which diminish the surface tension and consequently lead to the protrusion of pseudopodia. Nothing of the kind occurs in a simple oil-drop; "pseudopodia" will protrude from it only if a substance such as alcohol is added to lower surface tension.

But it should also be possible to find an oil in which certain chemical changes occur. A droplet of such oil might produce within itself substances which diminish the surface tension thus imitating more satisfactorily the conditions prevailing in Amoeba. Can such an oil be obtained?

This task has been solved through work undertaken at the suggestion of Dr. G. W. Crile, surgeon and scientist of Cleveland, Ohio, who conceived the idea of studying the actions of materials extracted from the brain of freshly-killed animals. With the cooperation of an excellent experimentalist, Dr. M. Telkes, who worked in Crile's research laboratory in the Cleveland Clinic, this idea was carried out in 1931. Dr. Telkes extracted the oil from the brain of freshly-killed rabbits so skillfully as to preserve at least some of the essential properties of the material, particularly its enzymes (chemical activators).

Just as olive-oil is pressed from ripe olives, or cotton-seed oil from the seeds contained in cotton, so it is possible to extract the oil or fat contained in an animal's brain. The difficulty is that brain tissues contain about 90 per cent water. Dr. Telkes removed this by a very careful drying of the fresh brain-substance, using only low temperatures, as heating would have destroyed the enzymes in it, and thus its life-like properties. After the drying process was complete, the substance was placed in ether which dissolved only the fat-like material. The ether and the fatty substances dissolved in it were poured off, leaving behind a fat-free material. From this remaining fat-free substance, the portion soluble in water was removed by dissolving it in a salt solution. Dr. Telkes thus obtained two solutions from the original brain tissue. The first solution—in ether as solvent—contained all the fat-like materials of the brain. The second solution—in water as solvent—contained some of the protein material of the brain; moreover those salts were added which are known to be contained in the brain.

In order to produce microscopic drops of the fresh brain-oil, one single large drop of the first solution is dropped into a glassful of the second. The drop now breaks up to form many tiny droplets. The ether contained in the drops is evaporated by blowing air through the watery solution. The oil-droplets are not visible to the naked eye singly, but they make the water slightly turbid. (Of course, any oil forms droplets in water. The reader may be familiar with the appearance of a glass of water to which he has added a few drops of a mouth wash containing some oil, as many of them do. The slight turbidity indicates the presence of microscopic oil droplets.)

The single small droplets floating in the water solution of brain substance are then viewed under the microscope. They present a striking appearance; we see that they send out protrusions resembling pseudopodia, move around, and exhibit cell division. The protrusions are in most cases slender and thread-like. (Fig. 71.) If the droplets float in

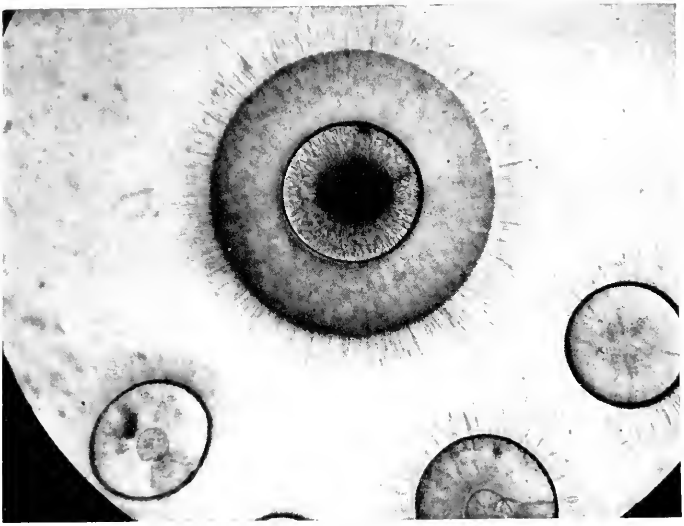


FIG. 71. OIL-DROPS FRESHLY EXTRACTED FROM THE BRAIN OF A HEALTHY RABBIT

It is seen that these oil-drops contain a water-drop in the center, that thin hairlike protrusions also grow from it at the outer surface as well as in the water-drop in the center. (Magnified 200 times.)

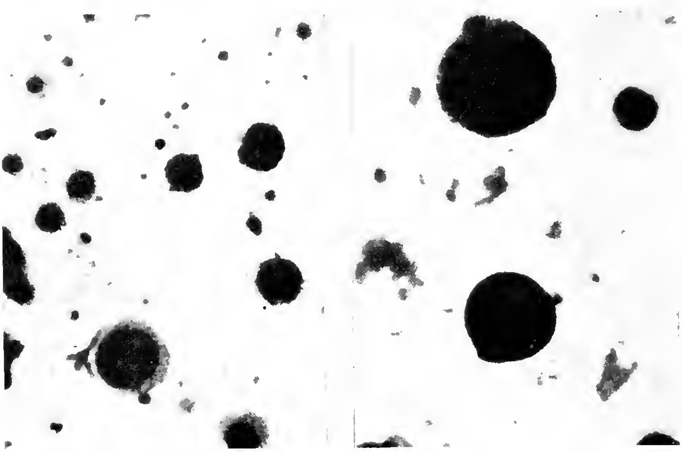


FIG. 73. OIL-DROPS OBTAINED FROM THE BRAIN OF A DISEASED ANIMAL

These oil-drops were obtained in the same manner as those in Figures 71 and 72. Note the absence of structures. (Magnified 400 times.)

a more alkaline solution they may be very broad. (Fig. 72.) It will be remembered that the simple oil-drops were also capable of sending out either thin pseudopodia or quite broad ones (Fig. 66).

The droplets of fresh brain-oil are obviously more involved than those of an ordinary oil like olive oil. Those with slender protrusions have a special structure in their center which gives them a strange appearance, as an inspection of Figure 71 shows. At first glance this center structure looks like the nucleus of a living cell. In reality it is a small drop of water enclosed in the oil droplet. Into this internal droplet of water, the same kind of slender pseudopodia will grow as grow from the periphery of the drop. This double development, from the periphery as well as to the inside, gives the whole structure its peculiar appearance, remotely reminding one of a living cell. But it would be absurd to maintain that an oil-droplet from fresh material is alive. A true life-like growth signifies an increase of the mass, and this never occurs in the oil-drop. On the contrary, it decreases in size after many hairlike pseudopodia have protruded from it.

The outstanding feature of living things is that chemical changes occur in them. Is it possible to demonstrate chemical changes in these oil-drops?

The chemical changes occurring most commonly in the animal body are those of respiration. These include the taking in of the oxygen of the air which is used to burn a part of the body material. Modern scientists have developed methods which make it possible to measure the degree of this respiration even with very small fragments of excised tissues, or with only a few living bacteria, in spite of their diminutive size. Dr. Telkes made the important discovery that droplets of brain-fat also exhibit respiration, thus demonstrating that chemical reactions occur in this fat. In the course of these reactions, substances are formed

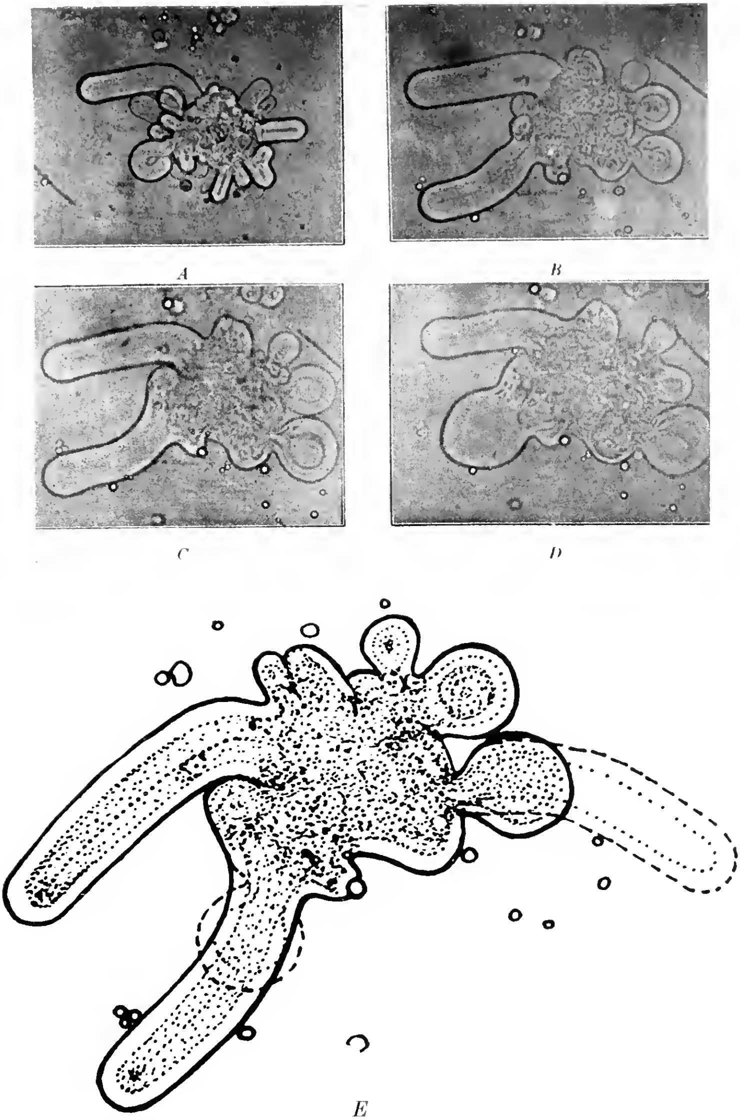


Fig. 72. Another Kind of Oil-Drop Freshly Prepared from Rabbit Brain

If the brain oil is placed in a more alkaline solution, the shape of the drop varies considerably. It is no longer round but shows an irregular contour, closely resembling that of a real Amoeba with broad pseudopodia protruding from it (Fig. 66). In order to develop these protrusions the oil-drop needs nourishment and air or respiration, as does the Amoeba. The pictures are of the same oil-drop, all magnified 400 times. *A* at the beginning; *B* three hours later; *C* six hours later; and *D* nine hours later. The slow protruding and retracting of the pseudopodia can be distinctly observed.

E is a diagram of this oil drop; dotted lines indicate the extension and retraction of the "pseudopodia".

which lower surface tension and give rise to the movements described; observe particularly Figure 72. We have thus realized the aim of our experimentation to obtain an oil in which chemical reactions occur, leading to surface changes and Amoeboid movements.

Although an addition of alcohol is necessary to produce Amoeboid movements in ordinary oil, (recall the experiment described on page 164) the oil freshly extracted from brain will more closely and spontaneously imitate the movement of an Amoeba if it is not disturbed by the addition of an agent like alcohol. Nevertheless the experiments with an ordinary oil are of value, although the results are very crude compared to the living cell. We need a crude imitation, if we wish to grasp the essential feature of a vital process which is shrouded in the deepest mystery. This first step is the most difficult one, for there is no compass to guide us, no logic or reasoning to help. Consequently this type of work seems uninteresting, particularly to those who are highly intellectual. Once a basis has been found, the human mind may more easily draw conclusions, or initiate further development by analogy or inference.

5. DEGENERATION, POISONING, SUFFOCATION, AND STARVATION IN MAN, ANIMAL, AMOEBA. . . AND IN THE OIL-DROP

The oil-drops studied by Dr. Telkes develop their peculiar structure only if the oil has been extracted from the brain of a previously healthy animal. Dr. Telkes obtained different results with an oil extracted from the brain of a rabbit which had died from extreme exhaustion, occurring after the animal had been kept awake for four days. The droplets made from the brain of this animal no longer exhibit the peculiar appearance characterized by outgrowths of tiny fibers, but appear as plain round drops, as will be seen by a comparison of Figures 71 and 73 (see page 177). From this remarkable finding we may conclude that, through nervous exhaustion, the very substance of the brain is changed.

Another striking feature of the oil-drops freshly prepared from brain is that they can be poisoned. Every one is familiar with the action of poisons upon human health and life. Science has made a special study of those poisons that do not act upon all organs at the same rate. They strike only certain portions of the body, but may strike so hard that this part is completely paralyzed. Usually some vital portion of the brain is thrown out of gear. The consequence is extremely grave; death quickly follows in most cases. To this class belong strychnine, morphine, and many others.

Many of these poisons act also upon the Amoeba. The poisoning is recognized by the disappearance of the pseudopodia while the animal becomes stationary and rounds up. After a while the cell falls into shreds which gradually dissolve. The same poisons will also "kill" the oil-drop. The drop no longer grows hairlike processes, nor maintains the internal structure described, but rounds up to a dark massive drop, like the oil obtained from the brain of exhausted animals. It is of great importance that we can study in this manner the action of poisons on oil-drops of brain-fat. Life in the usual sense of the word cannot possibly reside in an oil-drop; only certain life-like properties have been retained by it. These properties are destroyed by poison and the drop rounds up. Here is a specific action which is not exhibited by other artificial structures such as the inorganic growths of Leduc (Figs. 39–52), which are quite different from living things as far as their chemical make-up is concerned; nor is this specification exhibited in oil-drops of ordinary oil.

The nature of the specific action by which the poison acts on the brain-fat-drop has been investigated by Dr. Telkes. The action comes about through an inhibition of respiration of the oil drop (described above, page 178) as has been demonstrated particularly for the drops with broad pseudopodia shown in Figure 72. The slow retraction or extension of these protrusions can only occur if the drop respires. Poisons which arrest the respiration stop these slow movements at once. (Fig. 73.)

Another method of suppressing respiration is to prevent access of air to the oil drop by keeping the water in which it floats in a closed container. Presently all the oxygen of the air is consumed. The oil-drop shrivels in such air-free water, just as if poisons had been added. We may say that the oil-drop has been suffocated. (The Amoeba also can be suffocated, if it is kept in water from which all the dissolved air has been removed, and access of air prevented; it will then disintegrate and die.)

It certainly is worth while to reproduce in lifeless oil-drops properties like respiration, poisoning, or suffocation—as demonstrated directly or by the disappearance of a structure. All these properties are usually regarded as exclusively pertaining to living animals.

The oil-drop from fresh brain material can also be starved like an animal. Dr. Telkes showed that the development of this oil-drop does not occur if it is kept in pure water, without the water-soluble brain constituents (the second solution described on page 176). These brain constituents play the rôle of food for the oil-drop. The material which is burned up in respiration is not taken from the oil-drop itself but from the dissolved material in the solution. Oil-drops from fresh brain-material which float in pure water have nothing to burn. Under these conditions they fail to develop like a "well-nourished" oil-drop, with pseudopodia.

6. ARTIFICIAL CELLS AND POLITICS

The oil-drops prepared from freshly extracted brain material are of considerable importance in our attempt to understand the complex machinery which serves for motion in men and animals. Yet little enthusiasm for this important line of work has been aroused among scientists.

When Dr. G. W. Crile first described the surprising properties of these oil-drops from fresh brain material, he designated them as "autosynthetic cells." No reference was made to the fact that these cells are liquid throughout.

The knowledge of this writer about "autosynthetic cells" was not derived from the reports of Dr. Crile's clinic, but rather from personal inspection of the experiments performed there, and from repeating the experiments independently. In this work the writer had the invaluable advice of Dr. R. Chambers of New York University, who is extraordinarily expert on cell studies, and the inventor of one of the methods of micromanipulation. (Micromanipulation means the handling of the most diminutive objects—such as cells—under the microscope by the help of an intricate and delicate apparatus.) Dr. Chambers skillfully demonstrated to the writer at Woods Hole in 1931, that autosynthetic cells are nothing more than oil drops in spite of all their life-like properties.

The research workers of the Cleveland Clinic are not the only ones who attempted to name some special type of artificial cells. The same was done by A. L. Herrera of Mexico who has made it his task to discover new artificial structures of many sorts. He calls the entire field of his activity "plasmogeny" and uses striking semi-zoological names for whatever appears to him as particularly interesting. His "colpoids," for instance, are oil-drops consisting of motor gasoline and olive oil suspended in a water solution of soda; they move around in much the same fashion as other oil-drops, perhaps a little faster on account of the addition of gasoline which flows very easily. Any zoological nomenclature of this type is apt to produce the erroneous impression that the objects are really alive; such an opinion would hardly be upheld by a skilful experimenter like Dr. Herrera.

The account of much of the work done with moving oil-drops is indefinite and lamentably poor. Here is a vast field of research in which some noteworthy results have already been achieved, a few of which are described above. Herrera, in particular, has made many valuable experiments. But we must realize that in these scientific attempts—as in all human activities—certain rules cannot be neglected.

Scientific workers should never draw suspicious conclusions from their findings as, for instance, to say that moving oil-drops represent a form of life. If they violate this unwritten law, all of their results will be dumped into the waste basket of disregard—even if real treasures are contained therein. Another unwritten law by which every scientist must abide forbids the announcement in the lay press of unverified results that may give rise to general misconceptions. The public, of course, cannot possibly be informed on all details of every line of scientific research, hundreds of which are being pursued.

Concerning the so-called artificial cells, misunderstandings are very prone to arise on account of the wide-spread idea that "the cell is the unit and carrier of life." The cell as a unit of life is one of those meaningless slogans which arise through a misunderstanding of modern scientific specialization. The meaning of the "unit of life" is rather hazy. One may think of the growth of single cells, taken from an animal body, in an artificial nutritive medium. Such cells develop and multiply without direction or purpose in their own characteristic fashion. Each of these cells may be called a "unit of life," but such artificially grown living cells develop differently from those growing in the body. The body as a whole needs all its highly diversified cells for its functioning, as well as its non-cellular material, such as the blood fluid.

The cell is nothing more than one of countless other structures frequently occurring in plants or animals. It is a unit of life in the same sense as the legs or arms are units of life, since they are parts of a living human body. It should also be remembered that there are living things—the viruses—so small that they cannot consist of cells at all, since they consist of only a single molecule, to use the language of the chemist. Hence there are cases in which the unit of life, if there is any, is much smaller than the cell.

Moreover cells, or at least what looks like them, can be found also in non-living matter. The "autosynthetic cells" and the "colpoids" are by no means the only representatives of artificial cells. The old artificial cells of Traube, bags of a gelatin precipitate, have already been mentioned. Any or all of the artificial osmotic structures may also be designated as artificial cells, or perhaps, in some cases, as aggregates of artificial cells. Each of these cells imitates some definite feature of living cells. Each of these models is of value in the interpretation of life phenomena. Thus Traube's cell throws some light upon the origin and the importance of the cell membrane, while the various oil-drop cells explain cell movements and other features.

These facts are not generally known. Any announcement that artificial cells have been made may be hastily seized upon as the dawning of a new era. This explains the strange train of events which occurred early in 1931, when a news reporter of the *Chicago Tribune* came into the research laboratory of the Cleveland Clinic and took a look through a microscope at one of those oil-drops from fresh brain material. Not knowing what he saw, he believed it to be artificial life or something near it. While under this impression, he sent a red hot report to the *Tribune*, which was rendered still more exciting by the reporter's statement that he was the first layman to see this discovery and particularly that he did so without the proper permission of the administration of the Clinic. The first statement appearing in the *Tribune* was nevertheless quite moderate and authentic. But as the news spread to other papers, it became more and more exaggerated. Finally, it was cabled to Europe in a form that produced the impression that Dr. Crile had succeeded in making new life without progenitors, in the laboratory.

7. NERVES AND MUSCLES

In spite of all our efforts, we have accomplished no more than a partial understanding of the movements of the most primitive organisms. Hardly anything is understood concerning the mechanism of the muscles by which the more highly developed organisms move. The muscle is, moreover, no independent organ of motion; it can only work if connected with a nerve from which it receives a stimulus, which causes it to contract. It cannot even exist without a nerve, since it fades away if its nerve is severed.

A muscle consists of thousands of fibers and each fiber in turn is a bundle of still smaller fibers, or fibrils. Each nerve consists of several thousand nerve-fibers, just as a cable consists of a bundle of single wires. A microscopic view of a muscle and of a nerve-fiber is shown in Figure 74. All nerve-fibers ending in muscles form a part of an intricately interwoven system of countless other nerve-fibers, all of which terminate in the brain. The brain itself may be looked upon as a most highly-involved network of billions of nerve fibers, which form billions or trillions of interconnecting pathways. From this inextricable maze there emerge other fibers which terminate in the skin, or in the sense organs such as the eye, ear, nose, and mouth. These fibers carry sensations from the skin first to the brain.

A multitude of pathways thus exists for the propagation of all those impulses which arise by sensation of touch, pain, heat or cold, or through the eye, ear or other sense organs. These impulses pass through the fiber net-work of the brain or spinal cord, and terminate in muscles, glands, or other organs which they excite.

The nervous system acts not only upon the muscles which are subject to our will, but also upon all the internal organs. These organs are provided with a special set of nerve fibers

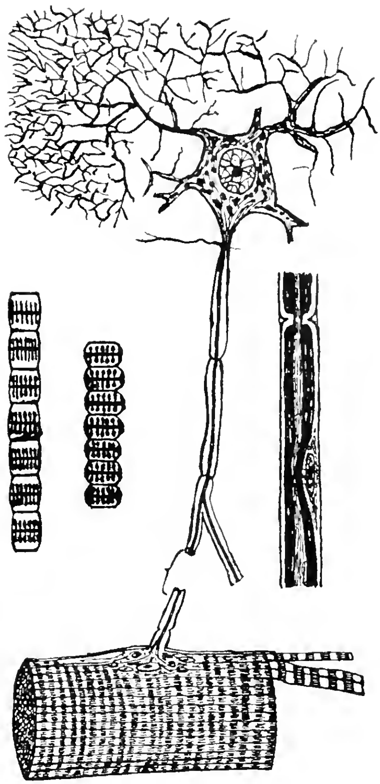


FIG. 74. DIAGRAMMATIC VIEW OF A NERVE FIBER AND A MUSCLE CELL AND THEIR INTERRELATION

The picture shows the highly involved make-up of nerve and muscle cells, billions of which are in our body. In the upper part of the picture the nerve-cell with its numberless nerve-fibers is seen. One of the fibers is particularly magnified and its details pictured. Below, the termination of the nerve on a highly magnified muscle fiber is pictured. It is seen also that the muscle fiber in turn consists of an immense number of smaller fibers each of which shows peculiar cross striation. At the left are highly magnified pictures of one such small muscle fibril. At the right is a highly magnified aspect of a single nerve fiber.

which do not directly connect the internal organs with the brain, but pass first through a number of intermediate relays or ganglia, as they are called. In this manner a separate division of the nervous system is formed, which although not subject to our will, depends upon the general condition of the brain, the state of emotion, and on numerous other highly involved factors.

The following statement taken from Dr. Alexis Carrel's recent book, *Man the Unknown*, eloquently describes the stupendous complexity of the brain: "Our intelligence can no more realize the immensity of the brain than the extent of the sidereal universe. The cerebral substance contains more than twelve thousand millions of cells. These cells are connected with one another by fibrils, and each fibril possesses several branches. By means of these fibrils, they associate several trillions of times. And this prodigious crowd of tiny individuals and invisible fibrils, despite its undreamed-of complexity, works as if it were essentially one."[1]

It would perhaps take more than a lifetime to describe all the details of the nervous system. The task of grasping its purpose and the mode of its functioning presents still greater difficulties. But no one dares even to guess at present how such a stupendously complex piece of machinery could have developed from the ocean-born self-regenerating enzymes or the primitive first cells which came from them. No one can explain at present how matter came to possess the faculty of organizing itself in such a manner. And yet this problem is the real aim and ultimate goal of scientific research. Some day in a remote future science will be prepared to attack it.

8. THE NATURE OF THE NERVE IMPULSE

In a thousand different ways nature performs its marvelous work in the living world. We are slow to recognize

[1] Quoted with the special permission of the publishers, Harper & Brothers, of New York.

it. In the daily rush of our lives few of us find leisure to listen attentively to its pulse, to explore the secret of its actions.

Let us embark on another journey of exploration, this time into the wonderland of the electrical actions which occur in the animal body. Here we hope to find a clue leading to an understanding of the nature of the nerve impulse. What is that strange agent that travels along the nerve fiber and after reaching the muscle elicits a contraction? After more than a century of investigation, much evidence has now accumulated to show that it is electrical in nature. It may seem natural to consider a nerve as a kind of electrical telegraph wire, sending messages from the brain to the muscles and other parts of the body. But such a comparison is hardly more than a play on words. On closer inspection it appears that a nerve and an electrical telegraph wire are radically different. The distinction manifests itself in the following points:

1. The wire consists of a metal, usually copper, which is an excellent conductor of the electrical current; the nerve fiber contains some sort of fatty material which is insulating.

2. An electrical current requires a closed circuit; hence two wires are needed to connect an object through which the current flows; in some cases the second wire may be replaced by the moist ground, by a system of conducting water pipes, by the rails in the case of electric locomotives, but there are always two conductors.

In the nerve-fiber, there is only one connection.

3. But more than all that: the propagation of the current along a wire occurs with the velocity of light, 186,000 miles per second, an incomprehensible speed.

In the nerve the impulse travels at approximately the speed limits of an automobile, varying somewhat according to the size of the nerve fiber.

Although not identical with an electrical current the impulse is nevertheless electrical in nature, since sensitive electrical instruments demonstrate that a negative electrical charge travels along the nerve fiber simultaneously with this impulse. What is meant here by electrical charge and how can it travel along the nerve fiber?

The charge in question is quite similar to that of a lead battery in an automobile, which—as is well known—often needs recharging. This battery consists of lead plates immersed in sulfuric acid. The charge is effected by sending a direct electric current through the battery which brings about certain chemical changes at the surface of the lead plates. These chemical changes constitute the charge. If the battery is discharged by connecting with the starter or with the lights, the chemical changes are reversed.

In order to form a conception of what may occur in the nerve fiber, we should imagine a lead-battery plate drawn out to a thin wire, surrounded on all sides by a thin layer of sulfuric acid. We then imagine this wire to be charged at one end by connecting it to the negative pole of a battery and by connecting the surrounding layer of sulfuric acid with the other pole of the battery, so that a current flows only through one end of the wire and the acid at the same end. One end of the wire would thus be charged and the rest remain uncharged, in a manner indicated diagrammatically in Figure 75. Assuming that such a wire acts in the same manner as a nerve-fiber, the following changes would occur automatically after disconnection of the charging battery. The charged end of the wire would generate a local current which flows through the adjacent uncharged portion, as indicated by a dotted line in the diagram. The adjacent portion of the wire would thereby become charged, at the expense of the initially charged end. The portion of the wire near the end, which has thus become charged, would act

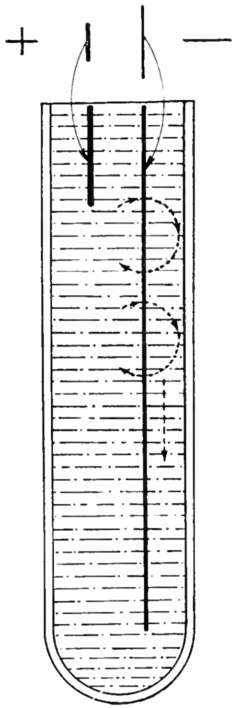


FIG. 75. DIAGRAM ILLUSTRATING THE MODE OF ORIGIN AND PROPAGATION OF AN ELECTRICAL CHARGE ON A WIRE SURROUNDED BY ACID

This diagram illustrates how a wandering electrical charge on a wire can arise. Imagine an electrical battery, one plate of which is drawn out to a long thin wire. The upper end of the wire is charged by connecting it with a negative pole of a battery and closing the circuit with another short piece of wire. This short wire is in contact with the acid and connected with the other pole of the charged battery.

in the same manner upon the next adjacent part of the wire, and this, in turn, on the next section. In this fashion the negative charge might travel on.

Unfortunately, experiments disprove our assumption that the electric charge can travel along a lead wire. We can charge the wire at one end, but this charge will *not* travel on. The solution of the problem of the nerve impulse was greatly handicapped by this failure, as well as the futility of other hypotheses propounded until, in 1918, Dr. R. S. Lillie, now a professor at the University of Chicago, demonstrated the correct way of carrying out the experiment. All we have to do, according to Lillie's suggestion, is to substitute an iron wire for a lead wire in the set-up and, instead of moistening it with sulfuric acid, immerse it in a narrow vertical tube filled with nitric acid solution containing 55% of that acid. (A previous treatment of the iron wire is also necessary: it is immersed for a short time in concentrated acid.)

If such a wire is charged at one end in the manner indicated in figure 76, the charge will actually travel along the wire. The electric negative charge of an iron wire manifests itself through visible chemical changes: a darkening of the formerly bright surface of the wire, and a development of small bubbles of hydrogen gas.

These visible changes are seen to sweep along the surface of the wire. Here we have a propagation of an electrical wave that is of the same type as that which travels along the nerve. It is not an electrical current passing through the wire. If it were, it would pass with a velocity far greater than our vision could follow. We can see that it moves at the rate of a few inches a second, which is the average velocity of the propagation of the nerve impulse. In many other respects, this traveling charge resembles the nerve impulse. The more we study it, the more similarities we find, so that we are finally forced to the conclusion that both are identical in type.

Dr. Lillie has demonstrated a close similarity between the traveling charge on the iron wire and the nerve impulse with respect to the following details:

1. *Various modes of stimulation.* A nerve can be stimulated electrically, or by irritant chemical agents such as acids, or simply by striking, tearing and stretching.

The traveling charge on the iron wire can be initiated not only by an electrical current, but by acids or other substances that touch the wire. Tapping or bending the wire will do it. This finding is not surprising since the charge of a battery in an automobile drops after violent shaking by riding over rough roads, as many a driver knows from experience.

2. *Importance of the direction of the flow of the current.* In order to charge a battery the current must be sent through it in the right direction. Many a driver has found out that his battery was dead after it had been connected with the generator with the poles reversed.

If the nerve impulse is comparable to a traveling electric charge, one anticipates that the direction of the flow is of prime importance. This is found to be the case: stated in scientific terms, stimulation is a "polar phenomenon."

3. *The "refractory period."* For a short time after an impulse has passed along a nerve-fiber, the fiber does not conduct. It has become "refractory." In exactly the same manner the iron wire fails to conduct after one charge has passed over it; a second charge immediately applied will not travel on. It certainly is noteworthy that even this special feature of nervous excitability finds its analogy. In the wire as well as in the nerve this "refractory period" keeps the waves traveling in one direction. The wave cannot run back over that portion of the nerve, or wire, over which it has just traveled since this portion does not conduct.

4. *Rhythmic nerve impulses and waves.* In most living animals we observe periodic and automatic movements, of which the beating heart is the best known example. Engines include mechanical devices such as the distributor, which ignites the cylinders at regularly repeated intervals, timed synchronously with the movements of the valves. In a beating heart, there is also harmonious timing of all its different muscles, accomplished without any rotating device or anything remotely resembling a timing shaft. The living organism, has means that are far simpler and yet as effective as complicated modern machinery. In the human heart, which beats 75 to 80 times a minute, each beat is initiated by a nerve impulse originating in the sinus node in the upper portion of the heart. From this point a bundle of fibers passes downward; the impulse thus spreads and causes a contraction of the various parts of the heart, one after the other. The most mysterious part of the action is the origin of the impulse in the sinus node.

Yet there is nothing peculiarly "vital" in such a rhythm. Iron wires immersed in nitric acid likewise show it. The best method of observing the effect is to surround the wire near one end with a narrow tube. (Fig. 76.) This end is then charged in the usual manner. Owing to the narrow tube around it, it remains charged and continuously sends traveling charges along the wire at regular intervals.

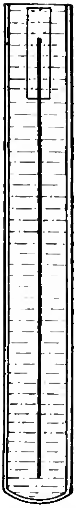


FIG. 76. SET-UP FOR GENERATING RHYTHMIC DISCHARGES

The upper end of the wire is enclosed in a narrow glass tube. When this end is charged as described in Figure 75, the end enclosed in the tube remains charged and continuously sends out rhythmic waves. One wave follows another at regular intervals.

This is an example of a "pacemaker." A similar mechanism exists in the upper part of the heart where a bundle of nerve fibers connected with the sinus node sends out impulses eighty times a minute. Each impulse initiates one regular contraction of the heart. It is remarkable that with a simple iron wire immersed in acid and surrounded by a glass-tube a regular sequence of traveling electrical waves can be produced which resemble closely the automatic impulses by which the heart is kept in motion.

9. THE PRODUCTION OF ELECTRIC CHARGES AND OF ELECTRIC CURRENTS IN LIVING TISSUE

We find valuable clues as to the nature of the nerve impulse by comparing the nerve-fiber with a battery plate drawn out to a wire, but there must also be distinctions. Ordinary commercial batteries work by means of their metallic plates, but nerves and other living tissues contain no metals at all. Instead they do have various kinds of fatty material and proteins. Can those organic materials give rise to electrical charges and currents?

Science has investigated and discussed this problem for 150 years; still the solution is not at hand and may not be for another century or two. Formerly it was even questioned whether living tissue can give rise to electric currents, but at present there can be no doubt about it.

To form an idea of the magnitude of the electric effects produced by tissue, we may compare them to those of ordinary batteries. The charge of a flashlight battery is measured whenever it is sold in a store; a single cell of such a battery, when it is good and fresh, measures 1.5 volts. The charge of a lead battery as used in automobiles is 2 volts for each cell. Since there are usually three cells connected in series, the entire battery has a charge of 6 volts. But the charge which travels along a nerve fiber is much smaller, only 0.05 to 0.1 volt. This feeble charge is generated in an unknown manner somewhere in the brain or other tissue.

There are, however, instances in which animal tissue may give rise to very much larger charges: in certain types of "electric fish" the charge may rise to nearly 100 volts. These creatures have special electric organs which consist of very thin discs, superimposed like stacked-up squares. These discs are made of fat, or a similar material, and are separated by a liquid, or by gelatinized layers of some sort. The whole electric organ thus resembles a Volta cell or a modern "layer-built" battery commonly on sale in radio stores. They consist of alternating layers of metallic plates with gelatinized watery layers between them. The electric organ of a fish is also layer-built, but substitutes layers of fat or some other organic material for metallic plates. Each layer of this organ is extremely small, but all together make up for their size by their quantity and thus are able to produce really high voltage currents—high enough to kill other fish in the vicinity.

Such electrical organs exist only in fish, and are found in many of them without relation to the affinity of groups. The "torpedoes," which are flat like a skate, are one of these groups. Fishermen give them a number of nicknames, all of which have reference to the effect felt when grasping the fish. They can produce a discharge which is quite disagreeable, although hardly ever dangerous. In order to experience this, the fish should be held with the whole hand, passing the palm under the belly and pressing the thumb on the back. The current produced by the fish will then pass from the thumb to the palm of the hand, since the "vital" electric batteries are arranged vertically to the large surface. The shock is sometimes so strong that it is felt in the arm and even in the shoulder and in the side. This intense effect upon a human being gives us an idea of what can happen in the water when such electrical shocks are brought to bear upon the small creatures there. The electrical battery in the fish is only discharged when the fish is excited; in other words, it takes a nerve impulse to connect, somehow, the battery to the outside and produce the electrical currents.

To another group belongs the most powerful of all electric fish, the electric eel of the Amazon River, which grows to a length of six feet. (Fig. 77.) Zoologically it is not related to ordinary eels. Its electrical capacity is far beyond that of any other fish. On each side it has one large electrical organ, reaching from the fore part of the trunk to the tail. This electrical organ consists of prismatic columns placed side by side; but the columns are divided horizontally in this fish and not vertically as in the torpedo. Consequently we find a difference in the direction of the current discharged. In the torpedo the positive pole is above, the negative pole below; in the electrical eel the positive pole is in front and the negative pole behind. (Fig. 78.)

The arrangement of the batteries in the eel is obviously very effective as a weapon. Under the action of nerve impulses passing from the brain of the fish, its whole body

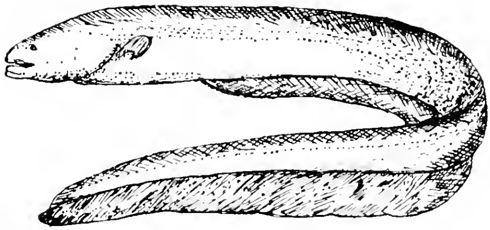


FIG. 77. THE ELECTRIC EEL

This fish has the most powerful electrical organs known; it can dispense shocks approximating a voltage of 100 volts.

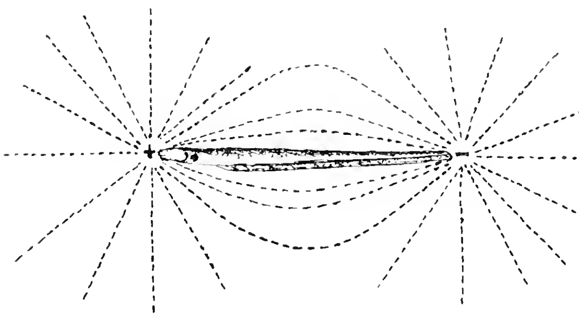


FIG. 78. LINES OF ELECTRIC DISCHARGE IN THE ELECTRIC EEL

becomes a powerful electric battery. The lines of current radiate around the positive pole in front to join the negative pole behind. (Fig. 78.) This body, producing electricity of high voltage, is surrounded by water, which is a good conductor. Smaller fish that come within the sphere of these currents are electrocuted even if they do not touch the eel, particularly since the movements of the pursuing eel adds to this effectiveness. By bringing the head closer to the tail, the fish diminishes the distance between the poles and makes the discharge correspondingly stronger. It has been reported that a full-grown electric eel can knock down a horse which happens to step on it.

This marvelous living battery with all its baffling actions is a real enigma. It contains not only a high-voltage battery, but also a device which connects this battery with the water on the outside, for discharge. The nerve impulses from the brain of the fish make this connection automatically for a fraction of a second only. At rapidly succeeding intervals, the battery is turned off and on, many times a minute. These intermittent discharges of current are more dangerous to the victims than a continuous current.

If we attempted to make such a powerful and rapid action with a machine we should have to set up a very complicated device. We should need an automatic intermittent contact, and a battery weighing probably 100 times as much as the whole fish. Metal would be everywhere in this machinery: in the battery plates, in the wiring system. The fish, however, dispenses deadly electric shocks without any machinery, without the slightest metallic particle, his battery consisting entirely of plates of fat of some kind, in place of the metal. Is it possible to make a battery containing fat-layers with some aqueous solution between them, instead of metal plates in a watery solution?

The problem has been investigated by this writer. After much experimentation, he found out how to set up an artificial battery system containing fat layers similar to those in the electric fish. It is a general rule that any battery must be composed of plates of different composition in order to produce an electric current, and this rule applies also to an artificial fat battery. No electric charge or current would be produced if the consecutive fat-layers in it were identical. It is necessary to use differently composed fat-layers and to alternate them, as well as to insert salt-solution layers. A set-up of this type is capable of producing electric charges of an intensity which compares favorably with the living battery of the eel. Another secret has thus been snatched from nature; batteries without any metal can be made artificially which means that the living battery can be better understood. Continued investigation and closer comparison discloses numerous similarities between these artificial fat batteries and the batteries existing in living tissues.

We can now understand why the comparison of a nerve-fiber, consisting of fat, with a battery plate, consisting of metal, is justifiable. Fat-layers act like metals in several ways with respect to electrical properties. This is why the animal organism can behave like an electrical mechanism, although of a type wholly different from the electrical apparatus which is in practical use for various purposes.

10. THE MODE OF ACTION OF POISONS AND DRUGS

Every driver of a car knows that his battery must be filled up periodically with pure distilled water. Tap water, which contains traces of ordinary table salt, should never be used. Traces of this salt if added to the battery interact chemically with the positive plate and destroy it. Corrosive chlorine gas is formed which in turn passes to the nearby negative pole, thus destroying the entire battery beyond repair.

We have seen that a nerve impulse is a traveling electrical charge and that the living organism can produce electric charges like an electric battery. If the crude lead battery of our cars is so sensitive to salt, should we not expect the living battery with its traveling electric charges to be still more likely to be put out of commission by poison? We realize, of course, that the lead battery and the living battery differ in other respects. Living organisms are not poisoned by ordinary salt which "kills" the battery, but by certain other substances, real poisons such as strychnine.

This line of thought leads to the surprising conclusion that poisons may kill by an interference with the electrical mechanism through which the functioning of our nervous system, and hence our life, is maintained. It is certain that strong electrical currents, when passing through our body, interfere with the same electrical mechanism, and that this interference is the cause of their deadly action. Poisons would therefore seem to kill in the same manner as an electrical shock. This conclusion seems to be particularly applicable to those poisons which act on the brain and nerves (page 181). Evidence in favor of this explanation can be offered by demonstrating that a poison like strychnine will act upon the charge of one of those experimental batteries, composed of fat layers, that resemble the electric organ of the electric eel. Experiments by this writer have shown that this is the case; and that the amount of strychnine or another similar poison, necessary for such a purely electrical action, is quite small. A minute amount of strychnine is sufficient also for a fatal action in men or animals.

But it would not be wise to draw too sweeping conclusions from these analogies. Undoubtedly there are many other possibilities of explaining poisoning, for instance through an interference with the actions of the enzymes, those chemical activators which are in reality the essence of life. This latter explanation is at present preferred by most scientists.

ENTR' ACTE

ARTIFICIAL PARTHENOGENESIS

MITOGENETIC RAYS

EPILOGUE

ENTR' ACTE

The curtain falls on the array of artificial creatures and working mechanisms through which we have tried to understand the essence of life. We have met an odd-looking world that has taught us new truths. In outline at least, we can visualize how life came about: On the hot and sultry early earth, loaded with lifeless organic matter, violent thunderstorms raged. Unspeakably brilliant and powerful lightnings played in the heavens, loosing frightful forces upon the carbon containing gases of the atmosphere, bringing into existence numerous compounds of carbon. After millions of years, self-regenerating enzymes were formed. The amount of these substances constantly and inevitably increased, inevitably because their peculiar chemical action led to the marvel of transformation of other organic material into the enzyme itself. Thus one enzyme produced another, filling the oceans with material more and more closely resembling the substance of living plants and animals.

Slowly the organizing forces of crystallization and of osmosis acted upon this material: living organisms appeared and kept on developing to a bewildering multitude, of incomprehensible complexity. We stand aghast at this development; we turn from it to look into the abyss of our ignorance. Countless other organizing forces of nature must have been at work that we do not understand; we only feebly understand those we have explored.

But let us rejoice that we have made a start at the unraveling of some of them. Which of the ambitious little artificial creatures that we have studied reveal most to us of the essence of life phenomena? Let us question them all.

First, the crystalline growths. They do their utmost, and reproduce cells with a nucleus, spirals, fibers, nerve dendrites. We wonder how they do it without organic material. We find that living tissue also contains crystalline units. It is now less surprising that ordinary salt-crystals may assume life-like forms. They have taught us an important truth, as they leave the stage, but we want to learn more.

The invisibly small viruses or "living molecules" seem promising. They teach us how life may have arisen, how chemistry rules and regulates it. But we ought to be able to make such molecules artificially, to make a living pure substance, or "self-reproducing enzyme." Why can't chemistry do it? The research chemist tells us this is asking too much. "Give me several more centuries," he says, shrugging a shoulder; "it is a short period in view of the fact that life started on the earth a billion years ago." The parade passes on.

"Life came from the ocean" is the catch-word of the next group that passes in the parade; "study salt and water, as well as the forms which they produce, and you will find the secret of life." We follow their advice faithfully, and are indeed rewarded. We learn about the expanding and constricting force of osmotic pressure. How these ambitious osmotic structures stretch and grow! Do they not look like real plants? Even expert botanists are fooled. We acclaim them enthusiastically. Still there is the air of failure about them; they are too brittle, too transient; their their poor mineral bodies cannot compete with organic structures. So the suggestion comes to us: why not make osmotic structures of real organic material, preferably by means of enzymes? But before we can explore the suggestion the parade has passed on.

Enter the last group, to show why and how living things move around. Indeed those little oil-drops are quite successful in teaching us the elements of motion in the living world; but the essence of the action of a real muscle remains obscure. We invoke that modern goddess, electricity, to explain to us how the nerves may function: she shows us her telegraph system as it acts in the nerve-fibers. We keep asking questions, but many remain unanswered.

We ought to know more, we cannot be satisfied yet; the play must go on. We search for other members for our cast but they are hard to find. Many other attempts to unravel the puzzle of life have been undertaken, but were only partly successful. We cannot review them all, but let us select two which seem promising: artificial parthenogenesis, and the mitogenic rays.

ARTIFICAL PARTHENOGENESIS

Parthenogenesis is one of those high-sounding Greek terms that are nevertheless easy to understand. It means literally birth by a virgin. It signifies the initiation of development of a new animal solely from the female of a species, without fertilization by a male. Artificial parthenogenesis means that the process is brought about by some agent in the laboratory; natural parthenogenesis means that it occurs normally.

Every animal, with the exception of the very lowest forms of life, develops from the egg-cell or ovum which has grown in the ovary of the female animal. Before it can develop, it must unite with the germ-cell of the male which is motile and known as the spermatozoon. The development of the fertilized ovum occurs in the body of the female animal (that is in mammals) where it is nourished by the mother's blood until birth. In birds and reptiles the fertilized ovum is deposited in an egg which contains an overabundance of nutrient matter around the microscopic germ-cell. In every case, the ovum or germ-cell is of microscopic size, usually barely visible to the naked eye as a diminutive dot, never corresponding to the size of the animal which develops from it. A whale or an elephant develops from a germ-cell which is not very much larger than that of a mouse. This development may appear as the most baffling wonder of nature but it loses some of its miraculous aspect if we consider the wealth of forms which may develop from simple salt-crystals in the artificial osmotic structures. The germ-cell is certainly more chemically complex than a plain salt; and it does seem likely that the chemical make-up is responsible for the wealth of its development.

The first stages of development of the fertilized ovum are much the same in all animals. The egg-cell, immediately after fertilization, surrounds itself with a protecting envelope. Inside of this envelope, it divides in two, then in four, then in eight, then in sixteen smaller cells and so for-

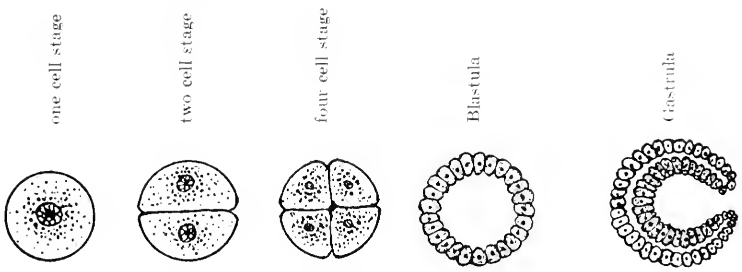


FIG. 79. DIAGRAM OF THE INITIAL STAGES OF THE DEVELOPMENT OF AN EGG-CELL

The diagram illustrates the successive stages of development; first, consecutive cell division by which the number of cells is increased from 1 to 2 to 4 to 8 to 16 to 32 to 64, etc.; second, the arrangement of the smaller cells thus formed into a blastula and subsequently into a gastrula, which is the initial form in the development of an animal. (Magnified 200 times.)

ward. The small cells thus formed group themselves to form a primitive organism, which soon develops further. In the lower types of animals that live in the ocean, both male and female shed their germ-cells, ovum and spermatozoon, directly into the ocean. Fertilization occurs due to the motility of the spermatozoon, which may hit upon an ovum. In this case the details of the process of fertilization can be readily watched under the microscope. The germ cells of sea urchins, starfish, or other invertebrate animals lend themselves particularly well to such experiments. All we need do is take some ova from the ovary of a sexually ripe female, suspend them in a little ocean water, then add some spermatozoon taken from a male, and observe the development under the microscope. The changes proceed with the regularity of clockwork. The ovum at once forms the fertilization membrane. After a few minutes the two-cell division occurs. After a few more minutes the four-cell stage is reached, and cell division proceeds. Finally the "blastula" and then the "gastrula" are formed, as pictured in Figure 79. After this, the animal begins to form a "larva," an initial form through which it passes in its development.

Biologists have long puzzled over how this initiation of the development through the sperm might be explained. It seemed that a definite answer had been found when Jacques Loeb announced in 1904 that he had succeeded in obtaining normal larvae from the unfertilized eggs of the sea-urchin by a certain treatment with acids and, subsequently, with strong salt solutions. Since Loeb disposed of one of the two parties to normal fertilization it might have seemed, to a superficial observer, that a 50% synthesis of the process of initiating new life was accomplished. This, of course, is by no means a reasonable interpretation of Loeb's experiments; the egg is far more essential to the development of the organism than is the sperm.

In many species the young develop from the ovum without fertilization by the male. Even Aristotle was aware of this, for he states that "bees produce drones without copulation." The same is true for ants, wasps, and other insects. In many cases, therefore, eggs develop without the spermatozoon. In other cases they cannot, but perhaps there is merely a slight handicap of some sort, removable by artificial means. Starting from some such assumption, experiments on artificial fertilization were undertaken by various workers a long time before Loeb entered the field, notably by T. H. Morgan, who treated eggs of sea-urchins and of worms with certain poisonous salts and observed that cell-division began. However the division did not seem to be the beginning of a development in these cases. It appeared to be a degeneration due to the poisonous action of the salts. On observing the degenerated products resulting from salt action on the delicate ova, the experimenters were led to the impression that any attempt to substitute artificial agents for such an exclusively "vital" agent as the fertilizing sperm would be doomed invariably to failure. Yet this unexpected success was achieved by J. Loeb a few years later, after initial experiments in which he too had unsatisfactory results. Whether his success was due to the freedom of his mind from prejudice or rather to his untiring and painstaking experimentation is hard to decide. At any rate the accomplishment was there; normal larvae of the sea urchin were obtained; nearly all eggs developed as they would after normal fertilization. The larvae exhibited a good vitality by swimming to the top of the aquarium like naturally-fertilized ones in contrast to the sickly individuals obtained in initial experiments which were unable to raise themselves that high. A substitute for the sperm had actually been found and it performed the function equally well, in this case at least.

Although Loeb was decidedly opposed to exaggerated conclusions drawn from his work, he hoped that definite evidence could be reached as to the nature of the fertilizing action of the spermatozoon. Even this, however, was very difficult to obtain. Loeb had devised a rather involved technique using two different agents, acid and strong salt solution. He attempted to show that these two agents, used consecutively, corresponded to the action of the sperm. Later, however, it was shown that under certain conditions the strong salt solution alone suffices to bring about the development of the egg-cell. Further progress to elucidate the nature of fertilization has not been possible.

Scientific discoveries hailed first as epoch-making, and later abandoned, are no rare occurrence in the science of life. The discovery of artificial parthenogenesis is one of these disappointing developments; all it has taught us is that a certain corrosion or destruction of the surface layer of the ovum may initiate its development, even in the absence of fertilization. This feature is also brought out by experiments on the artificial parthenogenesis of frog's eggs. The procedure carried out in this case consists in puncturing the eggs with a glass thread. It is a very crude method which works only in a very few cases. We can learn from these experiments that a mechanical impulse suffices to set the development of the ovum going, at least in some instances. Although not much has been learned about the mechanism of fertilization, we may look forward to future developments in the light of which we may hope to obtain a better understanding of the true significance of these vital processes.

THE MITOGENETIC RAYS

For many years Alexander Gurwitsch, formerly professor of histology at Moscow, now at the Institute for Experimental Medicine at Leningrad, had studied the incidence of cell-division in tissues under various conditions. His systematic investigations led him to the assumption that the immediate impulse which causes a cell to divide is not generated within the cell, but comes from an outside source. In order to divide, the cell must have manifestly reached a certain developmental stage, but even if it is ready and prepared to divide, Gurwitsch believed it took an impulse from the outside to set the division going. It seemed difficult, however, to find definite support for this assumption.

Finally in 1923 Gurwitsch resorted to a daring experiment in order to substantiate his view. He tested the possibility whether that extraneous impulse was transmitted to the cell in the form of a radiation. The outcome of this test, when performed under carefully controlled and favorable conditions, was successful in demonstrating the possibility that living tissue may send out rays which are capable of inciting cell-division in another tissue near it.

The initial experiment of Gurwitsch was carried out with a set-up in which two onion roots were held in close approximation, the one vertical, the other horizontal as indicated in Figure 80. After standing for several hours, sections of

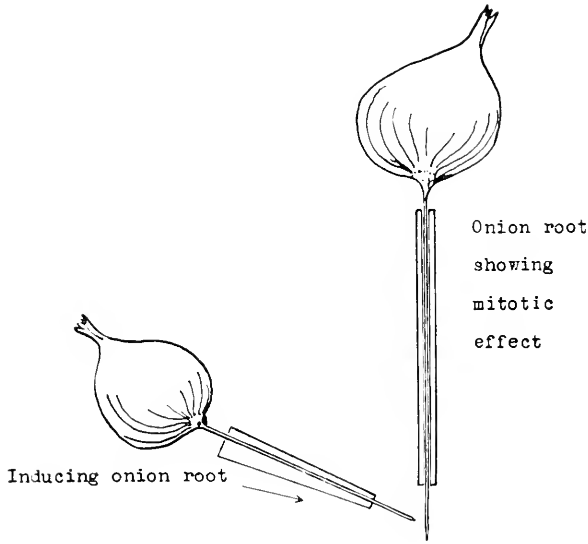


FIG. 80. TRACING MITOGENETIC RAYS IN THE ONION ROOT

The tip of the horizontal root sends out rays which act upon the vertical root. After an action of several hours we find in the vertical root a larger number of cells in the region opposite the tip of the other root. Many of these cells are still in the process of cell division. This effect comes from a radiation emanating from the root tip as can be definitely demonstrated. (According to Gurwitsch.)

the vertical roots were made. A larger number of cells, as compared with other regions, was then found in the vertical root in the region opposite the tip of the horizontal root.

The same observation is made if a thin sheet of quartz is interposed between the two roots, or if the inducing root is completely encased in quartz, but the effect disappears if glass is interposed or if the quartz lamella is covered with a layer of gelatin. The effect can also be transmitted through the reflections of a mirror. The increase in cell-division appears exactly at that spot where it would strike if it were a reflected ray. In such experiments pulp of onion roots may be used in place of whole root to produce the same effect. In the natural growth of the root, it is particularly the tip which is growing. The experiments of Gurwitsch indicate that this growing tip sends a radiation which acts on the second root.

The description of this new biological phenomenon excited considerable interest and instigated numerous attempts to repeat the experiments. However, considerable difficulty was experienced, since the effect is by no means readily observed. Numerous sources of error are present. It is not astonishing, therefore, that some experimenters, using the onion root method, have failed to find any mitogenetic radiation at all. Most of those who have seen positive results have obtained them only after initial negative observations.

In the further development of this research, Gurwitsch was assisted by many other scientists. They developed other more reliable and more convincing methods and the existence of such radiation was proved more definitely. Most of these methods are based on the increased cell-division of yeast. The conditions under which such radiation is sent out were investigated with great care, in an enormous number of observations by Gurwitsch and his associates. They found that almost any living plant, animal, or part taken from them, may exhibit such radiation.

However, the source of the radiation is not to be sought in the active growth or in the cell-division of any living thing. In fact tissues which are in active cell-division do not give off rays. Hence the term mitogenetic rays, meaning rays generated by cell-division, is really incorrect. On the contrary, the rays are used to bring about cell-division.

The origin of the rays is in certain chemical reactions in living tissues, as is shown by the possibility of producing rays through chemical reactions outside the body, in a test-tube. If any tissue sends out rays, it does so even if it is crushed to a pulp, showing again that it is not the living tissue as such which radiates, but the chemical reactions which occur in it.

Of particular interest is the finding of Gurwitsch and his associates that cancer-tissue emits a stronger and different type of rays. This may be a factor in the pernicious spread and growth of malignant cancers.

In view of the importance of the mitogenetic radiation, it seems strange that its presence has escaped the attention of scientists for such a long time, although we have long known of a great variety of special biological light-effects and light-emissions, such as the carbon dioxide assimilation of plants, which are influenced by light as described above. Failure to observe mitogenetic radiation (prior to Gurwitsch) may be due to the extremely low intensity of these rays. This is their outstanding physical property. It is very difficult, therefore, to trace this radiation independently; for instance, by the photographic plate. By the biological methods described, the radiation can be traced merely because of the marked sensitivity of the growing cell.

All these experiments show the great difficulties involved in the exploration of the very feeble forces which play an all important rôle in life processes, being comparable to the proverbial drops hollowing a stone. Gurwitsch has discovered some of these forces, in a lifetime of painstaking research work in the laboratory, and reported on his findings in numerous articles in scientific journals and some books. He has also developed a school of experimentation, in his home land, far away Russia. But unfortunately the rest of the world has not been able yet to learn of his skill in this delicate work.

Here is another difficulty which handicaps scientific progress: the very performance of the decisive experiments is so meticulous that few can repeat them. It would not be correct to say that Russia is the only country where these experiments on mitogenetic rays have ever been carried out successfully but probably nowhere else have scientists yet acquired that special skill and experience which is indispensable for the proper handling of these problems. Evidently the exchange of ideas and experiences at our international scientific congresses does not suffice to remove barriers which obstruct progress. A friend of science looks forward to a future of better communication between the students of nature.

EPILOGUE

As the curtain drops after the added scenes, the Manager of the Performance wonders how his show will be received by the critics and the public in general.

In the science of life, there are many problems and attempts to solve them, calculations, abstractions and hypotheses, experimental methods, special techniques, tabulated results, graphic presentations, statistical methods, applied mathematics, applied physics, and physical chemistry. What a mass of facts all presented with an honest effort, high expectations, lengthy discussions, and alas, so many delusions!

As a guide through this jungle we selected the approach by means of synthesis, a search for the origin of life on the earth, and for the characteristics of living and non-living nature. Is this the most appropriate mode of approach? Is our viewpoint superior to the old line of thought which looked upon life as existing only for its own purpose?

Our voice may not be heard in the uproar of antagonistic tendencies. It may seem that we have lost our way. Yet we have confidence that the time will come when views such as ours will be accepted at large.

What more has the Manager of the Performance to say? Some remarks should be added, he feels, about the highest developments of life: man and his mentality. Human life is, of course, the chief subject deserving of investigation. Many may readily agree with our assumption about the origin of life and its earliest development, but still maintain that we shall never be able to understand the nature of man's mental activity.

Yet there is nothing essentially mystical about the functioning of the brain. As we have already seen, the brain consists of an immense number of nerve fibers, billions of them. These form pathways which serve as outward conductors for the nerve impulses that enter the brain, by way of the sensory nerves, from such organs as the eyes and ears. The chief work of the brain is to select the pathways along which the nerve impulses travel through this jungle of fiber network. The pathway selected determines which muscles or other organs will move in following the stimulation of any given sense-organ.

Incidentally let us remember, at this point, that the nerve impulse which travels along a nerve fiber is an electric disturbance of a peculiar type but essentially the same as the electric charge which travels along a wire.

As experiments show, the pathway of an impulse depends largely on the pathways traveled by previous impulses. A subsequent impulse travels more easily over the pathway than did its predecessor. Since multitudes of nerve impulses from touch, seeing and hearing pass through the human nervous system all day long, each impulse soon has its established pathway. A pathway is much complicated by its branching in many directions, and even more by the "association tracts" which open up between several pathways.

Still another complication is the inhibition of one impulse by another incoming stimulus. The result is that many impulses do not cause any active movements at all. But they do prepare new pathways for impulses traveling over them later, which will elicit movements.

In a new-born baby, numerous tracts and associations of tracts form and constantly develop further. Later, interconnecting tracts open up between them. Memory and mental activity thus begin to develop. A number of associated tracts produce definite "memory images." Memory images once associated with each other are called into play on each subsequent occasion. Thus, the odor of a rose will call forth its image, its name, or even the visual images of persons or surroundings that were present on some former occasion when a rose was smelled.

The circle widens more and more as the interconnection between the tracts becomes more and more complex. By the joint function of memory images, observation transforms itself into perception. "Consciousness" is due to the fact that certain constituents of memory are constantly, or more frequently, produced than others. The complex of these elements of memory is the "ego" or the "soul" or the "personality." Some of the constituents of the memory complex are "the visual image of the body, certain sensations of touch repeated frequently, the sound of our own voices, certain interests, cares, and other impressions." (Quoted from E. Mack, Analyse der Empfindungen, Jena 1885).

The formation of memory impressions which constitute the basis of all training and education thus depends on the development of new functioning nerve tracts. This development, we might expect, would cease or decline in old age when every development ceases; memory formation would then become difficult. This conclusion is certainly verified by experience. It is well known that an old man finds it more difficult to remember current events than those in which he took part in his earlier days. His mental activity depends more upon the association tracts formed in his earlier life.

By studying the development of nerve tract associations, we form a rational idea about the functioning of the brain, and observe that even the most intricate and apparently mysterious operation of the mind becomes accessible to rational explanation.

Before concluding our journey of exploration the Manager of the Performance feels that the audience should know also of some more practical results of our science. So it is suggested that those who still have time and interest follow us to a discussion of the mode of action of drugs. This problem was the object of countless inadequate explanations in past centuries when practically nothing was known about the nature of life processes. Voltaire, the well known satirist of the 18th century, appropriately defined therapeutics as "the pouring of drugs, of which we know nothing, into a patient of whom we know less." In those times an incredible hodge-podge of messes such as worms, horse-dung, human urine, and the flesh and excrements of other animals constituted some of the customary remedies. Such loathsome medicinal ingredients have been discarded long ago, but many of the herbs used as drugs several thousand years ago are still in use at present; among them are squills in heart trouble; castor oil against constipation; and pomegranate against worms. These remedies and others were mentioned in an Egyptian papyrus 1500 years B.C.

Along with such time-honored remedies the modern doctor prescribes drugs which have only recently been discovered; important among these are insulin, a potent remedy for diabetes; and prontosil, the remedy for infections discovered in 1935.

Trial and error is still the best method of finding new drugs; a century ago or earlier no other method was known at all. Only quite recently have we learned to predict possible medicinal actions on the basis of our knowledge of the working mechanism of the body. Now we realize that an exploration of the source of origin of life on our earth and a search for the foundation of our existence is no idle pass-time!

A diseased person suffering agonizing pains or afflicted with a severe ailment wants immediate help. If medical science cannot give it he turns eagerly to anyone who promises relief, possibly to a quack or to one of the numerous systems of faith healing. This explains the blind acceptance of authority by the patient and the preference given to procedures flavored with a suggestion of magic. Such difficulties retard the progress of a rational school of thought in the art of healing.

Yet the ideas which we developed in the course of our exploration into the origin of life are now beginning to bear fruit. We have seen that life began with the enzymes or chemical activators and is still continued by a multitude of enzymatic reactions. The numerous enzymes in a complex organism like the human body cooperate and counterbalance each other to keep the whole body in normal health. In disease this orderly working is deranged and the aim of a rational treatment should be to bring the disordered chemical reactions of the body back to their normal status by administering the missing enzymes. Unfortunately we know, at present, only few of all the jointly-working enzymes of the body: the vitamins and the hormones. Vitamins can be extracted from food; hormones from certain organs, or glands, of the animals.

In order to find the source of vitamins, chemists fed experimental animals on special diets lacking certain vitamins. The disease produced by the absence of vitamins thus became known as well as the curative effects of their presence. This work led to the discovery of potent sources of the particular vitamins and later to their isolation in pure crystalline form. The final and most difficult step was to determine the chemical structure of these vitamins and to make them artificially from inexpensive material, which task has been successfully carried out for vitamins A, C, and D; vitamin B is also known chemically. Most interesting is vitamin D, popularly known as the sunshine vitamin, because of its production in the body, or in many foods, by the ultra violet rays of the sunshine.

In a similar manner hormones are extracted from the organs of animals and then subjected to a complicated process of purification before they are used in the treatment of human disease. By administration of the right kind of hormones, in those diseases in which they are missing, modern medicine has achieved its greatest triumphs. Examples of these drugs and their uses are cortin, made from the adrenal glands, administered in Addison's disease; liver extract used in pernicious anemia and ovarian hormone to relieve menopausal conditions; also insulin used for the treatment of diabetes.

Further progress in this line depends entirely upon chemistry, which will enable us to prepare more and more hormones in pure form. It should also be remembered that hormones are not enzymes, as such, but only members in a group of enzymes which cooperate to bring about enzymatic action. We see therefore that we are only at the beginning of rational healing.

In the light of this new knowledge we can better understand the nature and working of infectious diseases. In these conditions the body is invaded by foreign enzymes which interfere with chemical changes by directing them into abnormal channels. Poisonous material is thereby formed and piled up until eventually the functioning of the vital organs ceases. The aim of medical treatment in infectious disease must be to destroy or inactivate the foreign invading enzymes, which may be viruses, bacteria or still other larger parasites. This can be done by numerous poisons, which in this case we consider as disinfectants or antiseptics. A great difficulty is that most antiseptics also destroy or interfere with the body's own enzymes or kill body cells. For this reason most of them cannot be used at all. The real problem is to find antiseptics which inactivate only the invading foreign enzymes or viruses but not those of the body. This extremely difficult task has been mastered for some diseases only; syphilis is treated by the specific antiseptic arsphenamine or salvarsan, and malaria is treated with quinine, atabrine, and plasmochine. These drugs and some related ones are weapons which strike at the cause of the infectious disease; they are comparatively harmless to the body, but some poisonous side-action always remains. Nevertheless these poisons must be administered, since the damage and danger caused by the infection is greater than that caused by the drug. The ideal internal disinfectant which would kill only the virus and never damage the body has not yet been found.

Another aspect of the medical treatment in infectious diseases is to bind the poison produced by the enzymatic action of the virus in the body. For this purpose, antitoxins are prepared from the blood of infected animals. Still another task is to replenish those body hormones which have been destroyed by virus activity.

Since nearly all drugs which are now in common use have been introduced by the trial and error method it remains for science to form a clear conception of their mode of action according to the principles explained. We are led to assume an interference with an enzyme action as the common cause of many drug actions, but, of course, this statement is too vague. For more specific information we may determine the location of action of any definite drug; in fact many of them act exclusively upon certain organs. But even this information is rather indefinite since it remains to determine by what mechanism a drug acts on the organ in question. All we can do is to point to the exceedingly small amount in which many drugs act, which fact is suggestive of the possibility of an interference with enzyme actions. Thus, for instance, the homeopathic remedies are particularly noted for the low doses in which they are administered. But they are not the only ones to which our enzymatic theory might be applicable.

These are just a few examples which serve to illustrate the practical importance of scientific progress even if it seems to have only theoretical bearing at first sight. The more we learn about the working of the forces of nature in the living world, the better weapons can we acquire against disease, and the more perfectly can we keep our own existence in a balanced condition. Our thirst for knowledge shows us the road to the pursuit of human happiness as visualized by the old alchemists: it gives us power, through the control over the forces of nature, and good health by the gradual elimination of disease, so that we may hope to enjoy a long life which is as near to immortality as we can possibly expect.

We have come to the end of our explorations. We feel that we have reached a high peak from which we may view events present and past, even those of a much more distant past than has hitherto been visible.

The new truth we have learned deserves the continued effort of the best minds and hands for its further development. We have begun to see that life is not a sort of miraculous separate entity, imposed on our earth by a spirit or an invisible something. We have chosen to follow the line of objective observation, rather than the fictions originating in the human mind.

Life is one of the developments of the Universe, governed by the general laws of nature. It seems unique merely because of our limitations in knowledge. On account of this handicap, we still find difficulties in the application of natural laws to the many phenomena of life. But does it not seem like a jest to say that the living animals and plants should be unable to initiate and to regulate their existence according to these laws, merely because of our inability to comprehend all of them?

Dixi et animam salvavi.