WHAT IS LIFE

GASKELL

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BY

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INTRODUCTION

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Introduction

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Introduction

THE question "What is Life?" is undoubtedly the most fundamentally important problem of science. In seeking its answer, an enormous amount of information has been gained in regard to life processes, but the basic question is still unanswered. In fact, the very complexity and wealth of information about life processes have dispelled hope of any easy or simple solution of the central problem "What is Life?" It is to be expected, therefore, that any suggestion of an answer to this question should meet with skepticism. And, in the nature of the case, such an answer can at best be but an hypothesis, since there are no scientific observations which are believed to strike sufficiently near the roots of the problem of life to justify any claims to certainty. The utmost that can be demanded is that any attempt to answer the question should be a *good working hypothesis*, susceptible of test, and not inconsistent with well established facts and scientific principles.

The author's answer to the question "What is Life?" purports to be based on the facts of modern atomic physics. The first query that will naturally occur to the serious reader is in regard to the author's qualifications in the field of physics. To this I would say that her discussion of modern atomic physics is accurate, well balanced and worth reading for its own sake. The second query in the reader's mind will refer to her knowledge of biological, or life, processes. This I am not qualified to answer, but I can testify to having read her exposition of such matters with much interest and admiration of her evident knowledge of this field.

The answer to the question "What is Life?" is essentially found in the hypothesis that protons and electrons, in addition to forming by their various known combinations the ninety-two kinds of atoms, are also able to unite in combinations of a type as yet undiscovered and which are the "active" or essential ingredients of living matter. These so-called "Z" elements combine in specific ways with the ordinary known chemical elements to form living matter. Living matter is thus a "dual" system, whose basic constituents are protons and electrons. By analogies, reasoning or by further hypotheses, various life phenomena are then interpreted by this "dual" structure.

The honest physicist must admit that he knows no independent experimental evidence to suggest or support the hypothesis of these assumed "Z" combinations of protons and electrons. He must also admit that he really knows relatively very little about atoms, protons and electrons, and nothing at all about the explanation of life. Hence the author's fundamental assumption must be admitted as possible. Further, she has shown how it can be used as a working hypothesis in a variety of directions. Finally, it should be susceptible of experimental test. These considerations should support the author in her plea for serious consideration of her work on its merits as a stimulus toward an experimental test of her theory.

The decisive test of this theory would involve the proof or disproof of the existence in living matter of combinations of protons and electrons in a different unit structure from the ordinary atoms of the inorganic world. Failing this, there are certain possibilities in the nature of indirect evidence, such as the generation of life by some such combination of circumstances as described by the author as a "critical concentration of ions," or the energy transformations which would be predicted by the theory at the instant of death.

In conclusion it is scarcely necessary to point out that the author's work cannot be judged dogmatically, for the obvious reason that it deals with a phenomenon which has thus far resisted scientific analysis. The book stimulates serious thought and it is to be hoped that it will contribute to the successful solution of the problem "What is Life?"

KARL T. COMPTON.

Introduction

By Raymond Pearl
Professor of Biology, The Johns Hopkins University

Introduction

THE theories about the origin of life upon the earth which have hitherto been promulgated by biologists and others have had the charming quality of naïveté, but have not, on the whole, been otherwise convincing. Furthermore, they suffer from the common defect of lacking any possibility of experimental test. Perhaps primitive living substance did ride from somewhere to the earth some time ago, on the back of a meteorite, but precisely how is one to prove it? Or, perhaps, as Arrhenius urged, some spores came here from somewhere else on their own. But again one's only epistemological resource in dealing with such an idea is that kind of faith which sustains the embattled spiritualist in his struggles with scoffers.

That basic doctrine of biology, *Omne vivum ex vivo,* is, of course, in the absence of any rigorously defined concept of life, a perfect example of dogmatic mysticism, when philosophically considered.[1] And,

[1] The objection will at once be raised that *Omne vivum ex vivo* is a statement of fact, not of dogma. But the crucial evidential basis lies only in the circumstance that the implied opposite has not yet been objectively demonstrated.

as is the effect of all accepted mysticism, it has almost completely estopped any attempts at research on what is plainly the most fundamental of all biological problems.

In all fields of intellectual activity it is given to but few men to be both able and willing to think independently and originally. Unfortunately this is as true of biology as of anything else, and perhaps more so. There have been those, however, who have urged that experimental abiogenesis was the great goal of biology, and that it was a field of study in which young men should busy themselves. Why, then, has there not been more active research in this field? The answer, I think, is twofold: in the first place there has been the too willing acceptance of the dogma already referred to; in the second place there has been a great dearth of ideas about the matter, of sufficient precision to suggest significant experimentation. The attempts at what was miscalled experimental abiogenesis, which were so neatly bowled over by Pasteur, had little if any real bearing upon the problem. What that fight was chiefly about was merely efficient methods of sterilization.

There are abundant evidences that the quasi-religious inhibition of efforts at investigation of the transition zone between non-living and living matter is rather rapidly disappearing. The work of Löhnis and Enderlein on the life cycles of bacteria; that of Church on autotrophic flagellates; that of d'Herelle and his numerous followers on bacteriophage; and the biochemical studies of Baly and Benjamin Moore and their co-workers, demonstrate that considerable breaches are being made in the wall around this forbidden field of research. This wall was constructed with the greatest solidity about the middle of the nineteenth century, and then thought by its builders likely to last for all times. But the cement was not quite up to specifications.

So from a biological point of view the present is a propitious time for the appearance of Mrs. Gaskell's original and ingenious speculation. Unless a miracle happens, whereby normal human behavior is temporarily altered, this book will doubtless receive its due measure of the violent opposition which every really new idea regularly receives. Its most important part deals with concepts which lie outside the field of critical competence of most biologists. Furthermore, with a very few exceptions, biologists are entirely unfamiliar with a mode of thought—a point of view—which applies the data and theories of atomic physics to what they as biologists regard as specific, concrete realities, namely the phenomena of life. It is one thing to listen admiringly to the physicist talking about electron orbits and other such remote matters, but quite another to have him advance the idea that these things may have something to do with biology. To both the physicist and the biologist the really real is the familiar. Unfamiliarity always tends to breed a certain degree of prejudice and antagonism. But in this particular instance there is less need for concern over the standard and expected opposition to a new idea than is usually the case, for Mrs. Gaskell's hypothesis is capable of experimental test. And by such test, if and when made—and incidentally the making will be no easy task—either its supporters or its opponents will be confuted. The candor and moral courage with which she submits her ideas to this test are worthy of all praise. I find no hedging in the book, nor alibis carefully made ready in advance.

Mrs. Gaskell has read widely, though by no means exhaustively, in the literature of biology. Any professional biological reader of the book will note instances where she could have adduced more, and in some cases more pertinent, evidence in support of the particular point under discussion. In a sense all of the specifically biological chapters of the book, which discuss the biological implications and consequences of the theory are, at this stage, premature. If the theory is not, in fact, true, these discussions are idle; if it does eventually turn out to be true the discussion of its implications can then take on a degree of confidence and assurance on the biological side which they cannot possibly have now. As ancillary evidence to support the theory I think they have but little weight. But granting all this, Mrs. Gaskell's discussions of various biological problems, particularly that of evolution, have a refreshing novelty and shrewdness which gives them a value by no means negligible. In some degree she offers us, in this extremely stimulating and original book, that opportunity so rarely achieved, to see ourselves as others see us.

RAYMOND PEARL.

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INTRODUCTORY

I. On Rating a Theory

EVERY new speculation of science, every hypothesis or theory, that merits and receives a hearing is subjected to critical examination, and then rated according to well-defined and established criteria.

That hypothesis is an indispensable mental tool, "a legitimate instrument of logic," is not questioned. Mathematical reasoning is legitimate wherever there are "any premises sufficiently precise to make it possible to draw necessary conclusions from them."

T. U. Thiele, of the Copenhagen Observatory, in his *Theory of Observations*, states a fact which is generally recognized and frequently repeated when he says: "It will be found that every applied science, which is well developed, may be divided into two parts, a theoretical (speculative or mathematical) part and an empirical (observational) one. Both are absolutely necessary, and the growth of a

NOTE.—In this chapter copious direct quoting seems the best way to emphasize the fact that the rules for rating a theory are thoroughly established, and nothing remains but to recognize and accept them.

science depends very much on their influencing one another and advancing simultaneously."

In his presidential address (1920) before the British Medical Association, Sir Thomas Clifford Allbutt, late Regius Professor of Physics in the University of Cambridge, said: "Research, as it is working today, advances from fixed and measured bases; as observation it watches nature's march past; then as experiment it puts events to test under artificial conditions of separation or isolation, and measures their phases. But the laboratory cannot, as nature does, contrive the unexpected; so we must 'gear up our tiny machines to the vast wheel of nature,' and try for a first roughing out of an idea or concept. If we are to select our facts to any considerable purpose as crucial, we must first have an idea in our minds; and for this a certain kind of imagination is needed."

All of the brilliant modern discoveries have been possible only because venturesome minds have dared to speculate. But the inexorable demand is that every hypothesis must have a firm basis in facts. In no sense may it be a mere unsupported guess. With Sir John Herschel: "To experience we refer, as the only ground of all physical inquiry." There is no such thing as subserving truth in the abstract by the sacrifice of concrete truths. One adverse fact is sufficient to disprove the soundness of any hypothesis. Thus, "it is the modern custom now," as observed some years ago by Shaler, "to term the supposition of an explanation a working hypothesis, and only to give it the name of theory after a very careful search has shown that all the facts which can be gathered are in accordance with the view." "In its most proper acceptation," according to J. S. Mill, "theory means the completed result of philosophical induction from experience."

A theory that does not account for all the facts which are involved is an inadequate solution. In order to be entirely acceptable, a theory must be both sufficient and necessary. This means that the theory must fully account for the phenomena under consideration, and that they cannot be thus accounted for on any other hypothesis.

When thus fully accounted for, the phenomena are (in popular language) said to be "explained." "To 'explain' means," as Hans Driesch defines, "to subsume under known concepts, or rules, or laws, or principles, whether the laws or concepts themselves be 'explained' or not. Explaining, therefore, is always relative: what is elemental, of course, is only to be described, or rather to be stated."[1]

"A scientific explanation," John Fiske points out,

[1] *The Science and Philosophy of the Organism*, 51.

"is a hypothesis which admits of verification—it can be either proved or disproved."

What constitutes proof in any given case, of course, is determined by the nature of the terms of the speculation. Frequently a speculation concerns a *law*. In keeping with J. S. Mill's definition of "a law of nature," to discover a law of nature is simply to discover a certain relationship among the units of a given group of phenomena; it is to see a definite arrangement which before had not been observed. When a theory refers to a *law*, proof of the theory then necessarily means that the relations which the theory affirms are found to be such as the theory describes. Always, however, direct proof of a theory consists of facts, data of observation and experimentation, to which may be added the logical necessities arising from them.

R. D. Carmichael, of the University of Illinois, asserts: "The fundamental scientific activity is that which is expended in the search for truth, in discovering and establishing what can be made sure by experiments or by undisputed logical processes convincing to all who understand their nature."

For, as the late H. A. Bumstead remarked, "when one speaks of modern science, one means, I think, essentially the method of planned and reasoned *experiment*, and, with a few sporadic exceptions, systematic experimentation was practically unknown until about three hundred and fifty years ago. It marks a very great epoch in human history."

A theory, as such, is a thing of merely temporary existence. All speculation—hypothesis and theory—represents effort at interpretation of phenomena. In the course of time, sooner or later, inevitably, the "facts" (data of observation and experimentation) tend to establish the correctness of the original or modified interpretation or they invalidate and discredit it. If the facts do not support a hypothesis or a theory, it falls to pieces and is forgotten. This has been the fate of numerous hypotheses and theories. In the event that the facts substantiate the interpretation, again a hypothesis or a theory ceases to exist as such; for proof converts speculation into knowledge, and hypothesis and theory into accepted fact.

Thus, today, the nebular hypothesis, as developed by Laplace, continues to command high admiration, but merely as a brilliant speculation; since it has been shown (particularly by Chamberlin and Moulton) that pertinent facts and their mathematical necessities discredit it.

As Joseph Barrell, of Yale University, says, "A hypothesis, to gain scientific credence, must emerge successful from the test of observed fact and mathematical theory. The nebular hypothesis has not done so. It is on the defensive and has lost standing during the past generation."[2]

In contrast: Mendeleeff observed periodicity of qualities among the chemical elements, and arranged his periodic table (1871), boldly describing elements then unknown with which to fill gaps in it. The discovery by others of the predicted elements furnished superb proof of the correctness of his general interpretation (and the interpretation of others) of the phenomena. The progressive and periodic relationship of the elements is an established fact on which all later work upon atoms has thrown added light.

Theodor Schwann announced his view that plants as well as animals were constituted of cells. Experiment soon established the correctness of his speculation.

Hans Driesch criticises the expression cell-"theory." That organisms are built up of cells is, he explains, "a simple fact of observation, and I therefore cannot agree with the common habit of giving to this plain fact the title of cell-'theory.' There is nothing theoretical in it; and on the other hand, all attempts to conceive the organism as a mere aggregate of cells have proved to be wrong. It is *the whole* that uses the cells . . . . or that may not use them: thus there

[2] *The Evolution of the Earth and its Inhabitants*, 12.

is nothing like a 'cell-theory,' even in a deeper meaning of the word."

Relativity teachings, Minkowski's, Lorentz's, and particularly Einstein's (1905 and 1915) are receiving much attention. Some years ago, Dr. Ames of Johns Hopkins University, in speaking about Einstein's theory pointed out that "Einstein's hypotheses are not suggested directly by our sense-experiences, but are statements which seem reasonable; but their sole justification, from a physical sense, will rest in their deductions being in accord with observations."[3]

Recent observations, it seems, have confirmed the Einstein theory. Some affirm that the theory has been wholly established; others contend that its verification is not complete; while a criticism by Charles Lane Poor in essence amounted to saying that the theory (so far as the interpretation of the movements of the planets is concerned) was neither complete nor necessary.

(As is well known, the triple support of the theory has to do with [*a*] the displacement of the spectral lines of the sun—a deduction from theory which it was first thought had not been verified; [*b*] the bending of a ray of light passing through the gravitational field of the sun; and [*c*] the accounting for the motions of the planet Mercury.)

[3] *The Constitution of Matter*, 236.

Sometimes a long period of time intervenes between a speculation and its proof or refutation; and that which amounts to a proof of the correctness of the interpretation may be secured without the slightest reference to the speculation of long ago. This happened in the case of the atomic theory of electricity. Thales of Miletus, *ca.* 600 B. C., speculated on the discrete nature of electricity. Twenty-five hundred years later (1909) Robert Andrews Millikan isolated and measured the electron. Yet hardly for a moment could one suppose that the research work of Millikan, the epoch-making work of J. J. Thomson, and the efforts of Townsend, C. T. R. Wilson, H. A. Wilson, William Crookes, and of Pluecker and Hittorf, were inspired by the speculation of Thales. But that electricity is atomic is no longer a speculation, a hypothesis, or a theory, but an established fact.

It is plain, then, that a hypothesis or a theory is a thing of merely temporary existence, and that proof converts speculation into knowledge, and theory into accepted fact.

"The requisite standard of proof" has been raised in all departments of learning. Today, at least so far as recognized authorities are concerned, it is satisfactorily high: Everywhere there is insistence upon methods that can supply evidence in place of mere assertion, and in every branch of science there is demand for quantitative measurements. Karl Pearson, President of the Anthropological Section of the British Association for the Advancement of Science, in an address (1920), said: "I confess myself a firm disciple of Friar Roger Bacon and of Leonardo da Vinci, and believe that we can really know very little about a phenomenon until we can actually measure it and express its relation to other phenomena in quantitative form."

Pearson has this to say about the work of the late Wilhelm Wundt, who, holding the chair of philosophy at the University of Leipzig, established the first laboratory of psychology: "Wilhelm Wundt's great work runs to ten volumes. But I also know that in its 5,452 pages there is not a single table of numerical measurements, not a single statement of the *quantitative* association between mental racial characters."

T. Clifford Allbutt maintains:

"Science consists—as Plato said five centuries before Christ—in measurement."

Millikan, whose experimental work on the electron (mentioned before) is a synonym for exquisite exactness of measurements, concerning quantitative measurements, writes:

"It is only upon such a basis, as Pythagoras asserted more than two thousand years ago, that

any real scientific treatment of physical phenomena is possible. Indeed, from the point of view of that ancient philosopher, the problem of all natural philosophy is to drive out qualitative conceptions and to replace them by quantitative relations. And this point of view has been emphasized by the far-seeing throughout all the history of physics clear down to the present. One of the greatest of modern physicists, Lord Kelvin, writes: 'When you can measure what you are speaking about and express it in numbers, you know something about it, and when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thought advanced to the stage of a science.' "[4]
Millikan points out:

"There is an interesting and instructive parallelism between the histories of the atomic conception of matter and the atomic theory of electricity, for in both cases the ideas themselves go back to the very beginnings of the subject. In both cases, too, these ideas remained absolutely sterile until the development of precise quantitative methods of measurement touched them

[4] *The Electron*, second edition, 4.

and gave them fecundity. It took 2000 years for this to happen in the case of the theory of matter and one hundred and fifty years for it to happen in the case of electricity; and no sooner had it happened in the case of both than the two domains hitherto thought of as distinct began to move together and to appear as perhaps but different aspects of one and the same phenomenon, thus recalling again Thales' ancient belief in the essential unity of nature."[5]

Jacques Loeb asserts: "The epoch-making importance of Mendel's work lies in the fact that he, for the first time, gave not a *hypothesis*, but a *theory* of heredity, which made it possible to predict the result of hybridization numerically. His work forms the basis for all further work in this field which is of equal theoretical and practical importance."[6]

In the preface to his volume on tropisms Loeb writes: "It is the aim of this monograph to show that the subject of animal conduct can be treated by the quantitative methods of the physicist, and that these methods lead to the forced movements or tropisms theory of animal conduct, which has only recently been carried to some degree of completion."[7]

Concerning the application of quantitative meth-

[5] *The Electron*, second edition, 6.

[6] *Dynamics of Living Matter*, 185.

[7] *Forced Movements, Tropisms, and Animal Conduct*, 7.

ods of measurement to the problem of life, the late Svante Arrhenius said: "We cannot measure life in its various aspects quantitatively as we measure matter and energy. . . . . To detect means of measuring the quantities of life would be a revolutionary discovery which may never be made."[8] But Jacques Loeb declared that "biology will be scientific only to the extent that it succeeds in reducing life phenomena to quantitative laws."[9]

The statement that the critical demands of the day in science are satisfactorily high, surely is justified.

When, therefore, anyone ventures to offer for acceptance ideas radically different from anything else, and makes bold to call them a theory, it is but meet—provided the work has apparent merit—that the alleged theory be subjected to the severest examination possible. Unless the author has an established reputation in the particular field of inquiry to which the theory belongs, a preliminary rating would concern itself with questions such as have to do with the general character of scholarship as reflected in the work and evincing qualification of the author for the work, the value of the authorities cited, methods employed, importance of the subject, and originality.

[8] *Life of the Universe*, II, 252.

[9] *The Organism as a Whole*, 11.

This provisional rating is indispensable; since even an author's unquestioned eminence in his own special field and consequent high reputation, does not always guarantee the value of his theoretical work outside that field.

The element of clearness of presentation of a new view is an important factor. The number of persons—whether few or many, to whom a new theory makes immediate appeal certainly is not without its direct influence in determining an early or general hearing; yet by no means is the one whose work is on trial permitted to appropriate to himself what Kant said of his *Kritik:* "The danger is not that of being refuted, but merely that of being misunderstood."

If on cursory examination it appears that the general quality of the work warrants it, there follows inquiry into the congruity of the view with the accepted facts of the science or sciences to which the theory is related, and into the legitimacy of the use, or interpretation made of any such facts. There must be found present a twofold agreement: There must be agreement of the views with the facts of science and observation, and agreement between the premises and the conclusions.

If no known fact can be shown to be at variance it is conceded that the conclusion deserves to rank as a theory.

The final question is: What, if any, experimental proof of the theory is possible?

If the theory is amenable to proof, that is, if it admits of direct experimental test, the fate of the theory always is determined by the outcome of the test. If the result of the test is negative, the best thing that can happen to the theory is speedy oblivion. If the result is positive, the theory ceases to be mere theory, since proof changes theory into established fact.

II. On Presenting My Theory of Life

IT IS with some understanding of the ordinary methods of criticism of a theory that I have ventured to advance a new theory of life.

I am also aware of the discouraging and embarrassing fact that leading authorities up to the present have taken the position that to try to frame a definition of life is a hopeless attempt.

One remembers that Sir E. A. Schaefer said:

> "Everybody knows, or thinks he knows, what life is; at least we are all acquainted with its ordinary, obvious manifestations. It would therefore seem that it should not be difficult to find an exact definition. The quest has, nevertheless, baffled the most astute thinkers."

One further recalls that Lorande Loss Woodruff, professor of biology at Yale University, writes:

> "All [biologists] will undoubtedly admit that we are at the present time utterly unable to give an adequate explanation of the fundamental life processes in terms of physics and chemistry.

Whether we shall ever be able so to do is unprofitable to speculate about, though certainly the twentieth century finds relatively few representative scientists who really expect a scientific explanation of life ever to be attained."[1]

With authoritative pronouncements such as these before one, an attempt to frame a definition of life must appear superlatively foolhardy. It therefore seemed the part of wisdom, and I chose it, to submit my manuscript to a limited number of men privately before seeking a general public hearing for my views. Since my theory of life is built directly upon atomic physics, the first, central and basic requirement necessarily is that the views be sanctioned by atomic physics. My question, put to leading specialists in atomic physics, therefore was: "Do you find my views in accord with atomic physics?" To this question I have received affirmative answer from some of the highest authorities in the United States.

The granting that the presentation of atomic physics is in conformity with the modern findings, and that my reasoning is valid, is all I ask of any critic.

To gain the relative completeness of view of the organism which the theory presents, the facts of physical chemistry and numerous other related facts

[1] *The Evolution of the Earth and its Inhabitants*, 95.

were carefully taken into account. Quite needless to say, I myself had searched painstakingly to determine, as well as I was able, whether any facts could be found to be adverse to or discordant with my conclusions. I found none. Nor have any such facts been brought to my attention, though I especially invited criticism on this point.

Inasmuch, then, as I am not aware of the existence of any set of facts or single fact at variance with my conclusions, I may be permitted to claim that they deserve to rank as a *theory*, in the use of the term as previously defined.

Making that claim, I of course immediately face the inevitable question concerning *proof:* "What proof of your theory is possible?" In reply to this question I insist that (as shown in the chapter *On Proof*) *the central proposition of my theory* (*the general law of the structure of living matter, and the definition of life and of death*) *is amenable to proof.* It is subject to direct quantitative physical laboratory test. And, so far from wishing to evade the question of proof, I devote an entire chapter to its consideration. I do not believe that anyone can insist more strongly that there is *need* for laboratory proof of the theory than I have insisted, and shall continue to insist until the physical laboratory yields its answer.

However, the fact that the theory has not yet been established by laboratory test, cannot legitimately be used as an objection to the theory, inasmuch as it is one of the outstanding features of the theory that it, for the first time, shows the problem of life to be amenable to laboratory test.

Awaiting decisive laboratory test, it may not be forgotten or ignored that it has not been known to happen that a theory, unless it answers to the facts, can serve as a key to the easy solution of various and most diverse difficult problems.

The theory concerns a subject that is of universal and transcendent interest—life; and it is approached and discussed from many angles. Therefore it may not be amiss to emphasize the following:

1. The author has built exclusively with or upon the established facts of experiment and observation.

2. Judgment of the merits of the theory, it obviously follows, must be based solely on the same sets of facts.

No other inquiry has larger philosophical importance than the inquiry concerning life, since the overshadowing problem of human life necessarily is included in the general problem of life. One may say that the chief value of the inquiry into life indeed lies in its philosophical import, its contribution to philosophic thought. For many would say with Karl Pearson: "I am afraid I am a scientific heretic . . . .

I do not believe in science for its own sake, I believe only in science for man's sake."

The thinker does not and can not accept the cold facts of science about life, without inquiring into the meaning of these facts: What is their relation to the warm, throbbing questions about man's destiny and his "place in nature"? What is the place of "life" in the larger scheme of things of which we have cognizance? Certainly the problem of life directly touches the core of all philosophical inquiry: it indeed is the kernel of the problems of philosophy.

As Harald Hoeffding, professor of philosophy at the University of Copenhagen, admits, "it is difficult to draw a sharp line between philosophy and natural science." However, a broad general distinction between science and philosophy is found in that, characteristically, science concerns itself simply with the "how?" and philosophy chiefly with the "why?" of things.

It is easy, then, to see that there is a vast difference between a theory and a philosophic thought-scheme. The fact that a theory has profound philosophic import, does not confer upon the one who presents it the privilege of injecting philosophical considerations into it; nor does the fact that a theory has profound philosophic import, impose the duty of exhibiting such import. And, plainly, the theory may not be accepted or rejected because of philosophical considerations. Philosophical considerations may not enter.

The present effort is a definitely limited one, and expressly concerned merely with a theory—not with philosophy.

On presenting an invention or discovery to be patented, it is *obligatory* upon the inventor specifically to enumerate the points for which he claims originality, and to state the uses which his discovery or invention serves. Obviously, such enumeration reduces the labor of investigating the merits of an alleged discovery.

This consideration of expediency has prompted me briefly to enumerate what I conceive to be the elements of originality contained in my theory of life, and its uses as a tool. (Chapter Six.) I have found it easy to do this quite frankly, since I have studied these subjects long enough to be able to take a detached and impersonal view of my work. Besides, there is the overwhelming sense of the immensity of the subject and of the pitiful smallness of an individual investigator's capacity for achievement. And in gathering knowledge, I have felt like a child picking up pebbles on a shore strewn with pebbles, remembering—as a comforting (?) thought—that even the immortal Newton felt that in his explorations he was merely wandering along the shore of a great ocean, the wide expanse and unsounded depths of which he was unable to explore.

What is Life?

PART ONE

Preparatory

Chapter One

The Organism

A THEORY of life necessarily is a theory of the living organism, since the research of science into life is concerned exclusively with the concrete. To inquire into life in the abstract is worse than futile.

The lowliest organisms are mere unnucleated specks of protoplasm, living matter. The higher unicellular organism consists of protoplasm and a nucleus. All other organisms, from lowest to highest life-form, vegetable and animal, including man, are multicellular, each individual having originated in a single cell.

Thus the cell is the physiological unit of life. However, though among lowly life-forms like cells are found closely bound together in colonies, one of the higher organisms cannot be described as a colony of like cells. The higher organism is built up of various kinds of cells (tissue, gland, and yet other cells), that moreover serve the organism as a whole. It is well known that during the life of one of the higher organisms many of its cells die and are replaced by other cells, the process of regeneration in some of the simpler organisms even extending to the replacing of lost parts. As Hans Driesch insists, it is "the whole that uses the cells." Therefore, to describe the individual cells of the higher life-forms does not define the organism.

Cells are extremely complex both in chemical constitution and in structure, and of great variety, as shown by the vast body of facts of cytology.[1] The absolute specificity of the constitution and functions of the cell is shown in heredity, in which a host of specific traits as well as the general characteristics of the parent form are reproduced—and this in hundreds of thousands of different life-forms.

Obviously, the mere fact of the specificity of the germ-cell throws no light whatever on what is the essential nature of the process that determines the successive generations of organisms by means of the germ-cell.

The problem of life in its simplest form is the problem of protoplasm. But in the nature of things protoplasm cannot be analyzed. As Woodruff states: "From one point of view it is impossible to analyze protoplasm because the least disturbance of its fundamental organization results in a cessation of those

[1] *See* Edmund B. Wilson, *The Cell in Development and Heredity.*

phenomena characteristic of life, leaving matter in the non-living state before us."[2] For this reason physiological chemistry (biochemistry) has the insuperable difficulty to contend with that it is restricted to the establishing of the relationship between chemical constitution and reaction and biological function. Nevertheless, Jacques Loeb said: "We must realize that what we call life consists of a series of chemical reactions, which are connected in a catenary way."[3]

Certainly, *a comprehensive theory of life must be a definition of the organism that is absolutely fundamental. It must differentiate living matter from the non-living world; it must be descriptive of all living beings; and it must apply exclusively to living beings.* The fundamental definition of life must provide for all the wide differences as well as for the likenesses that are found from bottom to top in the scale of organisms; it must provide also for the psychic qualities exhibited by the higher organisms, and especially by man; and, finally, it must supply the key to the group of growths classed as neoplasms.

The major peculiarities of the organism that distinguish it from the non-living are:

1. Growth. (Synthesizing its own specific material.)

[2] *The Evolution of the Earth and its Inhabitants*, 83.

[3] *The Mechanistic Conception of Life*, 212.

2. Reproduction. A detached piece of the parent organism (or organisms) is the beginning of the new individual. Reproduction is effected in numerous ways; but from the simple division of the unnucleated speck of protoplasm, a division that is closely related to nutrition and that seems to result merely from redundant growth, through all forms of vegetable and animal life; and whether asexual or sexual or induced through physicochemical means (artificial parthenogenesis), *reproduction basically is the same in all.*

3. The relative stability of the organism in that autolysis does not take place during life (but does set in immediately after death)—the stability that is characteristic of and synonymous with the living state. The stability that ends with death, and that prompts the questions: *What is Life? What is Death?*

4. The psychic properties of organisms, not found in the lifeless world, and ranging from mere sensation of lowly life-forms to the psychic faculties of man.

Besides these major peculiarities of the organism, a number of conspicuous and significant minor peculiarities distinguish the organic from the inorganic. Characteristic of organic substances is the heavy molecule, some substances having prodigious weight. (*See* Molecule.) Carbon compounds are much less stable than inorganic products toward physical and chemical reagents. Though there is no hard and fast dividing line between polar and non-polar substances, broadly speaking, organic substances are non-polar as distinguished from inorganic substances (polar). (*See* pp. 92, 176.) Certain chemical reactions take place at a lower temperature in the living organism than in the inorganic. Numerous organic compounds contain the *same elements* in the *same proportions*, and yet show marked differences of properties. Thus there are 135 compounds of one formula. (Isomerism, practically limited to the organic.)

Air is an essential factor to nearly all organisms, the only exceptions being a class of bacteria (anaerobia) that thrive without free oxygen. Take an organism—one of the higher organisms, or say, a man—in full vigor of life and health: if he be deprived of air for only a few minutes, he dies. All efforts to restore him fail. Life cannot be restored. Jacques Loeb observes: "Death in these, i.e., higher animals, is due to cessations of oxidations, but the surprising fact is that if the oxidations have been interrupted but a few minutes life cannot be restored even by artificial respiration."[4] That oxygen is neces-

[4] *The Organism as a Whole*, 359.

sary to life, was shown by Lavoisier about one hundred and fifty years ago, but—as W. Mansfield Clark recently said—"what happens in the cell itself when oxygen is brought to it is as much a mystery as ever."

Salts play a large rôle in life phenomena. Thus, blood contains sodium chlorid and other salts.

From sixty-five to eighty per cent of the organism consists of hydrogen and oxygen in the form of water. According to Martin Mendelsohn, of the University of Berlin, the enormous stream of fluid substances that circulates through the body is kept in motion by the action of the cells and glands, with the heart "only a subsidiary organ of the circulation system—an unusually large blood vessel."

All the elements found in organisms are enumerated on pages 100 and 101. Carbon is present in all organic compounds, and organic chemistry is described as the chemistry of carbon.

Compounds that consist of hydrogen and carbon only, the hydrocarbons, are classed in two main divisions, the open-chain (aliphatic, including the organic fats) compounds, and the closed ring, or cyclic, compounds. These two types of the chemical structure of hydrocarbons also are the basis of the classification of all organic compounds. For it is held that all other organic compounds may be derived from hydrocarbons by the replacement of hydrogen atoms of hydrocarbons by atoms or groups of atoms (radicals) of other elements. As a convenient theory, then, all organic compounds are regarded as derivations of hydrocarbons.

The ideas of structure (pattern of combination) and of substitution (the disappearance of elements and the appearance of other elements or groups of elements) are the simple basic concepts of organic chemistry concerning the formation of the many thousands of complex organic compounds.

A highly important group of organic substances are the carbohydrates, (1) sugars, (2) starches and celluloses, compounds of carbon, hydrogen, and oxygen. The molecular formula is known for practically all the sugars. The structure of the molecule of the starches and of the celluloses is unknown. The *chemical constitution* of sugars and starches and the *formation* of these carbohydrates in the living plant, of course, are two very different things; the process, which can take place only with the aid of sunlight, involving the living plant, the soil, and the air (carbon dioxide, and nitrogen, since it has been proved that many, if not all, green plants are able to fix atmospheric nitrogen). (Moore, Webster, Mameli and Pollaci.[5])

[5] *See* Carleton Ellis and Alfred A. Wells, *The Chemical Action of Ultraviolet Rays*, 233.

The photosynthesis of carbohydrates in the living plant obviously involves the problem of radiation—one of the most difficult branches of physics. What wave-lengths of light are the effective ones? What does "absorption" of the rays mean? How, in what way, does the atom or molecule react to radiation? That sunlight exerts pressure has long been known (Poynting[6]), but recent research—the Compton effect—would tend to show, recalling Newton's ideas, that radiation is a discrete "corpuscular" quantity. Consideration of all this and of the constitution of the atoms (atomic physics,) then, necessarily enters the problem of the formation of starches and sugars.

About eighty-five per cent of the dry material of the human body and a large percentage of the solids of all living matter consists of proteins (proteids). Proteins are classified as protamines, albumins, globulins, histones, glutelins, etc. They contain carbon (about fifty to fifty-five per cent), hydrogen, nitrogen (fifteen to over seventeen per cent), and oxygen. Nearly all also contain a trace of sulphur, and a few contain phosphorus, iron, etc. As a group, proteins are well-characterized, and individual proteins are very specific. However, they are highly complex substances of unknown constitution, derived directly or indirectly from living matter.

[6] *The Pressure of Light.*

The chemical substances of which living matter is made up are grouped under five heads:

1. Water, and other inorganic materials.

2. Carbohydrates. About one per cent. (Pettibone.)

3. Proteins. About fifteen per cent.

4. Fats, and related compounds. About fifteen per cent.

5. Various water soluble compounds. Less than one per cent.

Concerning the chemistry of living matter, Jacques Loeb makes the broad statement: "Today everyone who is familiar with the field of chemical biology acknowledges the fact that the chemistry of living matter is not specifically different from the chemistry of the laboratory."[7] Again: "No variables are found in the chemical dynamics of living matter which cannot be found also in the chemistry of inanimate nature."

Of utmost importance to the organism are the numerous enzymes (ferments). The action of an enzyme is of extreme specificity, but the constitutions of enzymes are unknown. Until recently, the most advanced research had succeeded in specific cases in separating an enzyme that in its approximation to purity exceeded former preparations nearly

[7] *Dynamics of Living Matter*, 1.

a hundredfold. But no enzyme had ever yet been isolated when it was announced in September, 1926, that James B. Summer, assistant professor of biological chemistry at Cornell Medical College, had succeeded in the isolation and crystallization of urease.

Enzymes are produced by the cells of living organisms, and enzyme action belongs to the cardinal functions of living cells. Some recent research describes enzymes as being electrochemical in character (Fodor). The enzymes are organic catalyzers (some enzymes acting hydrolytically), and synthesizers.

The study of enzyme action is of foremost interest in connection with the proteins and carbohydrates. Recently, too, it has been urged that the process of fermentation and that of respiration show relationship.[8] H. von Euler maintains that in respiration the endproduct CO_2 results not only from splitting-products of carbohydrates, but that often also the fats (open-chain compounds) and constituents of the complex proteins contribute.

The problems of the dynamics of the living organism are intimately bound up with physicochemical processes—all chemical reactions and all physicochemical processes involve problems of energy (heat, work, etc.). It is well known that *all*

[8] Hans von Euler, "Enzyme und Co-Enzyme als Ziele und Werkzeuge der chemischen Forschung." *Sammlung chemischer und chemisch-technischer Vorträge*, XXVIII, Heft 6 und 7, 242.

life-processes are accompanied by *electrical* phenomena. Thus, functional change in a tissue, the beat of the heart, every twitch of a muscle, the secretion of a gland, the stirring of life in the seed of a plant, the beginning of life in the hen's egg—all are accompanied by electrical phenomena. Indeed, A. D. Waller's experiments employ a method of galvanometric tests whereby living things such as eggs, leaves, various organs, respond with a "blaze current" and Waller speaks of "electricity as a sign of life." For, the same things when dead do not respond electrically.

Much research, covering many years, with which names such as Féré, Veraguth, Tarchanov, Tigerstedt, and Boris Sidis are connected, has shown that *all* excitations—sensory, tactile, somatic, etc.,—and all human emotion and even abstract thought, cause galvanometric deflections.

Various facts, indeed an overwhelming array of facts, indicate that similar laws apply to life-processes and to the inorganic. There is the laboratory synthesis of numerous substances that formerly were thought to be products exclusively of life. The discovery of the first synthetic vitamin is a recent achievement. An electrical machine, constructed by John Hays Hammond, Jr., has duplicated the heliotropic movements of heliotropic organisms. In the Russian physiologist Kuljabko's experiments on the hearts of dead children, carefully prepared salt solutions caused the dead hearts to beat again. This is the more significant since—to quote Dr. Walter H. Gaskell—"the heart's motto, as Ranvier and Kronecker and Meltzer put it, is, 'All or none'; either it will not contract at all, or it will contract to the fullest extent possible at the time."

Temperature is an important factor in the metabolic and other processes of the organism as it is in inorganic reactions, and variations in temperature directly modify life-processes. This has long been known through the research of J. Sachs,[9] and of others. Askenay[10] and A. Kanitz[11] treated of it. Uhlenhuth has shown that temperature influences the time of the metamorphosis in salamanders. Jacques Loeb and others have shown that changes in the temperature of the air in which fruit-flies (*Drosophila*) are kept, directly determine a shorter or longer term of life of the flies. By lowering the temperature of fruit-flies twenty degrees Loeb prolonged the duration of their life by nine hundred per cent.[12]

[9] "Über den Einfluss der Lufttemperatur und des Tageslicht auf die stündlichen und täglichen Änderungen des Längenwachstums." *Arbeiten des Würzberger Institut*, 1872, 1.

[10] "Über einige Beziehungen zwischen Wachstum und Temperatur." *Berichte der Botanischen Gesellschaft*, VIII (1890).

[11] *Temperatur und Lebensvorgänge.*

[12] *Scientific Monthly*, December, 1919.

And there is the most striking phenomenon of all—artificial parthenogenesis. It was the monumental achievement of Jacques Loeb that the eggs of certain life-forms which normally develop only with the aid of a spermatozoon were caused to develop by physicochemical means. Also, other unfertilized eggs have been caused to develop by means of rays—ultra-violet rays in Jacques Loeb's experiments, radium rays in G. Bohn's experiments.

It is a noteworthy fact that observations made on organisms have led directly to important discoveries or advances in physical science. According to Wilhelm Ostwald, H. J. van't Hoff was led to his conclusions concerning solutions through a conversation with his colleague, the botanist De Vries. The twitching of the muscles of the leg of a frog (observed by Galvani), as Jacques Loeb says, "a misunderstood biological observation, became the germ for the development of electrochemistry." Helmholtz formulated his law of the conservation of energy following his researches into phenomena of heat of the animal body.

Chapter Two

Colloids and Life

NO INQUIRY into the constitution of living matter can proceed far without taking account of the outstanding fact that protoplasm *resembles* a colloid. It is generally asserted that protoplasm is colloidal in character, and indeed the organism as a whole is described as a complex unit colloid system. Thus the colloid chemist, Wolfgang Ostwald, says: "Organisms are merely special instances of colloid systems."

A comparison of the lowest life-forms, bacteria, with colloids is interesting. Unquestionably bacteria show the fundamental characteristics of organisms; viz., the synthesizing of their own specific material, and reproduction.

As to the close resemblance between colloids and bacteria, we find the following facts:

	Characteristics of Colloids are:	Characteristics of Bacteria are:
(*a*)	Brownian movement;	Active movement.
(*b*)	Electric conduction; i.e., they show charges and wander to poles;	The same. Have enormous energy.

(*c*) Specificity;	Absolute specificity.
(*d*) Selective adsorption;	Staining.
(*e*) Peculiarities of filtration;	The same.
(*f*) Some can be evaporated to dryness and then readily redissolved in water;	The same is true for bacteria.[1]
(*g*) Easily coagulated;	"Probably coagulation kills them in sunlight."

The general opinion is as stated by Dr. Rohland: "Bacteria are themselves of a colloidal nature."

At the other end of the scale of life one may not ignore facts such as that the human in the third month of intra-uterine existence is a system that consists of ninety-four per cent of water. But here it is evident that to describe the organism as a colloid system does not solve the difficulties of the organism, even considered merely from the point of view of colloid chemistry; since, for example, to say that the brain is colloidal, so far from solving the problem of the brain, at once raises the question why it is that, though normally the human brain begins to shrink at man's early maturity, his psychic powers continue to increase for many years.

[1] *See* Charles V. Chapin, "The Air as a Vehicle of Infection." *Harvey Lecture*, 1913.

However, biologists and physical chemists today are agreed that life is bound up with colloids, and that the physiological life-processes in fact constitute a series of colloidal phenomena.

Jacques Loeb says: "The material of which living organisms consist is essentially colloidal in its character."[2]

Thus Martin H. Fischer: "Living matter, whether of plants or animals, and under normal or pathological conditions, is chemistry in a colloid matrix."[3]

Sir E. A. Schaefer states: "For it is becoming every day more apparent that the chemistry and physics of the living organism are essentially the chemistry and physics of nitrogenous colloids. Living substance or protoplasm always, in fact, takes the form of a colloidal solution."

Wolfgang Ostwald writes: "Such particularly complicated phenomena as those of life take place in colloid media, and only in such . . . . The physical and physicochemical conditions necessary for life cannot be more accurately or more concisely summed up than in the words: All life processes take place in a colloid system. The colloid state is the means of integrating biological processes. More correctly expressed, only those structures are considered liv-

[2] *Dynamics of Living Matter*, 1.

[3] Translator's Preface to Wo. Ostwald's *Handbook of Colloid Chemistry*, 6.

ing which at all times are colloid in composition."[4]

Further, it is the opinion held by all the foremost students of the day who approach the problem of life from the physicochemical point of view, that life on the earth originated in the colloid state. Thus Henry Fairfield Osborn, famous paleontologist: "In the lifeless world matter occurred both in the crystalloidal and colloidal states. It is in the latter state that life originated."[5]

In treating of the "Initial Biologic Habitat," the geologist, Thomas Chrowder Chamberlin,[6] pictures the early earth as having been rich in colloids. Certainly, the requirements for colloidal formation are very limited. Given the early earth absolutely without life, but with continents formed, with water, and the atmosphere—any kind of an atmosphere that could develop into the present atmosphere, heat from the sun—if not direct light, the operation of the known laws of nature, and powerful action necessarily was present, action in the nature of reduction, or disintegration. Various causes inevitably contributed to the formation of colloid systems, granted only the occasion of a moderate temperature. It is a fact which cannot be doubted that it is impossible to postulate the existence of the earth in a

[4] *Theoretical and Applied Colloid Chemistry,* 82, 155.

[5] *The Origin and Evolution of Life,* 58.

[6] *The Origin of the Earth,* 250–261.

condition with continents formed, or with a solid crust, without immediately thereafter further postulating the beginning of reduction, or disintegration, of the continental surfaces. This reduction undoubtedly proceeded in varying degrees and at varying rates, depending upon the sum total of prevailing local conditions. At this early stage, temperature was a prominent factor. But the immediate and intimate factors in disintegration were the surface relations of continent, water—ocean—incipient ocean probably, and inland waters, and atmosphere. These provided at that early time all the various physical surface contacts known; namely:

solid—solid;	solid—liquid;
liquid—liquid;	solid—gas;
gas—gas;	liquid—gas.

That disintegration necessarily had to set in is beyond a doubt. And, inevitably, in the course of time colloids, as well as other solutions, had to form. On the importance of colloids in geologic history light is thrown by Raphael Ed. Liesegang, in his volume *Geologische Diffusionen.*

Concerning the formation of colloids on the lifeless earth we have, then, two fundamental propositions; namely: (1) we are bound to assume that the formation of colloids, *as of other solutions,* was inevitable; (2) a definite grouping of elements does not enter into the question of the initiation of the process, which necessarily became more and more complex with sufficient time—the years, of which Suess remarks, "What are a few thousand years in the course of planetary events?"[7]

But merely to remember Huxley's "Bathybius Haeckeli" saves any one today from calling certain precipitates primitive organisms because they look like organisms, and from investing the colloids of the lifeless earth with the attributes of organisms. As Arthur Isaac Kendall, of the Northwestern University Medical School, observes: "Between the lifeless colloid and lowliest known living things there is a mental barrier."[8]

Many are convinced that there is an *actual* barrier between non-life and life that cannot be bridged except by means of an outside agency. Thus Svante Arrhenius, whose place in the history of science is secure because of his brilliant work on electrolytic dissociation, especially espoused the ancient idea of panspermia to account for the origin of life on the earth. Some believe that, as Kendall holds, "it is not beyond the bounds of reason to look confidently to a day when science will triumph once again, and produce a colloid matrix in which chemical families are enmeshed."

[7] *The Face of the Earth,* II, 555.

[8] "Bacteria as Colloids." *Colloid Symposium Monographs,* II, 195.

Jacques Loeb said: "It is certain that nobody has thus far observed the transformation of dead into living matter, and for this reason we cannot form a definite plan for the solution of this problem of transformation."

Concerning the transition from the lifeless to life, however the transition is conceived to have been effected—whether by physicochemical processes or through some outside agency, always we are told that *colloids* were the medium.

What, then, are colloids?

The following is Wolfgang Ostwald's definition:

> "Colloids are dispersed systems, in which the diameter of the dispersed particles in typical cases lies between one ten-thousandth and one one-millionth of a millimeter. They are distinguished experimentally from molecularly dispersed systems by the fact that they do not dialyze; and from coarse dispersions by the fact that they cannot be analyzed microscopically. Colloids pass through filters readily, while coarse dispersions do not. Transition systems exist between colloids and molecular solutions and between coarse dispersions. The colloid state represents a universally possible state of matter. There is no reason why every substance may not be produced in colloid form. It may be accom-

plished either through the dispersion of non-dispersed or coarsely dispersed substances, or through the condensation of molecularly dispersed systems. To these ends not only chemical but mechanical, electrical and other kinds of energy may be used."[9]

Concerning the difference between colloids and crystalloidal solutions, Zsigmondy writes: "According to Bredig solutions of crystalloids and colloids may be distinguished by means of:

(*a*) diffusibility;

(*b*) the work necessary to remove the solvent;

(*c*) electrical migration;

(*d*) coagulation;

(*e*) absorption;

(*f*) irreversible changes of constitution and hysteresis;

(*g*) impermeability to other colloids;

(*h*) optical inhomogeneity;

(*i*) electrical formation of sols.

"It is evident from this brief résumé that there are many ways of distinguishing colloids from crystalloids. Notwithstanding this, no sharp line of demarcation can be established, for there are numerous intermediaries between both kinds of solutions."[10]

[9] *Theoretical and Applied Colloid Chemistry*, 34, 35.
[10] *Colloids and the Ultramicroscope*, 11.

Colloids do not constitute a peculiar kind of matter—as Graham, the founder of modern colloid chemistry perhaps thought in taking account of their dynamic qualities—but only *a peculiar condition, or state, of matter* (a fact to the establishment of which P. P. von Weimarn especially devoted much labor). Colloids are a peculiar state, or condition, of matter that can be assumed by any substance, even by salts, and that is independent of chemical constitution.

Colloids are systems that consist of the "dispersion medium" (which usually is a liquid, but which may be a gas or a solid) and the "disperse phase." Minute particles of solids, droplets of liquids, bubbles of gases—all may be colloidally dispersed. There are therefor innumerable different kinds of colloids. The simplest systems, of course, are those in which a single element, say silver or gold, is in the colloid state. But colloidal systems are found in most various degrees of complexity. Generally, research on colloids, whether in the arts or in nature has to do with a mixture of colloids; i.e., not a single kind of particle but two or more varieties of particles are present in colloidal solution.

The colloid state is determined by the state of dispersion, *the size of the particles*, of the disperse phase. This size ranges from 1 to 100 millimicrons.

The disperse phase of a sol then has *enormous surface*, which gives rise to the various sorption phenomena. Some of the properties of colloids vary according to the degree of dispersion. Thus, colloidal gold changes color with the size of the particle—it may show red or blue or purple.

Colloidal solutions are distinguished from true solutions in that the disperse phase of colloids is heterogeneous, giving the Tyndall (optical) effect, instead of homogeneous as in true solutions. A true solution is a molecular solution, whereas the particles in a sol are many times larger than molecules. The dispersed particles of a sol show lively movement, the Brownian movement, which is the more violent the smaller the particles. This movement is independent of external conditions, and persists for months or years—as long as the dispersion medium permits. The movements are due to collisions of the molecules of the medium with the particles, and thus the particles, being knocked about, do not settle down, but with reference to gravity rather behave similarly to the molecules of the gases of the air. It is the thermal agitation of the molecules of the medium that causes the molecular bombardment of the particles of the disperse phase, the Brownian movement.

The laws governing the displacements of these particles are the same for liquids and gases. The resistance offered by the medium to the movement of a particle-of-a-given-size through it is, of course, much greater in liquids than in gases. A kinetic theory of liquids that answers to the kinetic theory of gases, and Einstein's Brownian movement equation, then, account for the displacements of the particles of the disperse phase of a sol. Research on Brownian movement in gases by R. A. Millikan resulted in the exact evaluation of the gram-molecule, the Avogadro constant N (Loschmidt number L).

As for the particles of the disperse phase themselves—they always acquire electric charges, even in pure water (several and various factors contributing), and wander to poles. That colloids carry electric charges was first shown some thirty years ago (Linder and Picton), and was, as Stieglitz states, "one of the most important discoveries made on colloids."[11]

It appears that the phenomenon of electricity in colloids, that is, of a charged colloid particle, is in a class by itself. Faraday's laws do not apply to colloids; and there is no known method of determining the amount of the charge carried by an individual particle. Electrokinetic processes are inseparable from colloids. According to Herbert Freundlich,

[11] *Qualitative Chemical Analysis*, 131.

"electrical influences are of considerable importance in the study of colloids, but are here of a quite different kind from those with which electrochemistry has hitherto chiefly concerned itself. We have to consider here the so-called electrokinetic processes, which do not appear at all in galvanic cells, and only slightly in electrolysis."[12]

The colloid particles have a tendency to unite to form larger particles, the larger particles again uniting to form yet larger aggregates, and to precipitate, as their electric charges and other conditions and the presence of a small amount of electrolyte permit: There are the phenomena of coagulation, of flocculation, etc. Some conditions, some sols, are reversible, others irreversible. However, many disperse systems are very stable.

The foregoing is the briefest possible presentation of the leading facts concerning colloids. Advance in colloid chemistry has been rapid within recent years, due to the work of Zsigmondy, Smoluchowski, The. Svedberg, Wolfgang Pauli, Herbert Freundlich, Perrin, Hatschek, Martin H. Fischer, and many others.

However, certainly, since it is not questioned by anyone today that the ultimate interpretation of all physicochemical phenomena as well as of *all*

[12] *The Elements of Colloid Chemistry,* 75.

other *phenomena that involve matter*, must be found in the structure and forces of the ninety-odd atoms of the elements, research that treats of the "molecules" of the "dispersion medium" and their "bombardment" of the charged "particles" of the "disperse phase" (particles much larger than molecules, chemical constitution not necessarily given) and the "surface" of these particles, and of phenomena and relations in terms of these, obviously is *a limited inquiry that does not profess to be and is far from being an ultimate analysis.*

Colloids throw little light on the peculiarities of the organism that distinguish life from non-life; and, as Hans Handovsky says, "it would be foolish to believe that one can solve riddles of life with the aid of colloid chemistry."[13]

[13] *Leitfaden der Kolloid Chemie für Biologen und Mediziner*, x.

Chapter Three

Matter

ONE of the most striking changes that modern research has wrought, concerns man's concepts about matter.

In its magnitude and its far-reaching significance, this change ranks with the major revolutions of modern thought. First in these great revolutions of modern thought came the change from the Ptolemaic, geocentric, astronomy to the Copernican, heliocentric view. (With the years, the solar system itself, so far as man's ideas of its size and importance in the galaxy of universes is concerned, has shrunk into utter insignificance.) Next geology gave the Western mind an entirely new concept of duration—the unimpeachable record is not of a few thousand years but of millions of years, many millions of years. Next came the sweep of the broad concepts of evolution, the concept of a dynamic and orderly process of development.

And now, most recently, there has taken place the great revolution of thought concerning the constitution of matter: Whereas, formerly, the atoms of the elements were thought to be ultimate and indivisible units, the atom is now known to be a dynamic system made up of electric units. Today no physicist or up-to-date chemist believes in "the eternity of matter." Moreover, the unity, the essential oneness, of matter and electricity is fully recognized and emphasized.

The altered view of the constitution of matter is still so new, and the change in concept so radical, that some confusion in connection with the term "matter" is, perhaps, not surprising. Thus sometimes a careless reasoner will argue that because the atoms consist of electrons "there is no matter." But obviously it is crude and meaningless to say "there is no matter," since it is impossible even to write or print the statement without making use of pencil or ink and paper or some other similar mediums, all of which are chemical substances. *The term "matter" properly designates everything that can be defined in terms of the chemical atom.* Just because the atom has been found to be resolvable into its constituent units, and because, therefore, matter is not now considered to be an eternal and unchanging and primary condition, is then no valid reason for denying the existence of matter.

The facts of atomic physics, however, supply convincing proof that *matter is merely a condition,* the condition of positive and negative electrons grouped in the manner and pattern of the elements. For when the constituents of an atom are not in the specific combination that spells the atom, they are ultimate units (positive and negative electrons) with properties of their own.

Sometimes, rather loosely, electrons are referred to as "material," because of the "mass" of the electron; though in view of the marked differences between electrons and atoms it is desirable that the terms "matter" and "mass" should not be employed indiscriminately and as exact synonyms. "Mass" is not held by physics to be a measure of *extension,* or the quantity of matter, but—of electromagnetic origin—a measure of the energy content of a body, relative (changing with change of velocity), and registering as resistance to change (acceleration) of motion. (On the basis of the relativity principle of Einstein, the mass of a body is considered equal to its energy content divided by the square of the velocity of light. E. Madelung, P. P. Ewald, Max Born.)

It is an aid to clear thinking to reserve and apply the term "matter" exclusively to the ninety-two chemical elements, the atoms, and their compounds.

Concerning the elements, the basic and rudimental concepts are definite and simple.

1. The atoms of the elements are built up of positively charged nuclei and electrons.

2. The elements form a definite and limited series. It is now well known (especially because of Henry Moseley's work) that the elements form a series from hydrogen, atomic number 1, to uranium, atomic number 92. *This series is one of simple arithmetical progression*, and represents *the basic classification of the elements.* The atomic number (as was suggested by Van den Broek[1]) is determined by the number of free positive unit charges on the nucleus of the atom, every succeeding element adding one unit to its number of charges.

Not atomic weight, arbitrarily on the basis of oxygen=16, which gives hydrogen=1.0077, helium=4, to uranium=238.2, but *atomic number* gives the truly basic conception of the progression of the atoms in the natural system of the elements. In the lighter atoms, that is from helium, atomic number 2, atomic weight 4, to calcium, atomic number 20, atomic weight 40.07, half of the atomic weight about equals the atomic number. From calcium on to uranium, atomic number 92, atomic weight, 238.2, there is increasing disparity between atomic number and atomic weight.

[1] *Physikalische Zeitschrift*, XIV, 33, 1913.

Besides the basic arithmetical progression and the increase in atomic weight, the series of the elements shows a periodic recurrence of similarities of properties, which latter have led to the grouping as found in the periodic table. The periodic table now shows a grouping into eight periods, with the rare gases placed as the first period or (preferably) as the eighth period. However, this does not fully convey the periodicity shown by the elements. For on the basis of similarities of properties, the elements also show first a period of two elements, hydrogen and helium, followed by two small periods of eight elements each. Then come larger periods of eighteen elements, with interruptions (the rare earths, from cerium to lutecium). Finally, there is the great period of thirty-two elements, which is followed by a period of only six more elements, breaking off with uranium.

To account for the fact that the series of the elements ends with uranium, when the period of six elements of which uranium is the last, could easily be conceived extended to include more elements, possibly to the rounding out of the period to thirty-two, Sommerfeld suggests that any possible elements that may have followed uranium in this period are now non-existent due to their radioactive decomposition.

However that may be, it is certain that the elements form *a definite and limited series.* This is the series that properly appropriates the term "matter."

3. *The series of the elements is determined by the constitution of the nucleus of the atoms.*

The atomic number of the elements is determined by the number of free unit charges on the nucleus of the atom; but the number of free unit charges (outer, or orbit, electrons) that an atom can carry is, of course, determined by the constitution of the nucleus of the atom. Thus at once it appears that *the nucleus of the atom determines the atom and all its properties.* Change in the nucleus of the atom—ejection of alpha particles (helium atoms) or of beta particles (negative electrons) in radioactivity, changes the element. An alpha-ray transformation changes the place of the atom in the periodic table by two units to the left and reduces its weight by four units. A beta-ray transformation, on the other hand, raises the element one unit to the right, without any noticeable change in atomic weight. (Soddy, Fajans.) It is not questioned today that it is the nucleus of the atom that determines the element.

4. The ninety-two atoms, the ninety-two elements, are the building-blocks out of which the entire world of matter is composed.

The existence of matter is, of course, not limited to our own little earth. That the elements found on the earth are also present on the sun, was determined many years ago; and as the result of modern astro-physical research (Saha, Russell, Plaskett, Eddington, and others) it is now believed to be almost a certainty that all heavenly bodies contain all of the elements found in the earth.

It may be well to remember that, as Aston remarked, "starting with our standard bricks, the protons and electrons, we may make, theoretically at least, an infinity of systems by the combination of any number of these."[2] But on the assumption that all stellar bodies are constituted like the earth and our sun, the total of these bodies, then, would represent the amount of matter in existence.

A. W. Bickerton, pupil of Tyndall and teacher of Rutherford, points out "the certainty that our vast earth is but a minute speck of cosmic dust, absolutely insignificant in the ocean of space that lies within our own cognizance."[3]

Forest Ray Moulton, well-known astronomer of the University of Chicago, writes: "Since no other star has been found whose parallax is so great as one second [which corresponds to a distance of about

[2] *Isotopes,* second edition, 127.

[3] *The Birth of Worlds and Systems,* 127.

19,000,000,000,000 miles] it follows that the unit sphere whose center is the sun contains no other known sun. The earth compares in volume to this enormous space about as a minute particle only 1/20 of an inch in diameter does to the whole earth."[4]

The present-day teaching of some of the leading astronomers concerning the extent of the universe is that embodied in the so-called "island universe" theory. The Milky Way, the marvelous Galaxy in which the solar system is located, is believed to be an "island universe." That there are great numbers of "island universes," is the startling new teaching. And each "island universe" is conceived as composed of millions or billions of stars.

And yet, incomprehensible as the unknowable magnitude of the number of stars and worlds in space is, the entire universe of "island universes" of them sinks into insignificance when compared with the well-nigh incomparably greater magnitude of stellar distances. Herbert Spencer admitted that "the thought of Space compared with which our immeasureable sidereal system dwindles to a point, is a thought too overwhelming to be dwelt upon."[5]

That the total amount of matter in space is almost infinitestimal — Lord Kelvin[6] thought ultimately

[4] *Introduction to Astronomy*, 505.

[5] *Facts and Comments*, 292.

[6] *Philosophical Magazine*, August, 1901 and January, 1902.

really infinitesimal—compared with the volume of space in which it is found, thinkers find the most staggering fact of all.

Chapter Four

The Atom

THE old view that the atoms, the units of the elements, are ultimate and indivisible units necessarily was abandoned with the discovery of X-rays (W. C. Roentgen, 1895) and the discovery of the spontaneous rupture of the atom in radio-activity (Henri Becquerel, 1896). The heaviest known atom, uranium (atomic number 92, atomic weight 238.2) breaks up into a whole series of other elements, of which radium (Mme. and M. Curie, 1898) is one. There came the knowledge that the atoms are built up of positive and negative electrons, and that the atom is a system that consists of a positively charged nucleus which is surrounded by the negative electrons (Sir Ernest Rutherford, 1911).

This view of the atom having been established, numerous other *now well known* facts about the atom came to light:

Note.—For an exhaustive treatise on the atoms and mathematical treatment of atomic structure, see A. Sommerfeld, *Atomic Structure and Spectral Lines*, preferably the fourth (German) edition.

A singly charged atom is an atom that has gained or lost *one electron;* a double charge means the gain or loss of *two electrons*, and so on. Through the *loss of electrons* the atom acquires its positive charges; and through the *gain of electrons* its negative charges. The electropositive elements are the atoms with a *tendency to lose electrons;* the electronegative elements those with a *tendency to gain electrons.*

Enormous energies are locked up in the atom, as shown in the emission "with explosive violence" of the alpha particle and the beta particle in radioactivity.

Some elements are simple, thus hydrogen, helium, carbon, oxygen, and others; some elements (isotopes) consist of atoms that, having the same physical and chemical properties, differ in atomic weight. Thus chlorine, atomic weight 35.46, is an isotope that consists of chlorine atomic weight 35.0 and chlorine atomic weight 37. (Aston.) Ordinary lead has atomic weight 207.2; lead derived from radium, 206.0; and lead derived from thorium, 207.9.

All atoms are built on the same general plan.

The atom is not an impenetrable structure. The thermal agitation of molecules does not supply sufficient energy to permit the interpenetration of atoms. But an atom endowed with sufficient kinetic energy, readily can enter another atom. Thus an atom is not assured sole occupancy of its domain. According to Millikan, "the notion that an atom can appropriate to itself all the space within its boundaries to the exclusion of all other atoms is then altogether exploded . . . ."[1]

The atom is an exceedingly open and loose structure. It is generally agreed that if the constituents of the atom were packed close together, they would occupy only an infinitesimal part of the volume that is the volume of the atom. As Millikan has shown, a wall of lead at least sixteen feet thick would be required to absorb the "cosmic" rays. In his new cathode tube, Coolidge passes a stream of countless billions of electrons through a window that is made of a nickel plate about 500,000 layers of nickel atoms thick (although only one-half of one-thousandth inch in thickness), and only at rare intervals does an electron collide with an atom in the passage though the 500,000 layers.

The alpha particle that is emitted by radium, and that is 8,000 times more massive than an electron, shoots through about 130,000 molecules of air before being stopped. All the evidence forces to the conclusion that, as Millikan says, "the atom itself must consist mostly of 'hole'; in other words, that an atom, like our solar system, must be an ex-

[1] *The Electron*, second edition, 194.

ceedingly loose structure whose impenetrable portions must be extraordinarily minute in comparison with the penetrable portions."[2] "Even more open than that of our solar system," another (Aston) describes the structure of the atom.

A number of atoms have been stripped of their valence, or outer, electrons by Millikan and Bowen. In these experiments, in succession, 1, 2, 3, 4, and 5 of the outer electrons were stripped from lithium, beryllium, boron, carbon, and nitrogen, atomic numbers 3 to 7.[3]

Some atoms have been shattered. In 1919, Sir Ernest Rutherford and his assistant, L. B. Loeb, first split the nitrogen atom (by bombarding it with alpha particles).[4] Since then it has been shown (by Rutherford, Chadwick and Ellis) that the nuclei of many of the light elements are disintegrated when struck by very swift alpha particles. In every instance the particle ejected from the atom following an impact of an alpha particle on the nucleus is a single positively charged hydrogen nucleus, or positive electron. The transmutation of elements is a fact of observation, insofar as in the radioactive, uncontrolled (and uncontrollable), changes, an atom through loss of an alpha particle

[2] *Ibid.*

[3] *Physical Review*, July, 1924.

[4] E. Rutherford, *Philosophical Magazine*, XXXVII (1919).

or a beta particle is transformed into a different element. The remarkable experiments of Rutherford in dislodging positive electrons (hydrogen nuclei) from an atom, can only be interpreted as constituting experimental transmutation of one element into another. Sommerfeld says what becomes of the shattered atom cannot yet be definitely stated in every instance, but probably *nitrogen in losing two hydrogen nuclei is changed into carbon.* Aston asserts: "There can be no doubt that alchemical transmutation has been achieved."[5] That Dr. Adolf Miethe's experiment (1924) in which he believed mercury had been converted into gold has been discredited by H. H. Sheldon and by other physicists, obviously does not affect Aston's statement.

So long as the nucleus of the atom remains intact the element retains its individuality and position, or atomic number, in the series of the elements.

Since it has been established that the atom is a system that consists of positively charged nucleus and (negative) electrons, the question has been how to conceive of the grouping of the electrons around the nucleus.

In 1913, Niels Bohr, accepting the "nucleus" atom

[5] *Isotopes*, second edition, 125.

formulated by Rutherford, and calling in the quantum theory (Planck), advanced the concept of the atom as a dynamic system in which the negative electrons revolve about the nucleus as the planets do about the sun, but in quantised orbits. Others pictured a cubical atom, with the valence electrons fixed in certain equilibrium positions. However, though the cubical atom seemed to harmonize singularly well with the facts of organic chemistry, the idea that the atom possibly may be a system with static valence electrons, has been definitely and completely abandoned.

The Bohr theory, that at first described only circular orbits of the one orbital electron of hydrogen and ionized helium, was greatly expanded by Arnold Sommerfeld, who describes elliptic orbits as well as circular orbits and applies the theory to all the elements. The Bohr-Sommerfeld atom has been found to succeed to a remarkable degree in the interpretation of spectra and the chemical properties of the atoms.

Every physicist today holds the atom to be a dynamic system, and the modified Bohr atom is the accepted theory of atomic structure. Millikan says of it: "For the present at least it is truth, and no other theory of atomic structure need be considered until it has shown itself to approach it in fertility. I know of no competitor which is as yet even in sight."[6]

Thus J. D. Main Smith: "It is the only existing theory of the atom which is in conformity with the known facts of atomic structure and spectrum analysis. It must consequently be accepted that the atom of the physicist and the chemist is a dynamic atom, and theories based on static electrons must give place to it, no matter how difficult the conception of the dynamic atom may be for the mechanism of chemical combination."[7]

It is true that to interpret the valency phenomena of organic chemistry in terms of orbital electrons at first sight offers difficulty. And obviously, if the Bohr-Sommerfeld atom really gives the correct picture of the atom, it eventually must make possible the solution of all problems of valency. In a "Kelvin Lecture," J. H. Jeans observed: "At present the hydrogen atom and the positively-charged helium atom are the only structures which are completely understood, but there can be little doubt that in time the method will unravel for us the secrets of even the most complicated of atomic and molecular structures."[8]

Perhaps no fact of science has been more thor-

[6] *The Electron*, second edition, 228.
[7] *Chemistry and Atomic Structure*, 163.
[8] *Nature*, March 7, 1925.

oughly established than the fact that, as first taught by Dalton in 1808, *the atom is the unit in chemical changes.* The overwhelming proof consists in the demonstration whereby in numerous instances the quantitative analysis of a substance has been followed by the synthetic production of that substance. In the laboratory synthesis of the substance, the atoms may be gathered from various sources and, combined according to the ratios indicated by the analysis, will produce and approximately duplicate the substance. As is well known, there are now many synthetic substances, some of which are of great industrial importance. And the work of chemical analysis and synthesis is going steadily on, according to no haphazard methods.

The valency properties of the atoms are experience facts. Long before the intricacies of atomic structure were even suspected, the "loves and hates" of the atoms were known, and the elements were grouped according to their chemical combining power, or valency, as determined by experimental data. Chemistry reckons with *principal* valencies, with *residual* valency, and with *free* valency, besides recognizing *nulvalent* atoms.

According to J. D. Main Smith, "Professors Thorpe and Morgan both agree that the time is not yet ripe for the application of general electronic theories to organic chemistry." However, there is no other key to valency save the structure of the atom, since all problems of energy involved in valency are bound up with the atom's structure. *If the atom really is a planetary system, then all atomic functioning and all relations among the atoms must be described in terms of the atom as a planetary system.* Therefore the molecule of the chemist (sharply distinguished from the molecule of physics, a convenient unit of measurement in the kinetic theory of gases) is now pictured as *a system of planetary systems.* A radical is a cluster of planetary systems. Chemical bonds are referred to the interrelations of the atoms as planetary systems, and to specific valence electrons.

All associations and dissociations of atoms, all the manifold changes and properties whatever of all chemical substances that are known to be due to number and manner of combination of atoms, are interpreted in terms of the dynamic planetary atom and its orbital electrons.

The *radius* of an atom is defined by the path of its outermost orbital electron or electrons.

An ion (charged atom or molecule) is a planetary system, or a system of planetary systems, that has suffered change through the gain or loss of one or more orbital electrons.

This is the general concept. It makes no difference what the chemical constitution of a substance may be, or how complicated the phenomena that are to be interpreted, or whether the phenomena fall under simple chemistry or any one of the several branches of physical chemistry or under biochemistry, this is the sole method of interpretation that accords with the accepted view of the atom.

It is a curious circumstance that the planetary atom (to which the spectroscopic facts undoubtedly testify, and that interprets well the periodic properties of the elements, and which therefore has been generally accepted) seemingly encounters difficulties in connection with organic chemistry. This impressively serves to emphasize the fact, which chemistry always has had to deal with, that chemical substances fall into two classes, the organic (carbon compounds) and the inorganic. Carbon compounds are much less stable than inorganic substances toward physical and chemical reagents, and require methods of analysis different from those employed for the inorganic. Generally the molecule of organic substances is much heavier than the molecule of inorganic substances. Indeed, the very heavy molecule is one of the chief characteristics of organic substances.

The differences between substances that led to their classification as inorganic and organic, are found to coincide roughly with the broad classification of substances as *polar* and *non-polar.*[9] Gilbert N. Lewis describes them thus:

> "The very striking differences in properties between the extreme polar and the extreme non-polar types are summarized in the following table . . . . :

Polar	Non-polar
Mobile	Immobile
Reaction	Inert
Condensed structure	Frame structure
Tautomerism	Isomerism
Electrophiles	Non-electrophiles
Ionized	Not ionized
Ionizing solvents	Not ionizing solvents
High dielectric constant	Low dielectric constant
Molecular complexes	No molecular complexes
Association	No association
Abnormal liquids	Normal liquids."[10]

These, then, are the various peculiarities and characteristics that offer special difficulties and that, all of them—not differences of state caused by temperature and pressure conditions—must find their ultimate interpretation in terms of the structure of

[9] *See* Gilbert N. Lewis, *Journal American Chemical Society,* XXXV; and W. Kossel, *Annalen der Physik,* XLIX.

[10] *Journal American Chemical Society,* XXXVIII.

the atom, in so far, or inasmuch, as the grouping and combination of *atoms* are involved.

But that the facts of organic chemistry, the most complicated of phenomena and intimately bound up with biochemistry, have been offering great difficulty to the planetary atom, simply means that *it takes time for a basic theory that answers to a broad general fact to find complete application.*

The Bohr-Sommerfeld theory gives the model of the *single* atom. In the interpretation of the single atom, the series of the atoms, the theory has been eminently successful. Careful scrutiny of the evidence by those qualified to judge, and of duly critical temper, has led to the general acceptance of the planetary dynamic atom.

However, the dynamics of the atomic system and of each of the individual constituents of the atom are such that when two or more systems unite, inevitably the nuclei of the atoms will exert marked influence on each other, with consequent changes in the positions of the orbital electrons that are involved. Millikan explains: "When atoms unite into molecules, or into solid bodies, these orbits will undoubtedly be very largely readjusted under the mutual influence of the two or more nuclei which are now acting simultaneously upon them."[11] "These

[11] *The Electron*, second edition, 230.

complications register in the spectrum," says J. Franck.[12] Irving Langmuir said that "recent work on spectra has shown that a molecule cannot be set in rotation without changing the configuration of the electron orbits."

It is well known that the hydrogen molecule does not show as an exact duplicate of two single hydrogen atoms, but shows marked changes, in that the orbital electrons belong to both nuclei in common.

All orbital changes of the path of a planetary electron are defined in terms of quantum conditions.

The modified Bohr theory of the atom, then, pictures the atom as a planetary system in which the planets are negative electrons that revolve about the central body, the nucleus. Max Born tersely says that "the two facts of experience that served as a basis for the considerations that led to the Bohr theory of the atom are: (1) the stability of the atoms; and (2) the validity of the classical mechanics and electrodynamics for macroscopic occurrences."[13]

In picturing the atom as a planetary system, several differences are recognized. Thus, whereas there is mutual attraction between the planets as well as between the sun and the planets, the negative electrons while held in their orbits by the

[12] *Zeitschrift für Elektrochemie und Angewandte Physikalische Chemie*, Juli, 1925.

[13] *Vorlesungen über Atommechanik*, I, 18 (1925).

attraction of the nucleus, repel each other. Again, it is the gravitational mass of the sun that attracts the planets, but in the atoms it is the *charge* on the nucleus and not its mass that attracts the electrons. Newton's law of gravitation therefore is replaced by Coulomb's law of electrical attraction. Further, whereas the planets of the solar system keep to their several orbits, the electrons of an atom (responding to excitation, and accompanied with marked changes in energy) jump, or fall, from one orbit (or energy level) to another.

Again, because it was found that the application of the classical theory led to inconsistencies with the facts of the atom's stability, energy changes in the atom are duly reckoned with on the quantum theory. Thus there has resulted the new mechanics of the atom; and in agreement with the finding that in the series of the elements, beginning with hydrogen, atomic number 1, with each succeeding element one electron is added to the atom, the modified Bohr atom pictures *the successive binding of the electrons in the field of the nucleus.*

In the modified Bohr theory, the requisite number of electrons—the number permitted by the nucleus—are grouped around the nucleus in concentric orbits, orbits of various types, and in successive "shells," or "energy-levels," the K-shell screening the nucleus, and successively the L-shell, the M-shell, and other shells. However, it is fully understood, these "shells" are not actual barriers in space in the atom, but mere "energy-levels," since the orbits of some of the outer electrons penetrate the orbits of inner electrons. Indeed the complexity of interpenetrating orbits is very great in some atoms because of the large number of electrons in each class of orbits and because the orbits occupy all three dimensions of space. As J. D. Main Smith points out: "Only by an extreme license in the use of words can each class of orbit be regarded as constituting an energy level or shell in an atom, for the orbital interpenetration makes a precise conception of levels impossible except in the case of truly circular orbits."[14] Such interpenetration of orbits affects the stability of the atom. Atoms vary greatly in respect to stability.

The spectral lines of the atoms, checked by the periodic properties of the atoms, are being interpreted as necessitating the various orbits with various numbers of electrons in an orbit, and the orbits at various distances and of various forms. Further, the spectral lines are interpreted in terms of wavelengths and in terms of a quantum analysis. It is a postulate of the Bohr theory that an atom can radiate or absorb energy only when an electron is

[14] *Chemistry and Atomic Structure*, 170.

"activated," that is, changes its orbit, or goes from one energy-level to another. This important proposition has been experimentally verified. Thus Karl Taylor Compton and his collaborators at the Palmer Physical Laboratory (Princeton) found that "the activated states of hydrogen are exactly as he [Bohr] predicted them." "It was similarly found," Dr. Compton said, "that the light of every particular wave-length requires a definite amount of energy for its emission and this energy is the energy of a corresponding activated state of the atom." (*See* Quantum.)

The entire field of exploration of the atom through spectrum analysis has been opened up—from the series of the infra-red (Paschen) to the extreme ultra-voilet (Lyman, Millikan, Bowen, and others) and X-rays (*see* X-rays).

It is, of course, well recognized, and there could be no confusion concerning this fact—at least not in the mind of a physicist—that the Bohr theory of the atom *accepts the nucleus* of the atom and builds around it in accordance with the evidence of spectra and of the properties of the elements.[15]

The exact number of positive and negative electrons contained in the nuclei of the atoms is believed

[15] As already noted, the "nucleus" atom theory was first advanced by Rutherford. In connection with an impenetrable nucleus, however, Lenard's work, too, may not be forgotten.

to be definitely known; but *how* the nucleus is built up, that is, the *manner* and *pattern* of the combination of the constituents of the nucleus, is not yet known. Radioactivity gives glimpses. Aston considers it "evident" that "the nuclei of even light elements are very complex structures."[16] Whatever the manner of the combination, the enormous energy that is displayed in radioactivity is locked up in the *nucleus*.

Some hold that the nucleus is built up of hydrogen and helium atoms.

Nuclei vary greatly in their stability.

The close packing of the constituents of the nucleus as compared with the loose structure of the atom, is certain; since the minuteness of the nucleus of the atom as compared with the volume of the atom, has been established.

The impenetrability of the nucleus has been shown.

The relationship (not the periodicity itself) of properties of the atoms that has led to the classifications of the periodic table of the elements, and the fact that the elements form a series that progresses arithmetically from hydrogen, atomic number 1, to uranium, atomic number 92, indicate relationship of pattern, or the same general manner of combination of the constituents for all nuclei.

[16] *Isotopes*, second edition, 124.

Sommerfeld, Max Born, and other leading investigators hold that the nucleus is built up according to the same laws that govern the building-up of the atom. Sommerfeld expresses the conviction that the nuclei are built up of elementary constituents according to the same principles of construction; namely, according to the rules of the quantum theory, as the atoms are built up from nuclei and electrons.[17]

All are agreed that the nucleus of the atom determines the atom. Irving Langmuir said: "Nearly all of the work on atomic structure has shown that each atom may exist in enormous numbers of different states and that the state of an atom may be modified by nearly every external agent that acts upon it." Again: "Each atom may exist in multitudes of various forms depending on external conditions. The nucleus is the only part of an atom that is absolutely characteristic of it."

The atom may undergo various vicissitudes—it may be "excited"; various rays may pass through it and perchance work injury to the structure of the atom; it may lose some of its electrons to other atoms; or it may be "stripped" of electrons; it may share its domain with another atom, etc.; but it

[17] *Atombau und Spektrallinien*, vierte Auflage, 217.

will retain its identity so long as the nucleus remains intact.

Moreover, an atom that has lost one or more of its outer electrons *will recapture electrons as conditions permit.* Ionization, as observed especially in gases, is temporary, and the effort is to regain the neutral state. But when the nucleus of the atom loses one or more of its constituents, the atom is transmuted and changed irreparably.

The nucleus determines the atom. *The Bohr theory of the atom accepts the nucleus without having any definite picture to offer concerning how the constituents of the nucleus are combined in its structure.*

It is a well-known fact that comparatively few of the ninety-two elements are directly involved in the life-process. The chief chemical constituents of the organism are hydrogen, carbon, nitrogen, and oxygen. The human body practically consists of hydrogen, carbon, nitrogen, oxygen, phosphorus, and calcium, only small amounts of other elements being present. The elements that are found in all organisms are:

	Atomic number	Atomic weight
Hydrogen	1	1.008
Carbon	6	12.00
Nitrogen	7	14.008
Oxygen	8	16.00

Sodium	11	23.00
Magnesium	12	24.32
Phosphorus	15	31.04
Sulphur	16	32.07
Chlorine	17	35.46
Potassium	19	39.10
Calcium	20	40.07
Iron	26	55.84

Other elements found in mere traces or large amount in certain organisms are:

	Atomic number	Atomic weight
Fluorine	9	19.
Aluminium	13	27.1
Silicon	14	28.3
Manganese	25	54.93
Copper	29	63.57
Bromine	35	79.92
Iodine	53	126.92

These may be of very great importance to the organism. Thus, iodine is stored in the thyroid gland; and metamorphosis in tadpoles was induced by feeding them with traces of inorganic iodine. (Swingle.[18]) In its chemical behavior iodine, as well as fluorine and bromine, shows much resemblance to chlorine.

Small quantities of cobalt (atomic number 27,

[18] *See* Jacques Loeb, *Scientific Monthly*, December, 1919.

atomic weight 58.97) and nickel (atomic number 28, atomic weight 58.68) have been found present in the human body, especially in the pancreas gland, according to Gabriel Bertaud (director of the biological chemical laboratory of the Pasteur Institute, Paris).

Among the elements named is the element that is the most abundant on the earth's crust, oxygen.

Hydrogen and oxygen as water form more than two-thirds of the earth's surface, and—as mentioned before—constitute from sixty-five to eighty per cent of the organism. The human embryo, it may be recalled, at an early stage of prenatal existence consists of ninety-four per cent water.

Nitrogen and oxygen are the chief constituents of the atmosphere—the air (a mixture of gases) consists of seventy-eight per cent (in volume) of nitrogen, and twenty-one per cent of oxygen, and small amounts of argon, helium, and other gases.

Carbon, though predominating in organic compounds, is relatively rare.

Sodium, magnesium, potassium, calcium, and iron, are some of the most abundant of elements. Sodium and chlorine (sodium chlorid) are present in sea-water (the ocean, habitat of numerous life-forms) to the amount of nearly three per cent by weight.

The three most abundant elements, oxygen, iron, and calcium, have even atomic number. (That the most abundant elements are of even atomic number, was first pointed out by Harkins, 1917.)

All the elements found in organisms in large amounts are some of the lighter elements. Most of them belong to the two small periods of eight elements each, the exceptions being hydrogen (first period of two, or standing alone), and potassium, calcium, and iron (fourth period of eighteen).

According to the research of Aston, hydrogen, carbon, nitrogen, oxygen, sodium, phosphorus, and sulphur are simple elements. The rest are isotopes.

Sodium, potassium, magnesium, calcium, and carbon are electropositive; nitrogen, phosphorus, oxygen, sulphur, and chlorine, electronegative. Potassium shows weak radioactivity.

Carbon and nitrogen are among the elements that have been stripped of their outer electrons by Millikan.

Nitrogen, sodium, and phosphorus have been shattered by Rutherford.

Nitrogen, it is well known, is very important to life, although it does not support combustion; and it is especially interesting that the product of nitrogen shattered (with the loss of two hydrogen nuclei) would be *carbon*.

How the models of the atoms of the electronegative elements oxygen and nitrogen are to be pictured, is not known. Sommerfeld says that at any rate it must be assumed that they are characterized by a certain lack of symmetry in certain of the paths of some of their orbital electrons.

Hydrogen is an electropositive element. In the hydrogen atom we have one unit each of the two fundamental building blocks, the two ultimate *known* constituents and building blocks of all things. (More than a hundred years ago Prout advanced the hypothesis that hydrogen itself was the unit of which all other atoms are multiples.)

Many believe that electrons, positive and negative electrons, indeed are the two ultimate units. However, science today makes no dogmatic assertions concerning whether electrons are or are not the ultimate constituents of things. Ehrenhaft thought he had evidence for the existence of a unit much smaller than the electron. But his experiments were shown to have been faulty, and thus his reasoning invalid. Recently J. J. Thomson suggested that the electrons in the atoms may be surrounded by much smaller particles. But assumptions of the existence of units smaller than the electron are for the present purely speculative. The electron in its two forms is the smallest unit of the existence of which there is actual physical laboratory proof.

One each of the two *known* ultimate electriacl units, then, form the hydrogen atom. Hydrogen always takes the form of a molecule (H_2) that can be separated into its atoms only under specific conditions: (1) excessively high temperature is required, as in some of Irving Langmuir's work; or, (2) at ordinary temperature the impact of ions (as Nernst says) will split the molecule. Hydrogen, a gas, united with another gas, oxygen, as H_2O forms a liquid. This liquid again can assume various familiar states. Hydrogen in other combinations contributes to the formation of solids.

Thus it is plain that the various manners of combination of electrical units produce various states as widely different as possible:

1. Electricity, positive and negative electrons.
2. Matter { the gaseous state; the liquid state; the solid state.

This broad reflection obviously in no way goes into the various states of matter. The point is only that the most diverse and seemingly unrelated states and properties, or qualities, result from the combination of the two ultimate units, the positive and the negative electron, the differences depending only upon *number of constituents and manner of combination.*

Much experimental work has been done on the *displacement of electrons* in the ionization of gases (nitrogen or oxygen, etc.) by means of X-rays, beta-rays, and alpha particles. The experiments and the attending phenomena vary with conditions, but, of course, all ionization means that a unit electric charge has been torn violently from an atom (or molecule), or that two or more such unit charges have been torn away. Ionization always implies that there has been *gain* or *loss* of one or more electrons. Interpreted in terms of the dynamic planetary atom, it means the gain or loss of one or more *orbital electrons;* and, since the radius of the atom is determined by the orbit of its outermost electron or electrons, it generally (though not necessarily for all atoms) means alteration in the radii of the atoms or ions that are concerned.

Concerning ionization in *liquids* (in which molecules are split up "spontaneously") it is known that ionization takes place when a salt (or similar substance) is dissolved in water or certain other liquids. And, Bloxam says, "the molecules in an electrolyte must be regarded as being *already* ionized, nearly completely in dilute solutions, and to a certain extent in all electrolytes .... Judging by conductivity, ionization appears to be practically complete when 1 gram-equivalent of a salt is dissolved in 1,000 litres of water."[19]

The *displacement of electrons* involved in the ionization that takes place in an electrolyte or in a colloidal solution, is not caused like that in a gas. In the latter a stream of electrons or alpha particles or X-rays is shot through the gas at great speed, possibly passing through a very large number of atoms (molecules) before striking and dislocating an electron. Indeed, W. F. G. Swann has shown that "corpuscles having the velocity approximately that of light .... would be unable to eject an electron from an atom of oxygen, the more easily ionizable of the two main constituents of the atmosphere."[20]

The passage of the electric current then is not needed to bring about ionization in an electrolyte, the condition of dissociation resulting from the direct action of one atom (of a molecule) upon another. It is believed that "many salts, acids and bases are dissociated when they are dissolved." (Bloxam.[21])

However, the acquiring of an electric charge is a

[19] *Chemistry*, eleventh edition, 313.

[20] *Journal of the Franklin Institute*, February, 1926.

[21] *Chemistry*, eleventh edition, 313.

common phenomenon. It was so simple a thing as the rubbing of amber that led Thales of Miletus (600 B. C.) to speculate on electricity.

One of the most interesting of the phenomena of ionization is the photoelectric effect, or the emission of electrons caused by the influence of light. That organic compounds may exhibit the photoelectric effect, the experiments of Harry Clark clearly show.

The ultimate in dissociation is yielded by hydrogen: Some atoms (some of the metals) have so strong an affinity for oxygen that in water (H_2O) they will unite with the oxygen of a molecule of water, disrupting the molecule and leaving the H_2, which then, in a disturbed condition, is readily ionized. The positively charged hydrogen molecule (H_2^+-ion) is a system that consists of two nuclei and one orbit electron, or two positive electrons and one negative electron. When this one orbital electron is farthest away from the nucleus whose negative electron has been lost, this nucleus (or positive electron) then, being less tightly bound, again will readily be carried away by outside agency of sufficient kinetic energy. The positively charged hydrogen atom (H^+) consists of the hydrogen nucleus, or *one positive electron.*

It is, of course, well known that hydrogen ions are found when acids are dissolved and dissociated in water, all acids being resolvable into hydrogen ions.

The H_2^+-ion and the H_3^+-ion are known to be capable of a short existence—an existence, that is, for a time comparable with the mean free time between collisions.

What is Life?

PART TWO

Theory of Life
Based on Atomic Physics

CHAPTER FIVE

Theory of Life

I. GENERAL POSTULATES

THE prerequisites of the theory are:

1. A condition of a critical concentration of ions.

2. The (modified) Bohr atom.

The theory that results, taking this as our starting-point, is summarized on pages 152 and 153.

II. PARTICULAR ASSUMPTIONS

Outside the specific, central, basic and indispensable requirement that there be a condition of a critical concentration of ions, only a few of the simplest assumptions are needed:

1. Chemical constitution: This may be simple or complex. As suitable one may picture the presumable chemical constitution provided by the early earth—its crust, its waters and atmosphere—just prior to the advent of life.

2. Temperature: Any temperature within the limited range of temperatures favorable to the life-process.

3. Pressure: Ordinary atmospheric pressure at sea-level.

III. WHAT MAY BE IGNORED

In postulating a condition of a critical concentration of ions, the attention obviously is centered on a condition that occupies *a definite moment* in time.

The theory is concerned with that moment and the further happenings. What preceded and led up to the critical condition permissibly may be ignored, since ionization is not a hypothetical thing but one of the best-known of facts.

It is here not necessary, then, to inquire into previous chemical reactions, hydrolysis, electrolytic dissociation, electrolytic solution pressure, etc.; nor into the problem of heat, heat of solution, heat of ionization, etc.; nor into any of the other processes and factors that led to the postulated condition of a critical concentration of ions.

Whatever part the thermal agitation of molecules (an important factor in connection with Brownian movement) may have had in bringing about the required condition, it is not a direct factor at the critical moment.

"Surface phenomena," adsorption, surface tension etc., that play so large a rôle in colloids, are excluded as factors.

Gravity is not momentarily of concern.

The viscosity of the medium, a very important factor when the displacement of colloid particles or other particles or units of molecular dimensions are under consideration, *for merely the moment* postulated may be considered a negligible factor, since—as it will appear—the units whose movements are followed are electrons.

The inquiry, at the critical moment postulated, then, is not concerned with the mean free path of particles within the range of dimensions that are associated with colloidal phenomena, the Brownian movement of which (with introduction of the van't Hoff factor *i*) obeys the gas law. Obviously, questions of equilibrium to which Gibbs's phase rule would apply, are not directly involved. Nor, at the critical moment, does the inquiry pertain to the problem of valency, or the association of atoms to form molecules.

Though the importance of light and sunshine to life is well known, and the large place of radiation appears from the photochemical facts, the photoelectric effect, the Compton effect (serving as an interpretation), the activation of certain unfertilized eggs by specific rays, the lethal effect of sunshine on bacteria, etc., the problem of radiation need not enter at the critical moment. Radiation, direct sunlight or other radiation, is not a factor at this moment.

With these eliminations the inquiry is reduced to the utmost possible simplicity.

IV. WHAT IS MEANT BY "CONDITION OF A CRITICAL CONCENTRATION OF IONS"

Primarily it is a condition that perhaps is possible only in a liquid solution (liquid: slight compressibility, the molecules presumably in contact), and that probably cannot obtain in a gas or a solid.

Further, since hydrogen ions are needed, and free hydrogen ions are found only when acids are dissolved and dissociated in water (Nernst[1]), water is postulated.

Hydrogen ion concentration has various (definite) values according to the extent to which dissociation takes place. "Ionic concentration," of course, means the quantity of gram-atoms of an ion per unit volume in a solution.

A critical condition, the isoelectric point, of the colloidal state is that which results from the introduction of a small quantity of an electrolyte into the colloidal solution, when electrolytic movement is suspended and precipitation or coagulation of the particles occurs. This critical condition, needless to say, is entirely unrelated to the critical condition

[1] *Theoretische Chemie* (edition of 1926), 637.

postulated by the theory; nor is the concern with the movements of ions or colloidal particles in or through a solution.

The critical concentration postulated by the theory is merely *a local condition of ionization in which the concentration of ions, the crowding of ions, is such that some atomic domains overlap.* It means a condition of crowding of atoms and ions that is not relieved by any surrounding conditions.

The critical concentration of ions postulated is a critical condition in respect to:

1. The *concentration* of ions, as described; and

2. The *relations of specific ions,* in that *the proximity of some atom or ion with normal or acquired electropositive tendency* (that is, some atom or negatively charged ion that will readily part with an electron) *to hydrogen ions, preferably to a* H_2^+*-ion is required.* (*See* pp. 108 and 109.)

Concerning the *occurrence of the postulated condition*—a local condition—one must assume:

1. Undoubtedly there were innumerable simultaneous and repeated occurrences on the early, lifeless earth.

2. Undoubtedly, the condition was of repeated, frequent occurrence during geologic time.

3. The condition is producible in the physical chemistry laboratory.

4. The condition, under certain circumstances, occurs following injury to cell structure of a cell or cells of various living organisms, including man. (According to foremost authorities, there are no free ions in a cell; the trauma, however, having reduced the cell material to the condition of a solution in which undoubtedly hydrogen ions and other ions are present, a critical concentration of ions develops.)

In this critical condition of theory, the problem obviously is not one of the mean free path of a particle in a medium, or of a molecule in a gas or liquid. In this local condition of critical concentration, there is no longer any distance or space between molecules, but, the ionized atoms and molecules being crowded together so that even atomic domains overlap, there are only intra-atomic spaces.

Most obviously, ionization means alteration of orbital relations—

(*a*) of number of orbital electrons;

(*b*) of paths;

(*c*) of energy conditions.

Given the critical condition postulated—in no sense a condition of equilibrium—the problem of what adjustments will follow, has to do with the constitution and the electronic orbits of the H_2^+-ion and the other atoms that are concerned.

V. KNOWN CONSTANTS AND UNDETERMINED VARIABLES

The three great universal constants of atomic physics are well known:

1. The electron. $e = 4.774 \times 10^{-10}$ electrostatic units (Millikan); or (divided by c), $1{,}591 \times 10^{-20}$ electromagnetic units.

2. The ratio of charge to mass for the negative electron. $e/m = 1.769 \times 10^{7}$ electromagnetic (C.G.S.) units.

3. Planck's constant. $h = 6.55 \times 10^{-27}$ erg sec.

The positive electron (called by some *proton*, a name also used by Zsigmondy to designate certain colloid particles), the hydrogen ion, or hydrogen nucleus, carries a charge that is equal to that carried by the negative electron, but its mass is identified with the value of the mass of the hydrogen atom, 1.662×10^{-24} (in grams).

The negative electron moves at varying rates of speed; it is slow as the charge on an ion in an electrolytic solution; rapid as cathode ray—extremely so in a Coolidge tube; approaches the velocity of light (within less than one per cent) as beta ray; and it has various and varying rates of speed in the various orbits of the various atoms, and according to the state of the atom, neutral, excited, or charged. When the speed of the electron exceeds one-tenth the velocity of light, the mass of the electron varies with speed.

In the dynamic planetary atom, every orbital electron, besides its charge, has a path, or orbit, and velocity, or velocities, proper to the orbit.

The path, or orbit, is determined primarily by the nucleus of the atom to which the electron belongs, but it is modified by other energy conditions within the atom (other electrons), and also—it is abundantly plain—by external conditions (other atoms). Thanks to the quantum theory (Planck), all energy levels and energy changes of orbit electrons can be definitely quantised, and the unit value of all such changes is known to be *h*.

But (as was pointed out before) the values that have been worked out thus far, have to do with single atoms, the atom unrelated to its neighboring atoms; and the spectra of many of the atoms have not yet been satisfactorily deciphered. Thus, the model of oxygen is still in doubt. And what is the exact path of the one orbit electron of the H_2^+-ion? The exact paths and velocities of the orbital electrons in polyatomic systems, in the system of even H_2O, are undetermined. However, if the atom really is a planetary system, this does not make it any the less certain that in ionization in a solution, the captured electrons that constitute the negative charges on the ions, were orbital electrons that were pulled out of their path by the attraction of the atom (or ion) that gained them.

VI. THE SETTING UP OF NEW RELATIONS

There is postulated, then, a (local and momentary) condition of critical concentration of ions, and a hydrogen ion, let us say a H_2^+-ion (*see* page 108), and an atom or ion of electropositive tendency crowded together and with their domains overlapping. (It is, of course, understood that the *domain* of the atom or ion is described by the radius of the atom, and the radius is defined by the outermost orbit of the orbit electron or electrons of the atom.) The overlapping of the domains of the H_2^+-ion and the neighboring atom or ion (of electropositive tendency) is due to the encroachment of the atom or ion on the domain of the H_2^+-ion. This is plain if it be remembered that the hydrogen molecule carrying a positive charge consists of two nuclei (two positive electrons) and one orbit electron. This one orbit electron revolves about the two nuclei, and, however its path may be conceived, with reference to its nuclei is alternately at aphelion and perihelion.

With the orbit electron of an H_2^+-ion at aphelion, the domain of the ion is open in the region of that one of the two positive nuclei that is the farther one from the orbit electron. The two positive nuclei, positive electrons, are held together only by the one orbit electron, but they repel each other, while the positive electron (nucleus) with reference to which the orbit electron is at aphelion does not repel any negative electron. Hence the ready encroachment upon the domain of the H_2^+-ion.

Thus, then, is pictured the overlapping of the domains of the H_2^+-ion and an electropositive atom or ion at the critical moment.

As for the encroaching atom or ion—it may be an atom with only one electron in its outer orbit, rather loosely held, or it may be an atom or ion in which an electron describes a path that takes it from the interior to the periphery of the atom, there readily to be parted from the atom.

When, in the critical condition postulated, such a negative electron (while describing its normal or an aberrational path) gets into the field of the positive hydrogen nucleus of the H_2^+-ion with its orbital electron at aphelion, *something is bound to happen.* The electron may be drawn into the field of the H_2^+-ion in such a way that it will complete the hydrogen molecule; or, possibly, it may unite with the positive electron to form a normal hydrogen atom which means that (the positive electron having left the ion) the negative electron would revolve about the positive electron *at some distance;* or *the onrushing negative (orbital) electron will directly collide with the positive electron and will form an exceedingly close union with it.*

Which one of these things will happen, depends on the exact distance (within the critical limit) between the positive electron and the nucleus of the encroaching atom, and the path and kinetic energy of the negative (orbit) electron that are involved. It is certain that under the conditions postulated, one of these things must happen.

Obviously, whether a new hydrogen atom or an excessively close union results from the impact, the positive electron is lost to its ion and the negative electron to its atom.

In the event that, as postulated, the positive electron and the negative electron join in an exceedingly close union, the resulting unit, though consisting of the same constituents (one each of the two known ultimate units) that spell the hydrogen atom, of course would be *unlike a hydrogen atom. It would not be a hydrogen atom.* For in order that one positive electron and one negative electron should form a hydrogen atom, it is necessary that they should be found in those relations to each other that are proper to the hydrogen atom; that is, with the orbit electron revolving about the nucleus at a considerable distance. A positive electron and a negative electron not in such relations are not a hydrogen atom.

A unit consisting of a positive electron and a negative electron united in an extremely close union would not be a hydrogen atom, but a new and different unit.

We are forced to these conclusions by the general facts of the atoms and the electrons. Although at present other forms of combination are unknown, it would be mathematically absurd to assume arbitrarily that the pattern of the atom, our intimate knowledge of which has been acquired only within the last decade and a half, is the only possible pattern into which positive and negative electrons can unite. (*See* Aston, p. 79.) But unless we hold that the pattern of the combination of positive and negative electrons as found in the elements (atomic nuclei and orbits, as recently given by Bohr's theory and more recently identified by spectroscopy), is the complete scheme of the universe, or that any other pattern of combination of positive and negative electrons is impossible, we must admit the ready probability that under the conditions presented an exceedingly close union of a positive electron with a negative electron—a new unit—may result.

This new unit could not enter into combination *with atoms after the manner of the hydrogen atom, not having the mechanism of the hydrogen atom. This means that it could not form chemical combinations.*

On the other hand, *it could not become a "charge"* on an atom; since the constitution of the atom, of all atoms, (nucleus and definite number of orbit electrons) is such that it could not be added to the configuration of the atom, as say the electron that the chlorine atom captures from the sodium atom is added to the chlorine atom, as aid to the chlorine atom's electromechanical stability.

Here, then, is a new and different unit that cannot enter chemical combinations, nor become a charge on an atom.

Hence only one of two things can happen to it: This new and different unit (1) may get into a field so strong that it will be torn asunder, the negative electron being captured by some atomic system that has sufficient energy to lift it out of its union with the positive electron; or (2) *the new unit itself will capture* (both negative and positive) *electrons and build up a new structure.*

Since this new unit obviously does not belong to the configuration of any atom, and cannot enter into "chemical" combination with atoms (not being a hydrogen atom), nor become a charge on an atom, *what are its values?* And, in the event that it is not torn asunder immediately after its formation, *what relations will it have to the atoms?*

Concerning its values: Its energy content (mass), its path, its velocity, all (*a*) are predetermined by the specific conditions of the atom and ion of which the two electrons (the positive and the negative electron that make up the new unit) formerly were constituent parts; and (*b*) are modified by surrounding conditions (postulated to be conditions of critical concentration of ions). It appeared that at the critical point it is not a problem of "averages," and "mean values," or of "mass action" of a group of units of the same or various values; but it is a problem of *identifying particular atoms, ions, and electrons, particular orbits, and particular angles.*

It is true that, given the critical condition postulated, one may not select one atom as the only one that would lead to the formation of the new unit; but *any atom that readily would lose an orbit electron, any one of a number of atoms* (elements), *may figure in this peculiar relation to an* H_2^+*-ion.* While the general results would be the same for any one of a number of atoms, yet the different atoms would produce differences of results in the values of the new unit so far as the electrodynamics of the new unit are concerned.

If the energy content, the path, and the velocity of the new unit are to be evaluated, then first the electron involved must be identified; that is, its atomic origin (which element), position in the specific atom, and the values proper to it in the atom, must be identified. For, obviously, when a collision, as pictured, takes place, the force of the impact and the path of the new unit (direction relatively to [*a*] the atom and the ion of which the electrons had been a part; [*b*] other neighboring atoms, or ions), are determined primarily by the factors of the specific positions and values of the colliding units.

As for the new unit itself, (1) it will, of course, have the definite value of $2e$. (2) Its radius, because of the excessively close union formed, would be only little greater than that of the negative electron. (3) It would be neutral—positive charge satisfying negative charge. (4) While there may be a bare possibility that the negative electron could revolve about the positive electron following an impact and union, as described, *it is highly probable that the two units come into such near approach to each other and form so close a union that there is no revolution of the one about the other, but that the two rotating together execute a spinning motion.* (5) It would have peculiar magnetic properties, of X unit value. (Bohr's magneton? Hardly.)

It appeared that the new unit necessarily has an independent path. Whatever the new unit's energy content, whatever the direction followed, and whatever the velocity of its motion, it is certain that there is no interval between the time of the collision, the closest approach and complete union of the positive and negative electrons, and their shooting off on their own path. And inevitably there will be further collisions.

The condition postulated (critical ionic concentration) means the presence of many ions, hydrogen ions and other ions, and that there are no appreciable spaces between atoms (since in a liquid the molecules presumably are in contact). Therefore the new unit, into whatever path it is thrown, necessarily will collide with atomic and ionic constituents.

It is plain that under the conditions postulated the only *space* to be found is the space in the atoms and ions of the solution—intraatomic space.

It is plain, too, that to a unit of the size of the new unit, practically a mere point of force, the atom is an open structure that consists mostly of empty space, as it is to the beta-ray and to the alpha particle.

But though the path of the new unit necessarily would lead straight into or through atoms, and the atom is an exceedingly open structure, it does not follow that all atoms may be entered by it. It is easily conceivable that some atoms may be penetrable and others impenetrable, due either to their constitution or to the particular orientation in which they happen to be approached. Of course, in the problem of the penetrability of the atom, the rate of speed at which the new unit travels also is a very important factor; since a body going at great speed can enter and shoot through many successive layers of atoms any one of which might be impenetrable to that same body traveling at very low speed.

In the event that this new unit collided with an atom that would not permit its entrance, it would rebound, or it *might* suffer disruption, the negative electron being captured by the resisting atom. However, the probable velocity of the new unit (as roughly deduced from the history of the immediate atomic origin of its constituents and its formation) would be so low that generally the unit would survive the shock of the impact with an impenetrable system, and would bound away on a deflected path and into further collisions.

The probabilities then are that immediately after the formation of the new unit, it will collide with some electron and unite it to itself; and successively with others, both positive and negative, binding them in the *peculiar manner that distinguished the first union, and imparted the peculiar electromagnetic properties to the new unit.* Of course, with each addition the energy content is altered, increased, and *the electromagnetic values and electromechanical effects are multiplied.* Within a fraction of a second a vast number of such impacts and additions might occur. Not only ions will be made to give up loosely bound negative electrons, and the hydrogen ion positive electrons, but atoms will be entered.

When the new unit enters an atom, one of several things may happen:

1. It may pass straight through the atom, doing no harm to the atom and suffering no harm. This is an unlikely happening; since as mentioned before, and as Millikan and Bragg have pointed out with application to the planetary atom, a body shooting through our solar system at great speed might do no harm to the system, but going through it at low speed would have disastrous results. The velocity of the new unit hardly would have the critical value that would carry it through the atom without injury to the atom. Besides, the electromagnetic properties of the new unit are peculiar and very strong.

2. It may pass through the atom tearing away and carrying along one or more negative electrons.

3. *It may enter the atom, tear away an electron and drag along the atom itself.* The atom thus carried along would capture an electron as opportunity permitted and complete itself once more. Also the

atom would enter into chemical union with other atoms as permitted.

4. It may enter an atom and tear away one or more loosely bound positive electrons, and carry along the atom. This atom would then be changed into another element; thus, if it happened to be a nitrogen atom and lost two positive electrons to the new unit, it would be reduced to a carbon atom and would be carried along as a carbon atom. The atom thereafter would behave not like a nitrogen atom but like a carbon atom. The atoms thus dragged along would carry on their independent activities as determined by their constitution, and in keeping with the law of Coulomb, and would enter such external combinations as permitted. However, obviously, the equilibrium relations of the atoms would be affected and modified by the peculiar conditions that obtain.

And it appears: *This new unit that can neither become a charge on an atom nor enter into chemical combination with atoms, becomes an intraatomic quantity, by reason of its peculiar constitution, its erratic path, and its peculiar electromagnetic properties.*

There has then been formed a dual system, a system that is made up of two systems, one of which is material, built up of atoms; the other of which is immaterial, that is, not patterned after the manner of the chemical *elements. The immaterial system is intraatomic, and is the determining system: it organizes the material system.*

The *material* system is conveniently designated as the "Y"-system (symbol Y); and the *immaterial* system, the intraatomic system, as the "Z"-system (symbol Z). The dual system is designated as the "Y-plus" system, or simply as the "dual-system" (symbol Y^+).

Obviously, various factors that (as belonging to past history) permissibly were ignored for just the critical moment, immediately entered, and conditions rapidly became more and more complex. The process involves problems of chemical reactions, of heat and other forms of energy, of the mobility of the new unit and the viscosity of the medium, and so on.

The basic process involves (*a*) a catenary series of reactions; (*b*) the simultaneousness of various processes, producing a variety of phenomena; (*c*) the simultaneousness of several sets of catenary reactions, in which some may proceed at slower or faster rate than others; (*d*) the interrelations of the various simultaneous processes; the correlation of all processes. (*e*) As complexity increases, differentiation within the dual-system necessarily results. (*f*) As complexity increases various secondary axes will be established in addition to the main axis of the system.

Since the constitution, or pattern, of the Z-system that may develop is determined by the conditions (as postulated) which first give rise to it, and these may be simple or complex, various degrees of complexity of pattern may result. The Y-system would show complexity of organization to correspond.

Extremely complicated systems may result, given sufficiently complex conditions at the initiation of the process and continued favorable conditions in the medium.

The process involves (1) addition to (*a*) the Z-system, and (*b*) the Y-system; (2) transformations and transmutations (*a*) of ultimate units organized into the Z-system; (*b*) probable change of atoms from one element into another (as possibly from nitrogen to carbon) as the Z-system integrates itself; (*c*) chemical transformations.

From the first and throughout the process is one of "selective appropriation"; that is, the dual-system takes from its medium only what it can incorporate, leaving the rest.

It would appear, then, that a condition of a critical concentration of ions, as postulated, would lead (1) to the formation of a *new and different unit;* (2) to further collisions and "growth" of the new unit; (3) to the setting up of a dual-system.

The new unit formed, the Z-system, it must be carefully noted, represents a *primary union*, in that the ultimate units (positive and negative electrons) combine directly to form it. It represents a primary union in the same sense in which the hydrogen atom represents a primary union.

The general manner of combination, or pattern of the union, is different from that of the general pattern of the atoms (the elements), or matter. Hence the new unit, the Z-system, is not material but immaterial.

It is a dynamic system, possessing peculiar dynamics.

Unique qualities necessarily arise with and attend the unique manner of the combination of ultimate units into the Z-system, and are proper to the Z-system. The degree to which these unique qualities are present, of course, is determined quantitatively.

The general manner of the combination may result in a great variety of different forms, that collectively may show gradations from most simple to extremely complex, but it cannot result in an arithmetic series (such as the elements constitute).

The Z-quantity, and the Y-system as well, for every dual-system considered separately, and at any moment of time, is an algebraic sum of constituent units that results from the activities of the Y-plus system, and that varies from moment to moment.

The material system, the Y-system (the system built up of chemical elements), that is organized by the Z-system, of course retains the properties that belong to the chemical elements, showing only such modifications as result from readjustments of atoms and molecules, incidental to the building up of the dual system. However, during the process of the building up of the dual-system, the reduction, or transmutation, of one element into another element (as of nitrogen into carbon) necessarily would be a frequent happening, as the Z-system appropriates to itself positive electrons from one and another of the atoms that it enters and drags along.

The dual-system combines the properties of the two systems. It is unique: It is both material and immaterial. Thus the Y-plus system has a unique individuality. And by reason of its duality and peculiarity of constitution it reacts in a peculiar manner to its medium. Concerning the mobility of the dual-system: As Bloxam says, "it has been recognized that ionic mobility varies inversely as the viscosity of the solution"; but while the viscosity of the medium necessarily must be reckoned with, the essential difference between an ion (charged atom or molecule) and a dual-system is such that other considerations enter. Chief among these is the fact that dual-systems may present most various values of kinetic energy. The mobility of a dual-system then would depend mainly on its constitution and would vary from near-inertness of a very simple system to highly active automotive movements of complex systems.

The individuality, the stability of the dual-system is determined by the Z-system. The stability of the system as a whole (especially in the more complicated dual-systems) implies great instability and flux in detail processes. This individuality, a peculiar condition of stability of the system as a whole with instability—constant flux and change in parts—is maintained so long as the Z-system remains within the Y-system, the atomic system: The dual-system as such persists until the rupture between and the separation of the two systems.

VII. BALANCING PROCESSES

The process initiated at the establishment of the dual-system continues until a certain limit—the definite limit determined by the sum of the various factors that govern the dual system—is reached, when, obeying the mechanical laws of equilibrium, the system will divide. The process, however, will continue, each part, after the breaking in pieces (or division), continuing separately the process initiated, until once more the limit permitted is reached, when again division takes place; and so on forever, however *provided* that the medium, or environment (physicochemical constitution, temperature and pressure), remain in every way favorable to the process.

With no changes in the environment, all the resulting dual-systems will be exactly alike.

However, though the pattern of the Z-system (of the dual-system) is definitely determined by the conditions that prevail at its inception, such conditions according to the degree of their simplicity or complexity predetermining whether the pattern that ultimately may result will be simple or complex, the pattern may be modified by the environment; that is, a simple dual system in a more complex environment may become more complex if the pattern has not become so rigidly established that only the limited sets of catenary (and multiple simultaneous) reactions proper to that pattern may take place. This rigidity of pattern obviously means the establishment of a definite balance of relations.

It is inevitable that sooner or later in the endless chain of dual-systems that (favorable conditions prevailing) results from a given initial formation of the very first one of these dual-systems from conditions of a critical concentration of ions such as theory postulates—*it is inevitable that sooner or later* *the pattern would become so rigidly established that very little, if any, variation would be possible.* When in the chain of successive dual-systems this equilibrium is reached, all the dual-systems that follow necessarily would conform to this rigid pattern. This equilibrium at once preserves the pattern and is fatal to further change of pattern. If the pattern be very simple, the duplication of dual-systems would be nearly exact; a complex pattern still would permit some variations in the individual dual-systems.

Very readily a dual-system might develop into a compound such that if it gave off only a part of itself, that part (under suitable conditions) would continue the process and develop into another compound dual-system.

Once it is established, then, the dual-system will increase in both size and complexity until the limit of complexity that is permitted by the constitution (pattern) of the Z-system and the limit of size permitted by mechanical laws, are reached—provided that the environment be and remain favorable.

If for any reason the environment (physicochemical constitution, temperature, and pressure) becomes unfavorable, the process will stop, *obviously with the disruption of the dual-system. The two systems necessarily will separate, and the dual-system as such will cease to exist.* Unfavorable physicochemical conditions may be due to lack of the presence of suitable elements or the presence of injurious elements, to temperature too high or too low, or to unsuitable pressure conditions.

Then, too, there is the contingency that the pattern, or constitution, of the Z-system, first having resulted in the organization of a complex Y-system, which is a strictly limited chemical system, permits of only a limited series of reactions of the Z-system with the Y-system, the end of these reactions having been reached, separation of the systems follows.

Also, of course, *anything* that destroys the equilibrium between the Z-system and the Y-system will cause a disruption and separation of the two systems, and the cessation of the process.

The equilibrium between the two systems of the dual-system easily would be destroyed by electrical, chemical, thermal, or mechanical agency; and the destruction of the equilibrium and the disruption of the dual-system may be caused by a sudden happening or it may be the final effect of slow-working causes.

There are then various main sets of balancing processes involved:

1. The equilibrium between the Z-system and the Y-system (maintenance of the Y-plus system, or dual-system).

2. The equilibrium between the dual-system and its environment, or medium.

3. The equilibrium which involves few or many internal adjustments of the dual-system; adjustments of a chemical or physicochemical or some other character. There may be multiple sets of simultaneous correlated catenary reactions involved in the process of the maintenance of the dual-system, the correlation of which may require the slowing down of some reactions while others are accelerated; and the adjustment of secondary axes to the main axis of the system.

4. The equilibrium which involves the uneven ratio of the dynamic units of the Z-system to the unit volume (atoms) of the Y-system, and localized center or centers of great concentration and corresponding greater dynamic force. Obviously, even in the simplest dual-system this distribution hardly could be uniform.

5. The equilibrium which results in the breaking off of a part of a dual-system, and the continuance of the process in a chain of successive dual-systems.

6. The equilibrium of the Z-system, which implies the existence of the Z-system (ultimate units in a particular state of organization).

7. The equilibrium of the Y-system (autolysis) after separation of the two systems.

VIII. NEW PROPERTIES AND DYNAMICS

The *qualitative* differences shown by the atoms, the chemical elements, were recognized long ago. Later it was found that these qualitative differences are associated with *quantitative* differences; and Mendeleeff was able to predict the existence of certain elements and their qualities—elements that subsequently were discovered. Very recently it was found further that atomic weight is a mere approximation, and that *atomic number* supplies the basic classification of the series of the elements.

It is a basic law that all qualities and all qualitative differences whatever, found in matter, are determined by *number and manner of combination* of the units that are involved.

The number and manner of combination of positive and negative electrons determine the various atoms and their properties.

The number and manner of combination of specific atoms determine the multitudinous chemical compounds, molecules, and their properties.

The number and manner of arrangement of molecules determine the different states of matter and their properties.

Number and manner of combination of the constituent units determine all qualities and all qualitative differences whatever that are found in matter.

All differences in number and manner of combination of constituent units result in differences of qualities.

A peculiar, particular, number and manner of combination of electrons then presupposes certain proper qualities, *these qualities and no others.*

Of course, all this is well known and not questioned by anyone. But the tautology (if it be tautology) serves to emphasize the fact that *it is, then, impossible not to attribute certain appropriate definite characteristics, or qualities, general and specific qualities, to a combination of ultimate units—to every such combination.*

Therefore, very pronounced qualities, or properties, must be predicated as attending the combination of ultimate units into the Z-system, and as depending on such combination.

The Z-system would show qualities *entirely different* from those of the series of the ninety-two elements, by reason of the different *manner* of combination of the ultimate constituent units; and these general qualities would be most various quantitatively as determined by *number*, and would be extremely pronounced when represented by high numerical value.

Concerning the Z-system, therefore:

1. *Peculiar properties* must be predicated of the Z-system.

2. These properties must be *generic*, since dual-systems of great variety may result.

3. The generic properties of this specific quantity (the Z-system) must be rated *quantitatively;* that is, the individual dual-systems would exhibit likeness of fundamental properties, but would also show great quantitative differences of them.

It has appeared from the first that the Z-system is dynamic. It organizes the Y-system; but in turn it is modified by the Y-system. It maintains the dual-system as such; for on its separation from the Y-system the dual-system collapses—the Y-system showing none of the properties of the dual-system, but only those of a material system that would exhibit minor peculiarities of a chemical character not found in matter that has not been thus organized.

The energies of the dual-system, complicated values almost immediately after the formation of the dual system, become extremely complicated, multiplying with each succeeding reaction.

However, two general facts stand out:

1. The sameness of factors and units of values. The sameness of all those quantities and values that have been determined in the study of the electron and matter. The value of the charge of the electron (e), and of Planck's element of action (h) is always the same. All work, heat, radiation, etc., can be

described in definite units of measurements that always have the same value. (ϵ, a variable, equals vh.)

2. The differences because of the dual organization:

(*a*) The differences due to the difference between the pattern of the nuclei of the atoms and the pattern of the combination of electrons into the Z-system.

(*b*) The differences due to the interrelations between the Z-system and the Y-system, and the dominance of the Z-system.

These differences give to the dual-system different energy contents, different kinetic energy, and different mechanics, from those of a system constituted only of chemical atoms and ions.

These differences constitute a general complicating factor in all evaluations of the energy of the dual-system. Thus chemistry, when the chemistry of the dual-system is concerned, becomes chemistry modified by the Z-factors; physical chemistry and physics are modified in the same way.

The general peculiarities belonging exclusively to the Z-system obviously are not definable in the terms that are descriptive of the properties of the combination of atoms into material systems, and—in a class by themselves—plainly require a science of their own, a new science, to describe them.

Any one familiar with the data that have been used, of course recognizes that, given the conditions of a critical concentration of ions (as postulated), according to the accepted theories of the atom and simple known laws, the happenings necessarily would be about as outlined, and systems such as described necessarily would result.

IX. THE ORGANISM

The well-known major peculiarities of the organism that distinguish it from the non-living were carefully enumerated in Chapter One (pp. 49, 50), and it is assumed that they are fresh in memory.

A comparison of the peculiarities of the organism that need to be accounted for with the peculiarities that necessarily would belong to systems such as are outlined in sections six, seven, and eight of this chapter, shows marked similarity.

1. *Peculiarity of the dual-system.*—Unique individuality. It is distinguished from all other matter by reason of its duality.

> *Peculiarity of the organism.*—Unique individuality. The organism is opposed to non-living matter.

2. *Peculiarity of the dual-system.*—The process that is initiated with the beginning of a dual-system is an *irreversible* process.

Peculiarity of the organism.—The life-process is irreversible. Once life has been initiated, the life-process runs on until death.

3. *Peculiarity of the dual-system.*—The process that is initiated with the beginning of a dual-system is essentially a process of transformations and transmutations. The dual-system appropriates selectively of surrounding material and transforms it into itself.

Peculiarity of the organism.—The organism synthesizes its own specific material. The growth and maintenance of the organism involves active anabolism.

4. *Peculiarity of the dual-system.*—It is the Z-system that organizes the Y-system.

Peculiarity of the organism.—It is "life" that builds the organism.

5. *Peculiarity of the dual-system.*—The Y-plus system will continue the process of organizing, adding to itself after its peculiar manner, until a limit is reached, the limit set by conditions of equilibrium, when the system will divide. After division, *the separate parts have individual existence;* and the pieces severally will continue the process until they in turn have reached the limit permitted by the totality of the factors that are involved. Another division will follow; again the pieces will continue the process; and so on forever.

Peculiarity of the organism.—Woodruff observed the successive division of more than eight thousand generations of unicellulars (*Paramecium*), without the death of a single organism. Jacques Loeb said: "Unicellular organisms, like bacteria, algae or infusorians, seem to be immortal. They reach a certain size, divide into two, each half growing again to full size and dividing again, and so on. In this case we may say that it is practically the same individual which continues to live in the successive generations. Small pieces of a cancerous tumor can be transplanted successfully to other individuals and these pieces grow again to a large size. This process can also be repeated indefinitely, and it is the same cancer cell which continues to live in these successive transplantations, as it is the same bacterium which continues to live in successive generations. In this way it has been shown that cancers in mice may outlive many times the natural life of a mouse, in fact they seem to live indefinitely. . . . . It seems that this is true also for certain normal cells like connective tissue cells. Carrel has isolated connective tissue cells from the heart of a chick embryo and cultures of these cells living on the extracts from chick embryos have been kept alive now for seven years."[2] (These cultures have been kept alive now—1928—for sixteen years.) Carrel also found it true for tissues taken from various mammals, including man.

In experiments carried on by Dr. John M. Wheeler and his assistant, Dr. Daniel Kirby, it was shown that the iris section of live eye tissue, if suitably placed, will grow outside of a living animal body, the bulk of its cells doubling every forty-eight hours. But since Leo Loeb first demonstrated (1897) that, if placed in a suitable medium, certain tissues will grow outside the body, it has been fully established that in these cultures *in vitro* repeated cell-division would continue forever.

Raymond Pearl writes: "The experimental culture of cells and tissues *in vitro* has now covered practically all the essential tissue elements of the metazoan body, even including the most highly differentiated of those tissues. Nerve cells, muscle cells, heart muscle cells, spleen cells, connective tissue cells, epithelial cells from various locations in the body, kidney cells, and others have all been successfully cultivated *in vitro*. . . . . What I am leading up to is the broad generalization, perhaps not completely demon-

[2] *Scientific Monthly*, December, 1919.

strated yet . . . . [but] so near it as to make little risk inhere in predicting the final outcome, *that all the essential tissues of the metazoan body are potentially immortal.*"[3]

6. *Peculiarity of the dual-system.*—If the Y-plus system is a complex system (in harmony with the several sets of laws that govern its equilibrium), a small piece may become separated from the dual-system, which piece then according to its constitution may develop into a dual-system like the one of which it was a part. The process once started continues in an unending chain of dual-systems, given favorable conditions.

Peculiarity of the organism.—Through a minute piece that is detached from the parent organism (or organisms) reproduction in its multitudinous forms, results in the endless chain of successive generations of organisms.

Also, it is well known, in some of the lowly life-forms, as H. V. Wilson has shown in the case of sponges, isolated cells taken from a mature animal and placed in a suitable medium, may develop into a complete organism.

7. *Peculiarity of the dual-system.*—The unique qualities of the Z-system, qualities that do not attach to "matter."

[3] *The Biology of Death*, 67.

Peculiarity of the organism.—Unique qualities not found in non-living matter.

8. *Peculiarity of the dual-system.*—Unique dynamics.

Peculiarity of the organism.—The same.

9. *Peculiarity of the dual-system.*—The end of the process is a separate happening for every indidivual dual-system.

Peculiarity of the organism.—Death is an individual happening for every organism.

10. *Peculiarity of the dual-system.*—After the separation of the Z-system from the Y-system (the atoms and molecules of the Y-system no longer being bound together by the interlocking of the Z-system, and only chemical bonds remaining) the Y-system collapses.

Peculiarity of the organism.—After death the body disintegrates.

11. *Peculiarity of the dual-system.*—Marked peculiarities of molecular formation (of the substances of the Y-system), because the uniting of atoms into molecules takes place as a (chemical) process that is secondary to the activities of the Z-system.

Peculiarity of the organism.—The marked peculiarities of organic substances. (*See* p. 92.) E. J. Holmyard says: "While the general laws of chemistry apply to organic substances and inorganic substances alike, yet in the study of the former we meet with new, strange and often fascinating phenomena which are without parallel in the inorganic realm."[4]

The peculiarities of the new complex described answer to the peculiarities of growth, reproduction, and the living state of the organism, and to the state of the body after death.

It would appear that—

1. The dual-system in fact describes the organism.

2. The Z-system, the intraatomic system, accounts for the living state of the organism.

3. The Z-system accounts for the peculiar dynamics of the organism.

4. The Z-system, the intraatomic quantity, answers to life. (Greek *zoe*, life.)

5. The establishment of a definite rigid pattern that permits only the reactions possible to that pattern, accounts for the specificity of species.

6. The peculiar properties of the Z-system, that necessarily are utterly different from the properties of the material system by reason of the difference of manner of the combination—these properties because of the identification of the intraatomic system as life, are the peculiar properties of life, and thus account for the psychic contents of life, consciousness

[4] *Outlines of Organic Chemistry,* 1.

arising from and attending the peculiar Z-manner of the combination of ultimate units to form life. This Z-manner of combination supplying the *quality*, the degree to which the quality is exhibited, is determined quantitatively.

7. The complicating factors introduced to chemistry and to physical chemistry by the dual-system would answer to the complications that the organism offers to science. Chemistry modified by the complicating factors of the Z-system, answers to biochemistry; modified physical chemistry, to physiology; and the new and different science required to treat of the properties of the Z-system, obviously would be psychology—*a new psychology, that is exact like atomic physics, and that treats all psychic qualities quantitatively.*

8. The separation of the Z-system from the Y-system, the atomic system, accounts for the death of the organism, and for the effects of death on the body. It shows why autolysis does not take place during life but does set in immediately after death.

9. The process of the setting up of new relations would account for the origin of life on the earth.

Thus there follows this theory of life:

1. *The organism* is a dual system, an atomic-intraatomic system. The atomic system is material, and is the body of the organism; the intraatomic

system is immaterial (i.e., not built on the pattern of the atoms), and is the life of the organism. The two systems are built up of the same ultimate constituents, but on different patterns.

2. *Life is a quantity*, an immaterial quantity, that consists of the same ultimate constituents that likewise constitute the elements, but combined after a different pattern.

3. *The living state*, or the state of living, of the organism is due to the presence of the intraatomic system, life (a quantity) in the body.

4. *Death* is the separation of the two systems, the separation of life from the body.

5. The *psychic properties* of life, consciousness and mind, arise from and attend the peculiar manner of the combination of ultimate units to form life.

6. The *specificity of species* merely denotes that in the phylogenetic process the limit of possible sets of reactions permitted by the pattern of the intraatomic system, the life, of the organism has been reached. It is fatal to further advance and higher development. A species, then, is the *end*, not the beginning, of a series of developmental changes. (*See* pp. 207, 208.)

7. The *origin of life on the earth* was due to a local condition of a critical concentration of ions (as described) that, owing to the constitution and the dynamics of the atom and the electron, necessitated

the setting up of new equilibrium conditions which resulted in the origin of the dual-system, living matter. This condition, too—the condition, namely, of a critical concentration of ions, following trauma or other injury to cell structure, is the *cause of cancer* and of other neoplasms. (*See* pp. 181, 182).

It would appear that this new theory of life is *a definition of the organism that is absolutely fundamental; that differentiates living matter from the non-living world; that is descriptive of all living beings; and that applies exclusively to living beings.*

It provides for all the wide differences as well as for the likenesses that are found in the scale of organisms; it provides for the psychic qualities exhibited by the higher organisms, and especially by man; and it shows the cause of cancer and of other neoplasms.

X. THE LAW OF THE STRUCTURE OF LIVING MATTER

According to this new theory of life, living matter *invariably* consists of an atomic system (a system made up of chemical atoms) that is organized and interpenetrated by another system.

The atomic system is matter, or a material system; the intraatomic system is life, not matter, immaterial.

The two systems are constituted of the same kind of ultimate units (positive and negative electrons), but are built on different patterns.

The structure of living matter *invariably* shows this dual pattern.

Living matter, then, invariably is a dual system, the constitution (or pattern) of which is partly material and partly immaterial; the presence of the immaterial system within the material system constituting the living state.

Since "uniform relations" constitute a "law," the expression of this fact, then, is a statement of *the law of the structure of living matter.*

This law of the structure of living matter defines:

1. Living matter.
2. The difference between the living and the non-living:
   - (*a*) The difference between *inert* and *living*; the essential difference between living organisms and inert matter.
   - (*b*) The difference between *living* and *dead*; the essential difference between living organisms and dead organisms.

XI. LIFE

Concerning life, summarizing the foregoing, it follows:

1. *Life is a quantity.*
2. Life is not matter, and is unlike matter.

3. Life consists of *the same constituent units* as does matter.

4. Life represents a manner of combination of ultimate units different from the pattern of their combination to form the chemical atoms, or matter.

5. In the living organism, life is an intraatomic quantity.

6. This definition of life applies to *all* life-forms without exception: That which sometimes has been described vaguely as "the life-principle," that which determines the living state (or the state of living), whether of plants (all plants) or of animals (the entire animal kingdom) or of man, *alike in all,* is the intraatomic quantity "life."

7. Life forms a definite series, different from the series that from atomic number 1 to atomic number 92, is matter. All life-forms are alike basically in that, or in so far as, life is owing to a peculiar manner of the combination of ultimate units. The differences between one form and an other form are determined *quantitatively*; but there is *no arithmetical progression* (as in the elements), a very large number of different forms and variations of forms being possible.

8. Specific and different properties necessarily characterize the combination of ultimate units after a pattern unlike that of the chemical atoms, or matter; *the peculiar manner of combination that*

spells life, giving rise to the peculiar properties of life.

9. Since *all psychic properties attend life,* and life is defined as a quantity, it follows that the quantity "life" is identical with "soul." Life and "the soul" are not, as some have insisted, two different problems; nor is the problem of "mind" separate from the problem of life (as John Fiske thought). All problems of the soul and of mind are problems of the quantity "life."

XII. DEATH

According to the theory, death of an organism can mean only one thing: the rupture between and the separation of the two systems that constitute the organism.

What is Life?

PART THREE

Problems Involved

CHAPTER SIX

What Elements of Originality Are Contained in the Theory?

OBVIOUSLY, because this new theory of life states the basic law of the organism, it necessarily affects *all* problems connected with the organism.

The several elements of originality which, it appears, are contained in the theory, are the following:

I. It is the *first* correlation of the facts of the essential characteristics of the organism, physical chemistry, and atomic physics.

II. It *differs fundamentally* from efforts to interpret life in terms of physical chemistry (enzyme action, etc.), even though the chemical atom and the ions be reduced to the terms of atomic physics.

III. It is the first *relatively complete* theory of life based upon today's atomic physics.

Original is—

IV. The concept that the living state of the organism is determined by an intraatomic system, the Z-system.

V. The concept that dissociated (from atoms) elementary units recombine to form an intraatomic system, the Z-system, to which "X" qualities must be assigned.

Though I was forced to the conception by data supplied by atomic physics, it hardly needs to be pointed out that this concept is not included in to-day's teachings of atomic physics. Atomic physics treats of the constitution of the atom. It concerns itself with the "how?" of the combination of positive and negative electrons to form *matter*. But atomic physics has not treated of the combination of elementary units (dissociation "products") into complexes, or structures, *within matter*. Thus the theory for the first time shows the need of and advances the concept of other patterns of combination of ultimate units, and shows the need for physical laboratory research concerning the existence of any such other forms.

VI. The statement of *the general law of the structure of living matter;* the law of the dual, atomic-intraatomic, system.

This law is, I hold, *the basic and invariable general law* of the constitution of living beings on the earth. Certainly, the law is not an immutable (in the sense of "eternal") law; since life has not always flourished upon the earth. The general law of the structure of living matter is, like all other laws of which we know, *conditioned.* This does not, however, in the least detract from the *definiteness* of the law.

It readily appears that the law has immediate bearing on the problem of life on other worlds than ours.

VII. The statement of the *basic law of growth.*

VIII. The definition of life.

In this definition life is described as a quantity that is not matter but that consists of the same elementary units that constitute matter. The contention is that life is not a mere catenary series of chemical reactions. Life is a quantity—not of matter nor of undefined and undefinable "energy," nor of peculiar life-units or entities, but of the same constituents which make up matter, which are combined in a different manner.

Needless to say, this concept is revolutionary. Svante Arrhenius' pointblank statement may be repeated: "We cannot measure life in its various aspects quantitatively as we measure matter and energy . . . . To detect means of measuring the quantity of life would be a revolutionary discovery which may never be made."[1]

IX. The definition of the soul.

The soul is interpreted in terms of atomic physics,

[1] *Life of the Universe,* II, 252.

and is identified as life. The soul is defined as a quantity.

This is diametrically opposed to the view that life and the soul cannot be described in the same terms, and to the widely accepted view that "the soul consists of the sum total of cerebral functions."

Of course, vague notions of a "pre-existing" soul that at birth becomes incarnated or reincarnated, also are utterly discredited. Human motherhood thus acquires a new and peculiar dignity: with the beginning of the soul dating from the same moment as the beginning of the body of her unborn child, indeed holy, and akin to the brooding of Tetragrammaton over a formless world, are the woman's long days of her *enceinte* waiting.

X. The concept that all psychic qualities and properties are qualities and properties that attach to, and are peculiar to, and dependent on the Z-manne of the combination, or organization, of ultimate units.

It is the general concept that psychic qualities and properties (ranging from feeble sensation to man's psychic powers) *attend the organization of elementary units into a Z-structure* as chemical qualities and properties (ranging from inertness to violent reactions) attend the atoms. (*See* p. 141.)

This concept is entirely at variance with the idea that psychical properties inhere in matter (hylozoism), an idea of which De Maupertuis (1698–1759) was one of the earliest exponents, and which—entertained by not a few—has come down from the pre-Socratic Greek philosophers, particularly from the early Greek (Ionian) school of physicists.

However, my theory does not conflict with any other theory, since science has been utterly unable to account for the origin of psychic qualities.

XI. The concept that the relation of "mind" to the brain is that of an intraatomic electrical system (the Z-system of the brain) to matter.

Mind, I hold, is the organ of the soul that corresponds to the brain of the body. The mind is the mechanism of associative memory. The "truly psychical" in man finds its interpretation in the mechanism of the mind (thus conceived). Psychic properties inhere in the mind, not in the brain. The well-known fact (mentioned before) that normally the human brain begins to decrease in size when the individual is about twenty years old, while psychic, or mental, powers continue to increase indefinitely, has been an insuperable difficulty. To the new view this difficulty vanishes; and other difficulties connected with the brain find their ready solution.

XII. The definition of death. (*See* p. 157.)

This definition of death covers death wherever death occurs. Death may be "natural": Raymond Pearl shows that "duration of life belongs in the category of genetically definite and workable characteristics."[2] "For each organism," as Pearl says, "there is a specific longevity determined by its inherited physico-chemical constitution."[3] Or death may be due to any one of a number of other causes (disease, injury, poisoning, starvation). However caused, always death is nothing more and nothing less than this rupture, or separation.

This definition of death necessarily results from my theory of life, and complements it. For if (as theory asserts), the organism is a dual system, and life, or the Z-system, is an intraatomic quantity, then the cessation of the activities of the system (the death of the organism) *must mean the expulsion, or separation, of the quantity life, since the elementary units which* (in peculiar organization) *constitute the Z-system, life, cannot be disposed of in any other way.* Though in the atoms that (in almost countless numbers and of various kinds) make up the body, there is superabundance of space to contain within them an electrical system, yet the exquisitely exact quantitative (numerical) relations of electrons that determine the chemical atom—every atom of mat-

[2] *American Naturalist*, LVI, 187.

[3] *The Biology of Death*, 49.

ter—absolutely forbid any general, loose assumptions that, at death, the Z-system (the intraatomic quantity "life") might be "absorbed" by the matter, or added to the configurations of the atoms, of the Y-system. Death, then, can only mean the loss of a quantity, the dislocation, or severance, of the Z-system (life, the soul) from the Y-system (matter, the body) of the organism.

That no other definition of death than this is even remotely possible to the theory, is plain. And—of paramount importance—no other conception of death than this answers to all the facts of observation. For, observing that after the death of an organism inevitably the body disintegrates, it appears that the phenomena caused in the body by death are in full harmony with the finding that the living state of the organism is determined by its Z-system, and that death is the separation of that system from the matter, the Y-system. And only on the theory that life is the intraatomic Z-system of the organism, which determines the living state of the organism, and which is separated from the body at death (death being the separation)—separated, in the highest organisms at least, as a unit system—can one understand how it happens that, as Jacques Loeb said, "as soon as respiration has ceased only a few minutes the human body is dead, that is to say, will commence to undergo disintegration."[4] Since physicochemical laws govern the body *both before and after death*, the difference between the behavior of a living and that of a dead body is absolutely unaccountable except on the view of the theory.

Again: If as theory asserts, the organism is a *dual system*, and life, or the Z-system, is an intraatomic quantity, then *the final cessation of the activities of the system* (the death of the organism) *necessarily can be brought about only by the loss of the quantity "life."*

Obviously, this definition of death is diametrically opposed to the present teaching of many biologists and psychologists that "nothing leaves the body at death."

XIII. The peculiar conception of the organism as a dual system that consists of an intraatomic system, the Z-system (life, or the soul) and its matter (the body)—an atomic-intraatomic system.

I am well aware of the fact that in the remotest past of which historians find records, there is found present the belief of peoples that the organism, or at least man, is a dual system, consisting of body and soul. Indeed it would seem that "everybody" "always" has believed it—the exceptions are so few.

[4] *The Organism as a Whole*, 351.

However, the fact remains that today "science does not believe in the soul" except as described by the definition, "The soul is the sum total of cerebral functions." And surely no man of science would cite this general belief of humanity in the duality of man based on religious beliefs, mysticism, dreams of a wandering double, etc., as negativing my claim to originality for my conception of the organism as a dual system; since my concept is gained exclusively from the facts of the pertinent physical sciences, and the appeal is only to these facts.

XIV. The new method of approach to various lines of research that are connected with human psychology.

The entire body of the several groups of phenomena that are broadly described by the term "psychic" will have to be attacked by a new method, *the exact quantitative method.* This new method is necessitated by these "facts," asserted by the theory:

1. The soul is a quantity;

2. *All psychical qualities and properties are determined numerically*, that is, by number and manner of combination of elementary units;

3. *Mind* is the electrical organ within the brain;

4. *Consciousness* is a quality that arises after the manner in which chemical qualities arise (that is, the quality depends upon, or is determined by,

number and manner of combination of the constituent units that are involved;

5. *Memory*, conscious and associative memory, is definitely located in the mind, as a property or function of the mind (associated with the process that determines consciousness and thought proper);

6. *Behavior* is an effect that (given the dual system) primarily is the outward registering of internal constitution (degree of complexity of organization, etc.). Of course, every effect in turn becomes a cause.

It would require a separate volume only briefly to set forth the several problems of psychology in the light of the theory. However, in a word it may be said: All psychic qualities, all psychic activities, all psychic phenomena (both normal and abnormal) must be interpreted and rated *quantitatively.*

The methods (of interpretation of any psychic phenomenon or problem) *will have to be the exact methods of the physicist and of the mathematician.*

The *complete general "correlation* of the psychical with the physical," or with matter (which Mach saw as the far-distant goal of the research of future centuries,[5] and to which E. Hering also gave much thought), is established by the recognition of the duality of the organism, the atomic-intraatomic

[5] *Populär-wissenschaftliche Vorlesungen,* 490, 491.

system (of the theory). "The relation between the physical and psychic elements of a sensation," which, as Wolfgang Pauli says,[6] Mach recognized as early as 1865, finds its statement in the terms that describe the interrelations of the two systems of the dual-system, as which I describe the organism. The two systems, the qualities of both, and their interrelations, are conceived in terms of atomic physics. It is plain that the details of the interrelations and the interacting of the two systems, can be stated only mathematically. Since as Jaques Loeb set forth (after saying that "the unraveling of the mechanism of associative memory is the great discovery to be made in the field of brain-physiology and psychology"): "It is evident that this mechanism cannot be unraveled by histological methods, or by operations on the brain, or by measuring reaction times."[7] Atomic physics supplies sufficient exact data to enable satisfactory mathematical work on these problems. (But *see* p. 267.) And—to quote Loeb again: "It is com paratively easy for the physicist to give his data the form of a mathematical law."[8]

The theory for the first time shows the problems of "brain capacity" and of psychic powers to be

[6] *Physical Chemistry in the Service of Medicine*, 67.

[7] *The Mechanistic Conception of Life*, 74.

[8] *Dynamics of Living Matter*, 161.

mathematical problems. The mind (as the Z-system of the brain), psychic power, and thought—all must be rated quantitatively; but obviously, mathematics, and only mathematics, can determine the value, numerical value, of—

1. Elementary units that are crowded (organized) within an atom of a brain cell (spelling consciousness), as compared with the number of elementary units that constitute the Z-system of an atom of an ordinary body cell (spelling mere sensation) of the same individual;

2. The difference (in brain capacity) between man and apes;

3. The difference (in brain capacity) between one race and another race;

4. The difference (in brain capacity) between one individual and another individual.

An entirely new and very wide field for mathematical effort is opened up; since according to the theory *all* that concerns the organism which is not amenable to laboratory treatment, is subject to exact mathematical treatment at the hands of one versed in atomic physics. The psychologist (and the biologist) of tomorrow will have to be thoroughly informed in atomic physics, and skilled in the use of mathematics.

Once psychology adopts the methods that are made necessary by the quantitative view of life, it will come into its own by leaps and bounds. Today psychology does not compare favorably with the physical sciences, and has little value—except to the advertiser (teaching him how to control human behavior). Psychology may be said to be concerned almost exclusively with *behavior*, having "lost" (as someone put it) first the *soul*, then the *mind*, and finally *consciousness*. According to the theory, psychology must treat of all of these, and treat of them *quantitatively*.

XV. The statement of the difference between living matter and non-living matter.

Stephane Leduc, professor at l'École de Médecine de Nantes, whose exquisite osmotic forms bear a striking resemblance to life-forms, insisted upon "the impossibility of defining the exact line of demarkation between animate and inanimate matter"; and said further: "There is in fact no sharp division, no precise limit where inanimate nature ends and life begins."[9]

Others have made the same emphatic assertion. Félix le Dantec, professor of the Faculty of Sciences at the Sorbonne, maintains: "With the new knowledge acquired by science, the enlightened mind no longer needs to see the fabrication of protoplasm in

[9] *The Mechanism of Life*, 159, 147.

order to be convinced of the absence of all essential difference and all absolute discontinuity between living and non-living matter."[10]

Max Verworn, late professor of physiology at the University of Bonn, stated unqualifiedly: "An elementary difference between organisms and inorganic systems does not exist."[11]

Sir Jagadis C. Bose found many years ago that metal, plant and animal show the same response to certain stimuli, exhibiting "the same phenomena of fatigue and depression, together with possibilities of recovery and exaltation." "Among such phenomena," says Bose, "how can we draw a line and say: 'Here life begins'? . . . . Such absolute barriers do not exist."[12]

Frederick Soddy, however, declares: "I accept the, to my mind, complete break of continuity between the animate and inanimate worlds. . . . . As a physicist or chemist, I hold that there is no mystery in the proper sense in the inanimate universe, and I put the Rubicon between mechanism and life."[13]

Henry Fairfield Osborn (voicing the opinion of a large number of students) in the closing words of

[10] *The Nature and Origin of Life*, 250.

[11] *Physiologisches Praktikum für Mediziner*, 1.

[12] *Response in the Living and Non-living* (1902); *Plant Autographs and their Revelations* (1927).

[13] *Science and Life*, 154, 168.

his volume, *The Origin and Evolution of Life*, says: "The difference between the non-living world and the living world seems like a vast chasm when we think of a very high organism like man, the result of perhaps a hundred million years of evolution. But the difference between primordial earth, water and atmosphere and the lowliest known organisms which secure their energy directly from simple chemical compounds is not so vast a chasm that we need despair of bridging it some day by solving at least one problem as to the actual nature of life—namely, whether it is solely physicochemical in its energies, or whether it includes a *plus* energy or element which may have distinguished LIFE from the beginning."[14]

As Hans Driesch points out: "It is the final object of all biology to tell us what it ultimately means to say that a body is 'living.' "[15]

I insist, there is nothing intermediate between living matter and non-living matter. As in all other physical processes, the change from one state to the other state is definite and abrupt. As Poincaré explained, "a physical system is susceptible of a finite number only of distinct conditions; it jumps from one of these conditions to another without pass-

[14] *The Origin and Evolution of Life*, 281.

[15] *The Science and Philosophy of the Organism*, 16.

ing through a continuous series of intermediate conditions." Matter is either "living matter" or it is "non-living matter."

According to my theory, "living matter" always and only means a dual system, an atomic-intra-atomic system, as defined. (*See* p. 154.) The merest speck of protoplasm as a Y-plus system is different from non-living matter. Thus even the lowest and feeblest life-form is differentiated from all non-living matter, and differentiated by the basic peculiarities that are common to all organisms from lowest to highest. (*See* pp. 49 and 50.) That it is difficult, on ordinary examination, to distinguish between a speck of protoplasm and non-living matter, means nothing here.

XVI. The theory of the cause of the differences in properties between organic and inorganic substances.

As everyone knows, the matter of organisms, and the material products of life-processes, are described by chemistry as *organic substances*, or carbon compounds. (*See* pp. 51 and 92.) All other substances are *inorganic* substances. Very striking peculiarities are found to characterize organic substances, and—far from contributing the terms with which to account for the organism—must find their statement in terms of atomic physics.

The question is: What determines the peculiar differences between organic (predominantly non-polar) substances and inorganic (chiefly polar) substances?

According to my theory of life and law of growth, all organic substances that are formed, (*a*) body of organism, (*b*) the direct products of life-processes, are *secondary* combinations, the formation of which is directly or indirectly governed by another set of combinations; that is, by the Z-system, the primary system. Organic substances (that form the body of an organism) are available for analysis only after the Z-system, the primary system, has become separated from them. But obviously, the substances that are formed as one set of combinations that is limited by another (interlocking) set of combinations, necessarily must show marked peculiarities. It would appear that the *non-polar properties of substances,* as tabulated by Gilbert N. Lewis (*see* p. 92), *are just such properties as the theory would compel one to predicate of organic substances.* I submit: The properties of organic substances find the general statement of their cause, and the peculiarities of the formation of molecules of organic substances can find their expression, in the terms of my theory of life with its law of growth and of the structure of living matter. It is my theory, then, that *the differences in properties between organic and inorganic substances are due to the fact that* *organic substances either directly belong to a dual atomic-intraatomic system, in which system they* (*matter*) *form a secondary system* (combinations occurring as permitted by the combinations that take place in the primary system), *or are the direct or indirect product of such a system.*

Also: Since this theory of life is built on the planetary atom and predicates peculiarities of equilibrium conditions of the atomic system (of the dual-system) such as are actually found to characterize organic substances, and which peculiarities heretofore have seemed difficult to account for on the planetary atom (*see* pp. 91, 92), it follows that the theory removes these difficulties that have attached to the planetary atom.

XVII. The theory of the origin of life on the earth.

It is the concept that the origin of life on the earth was due to physicochemical conditions that developed a critical concentration of ions which resulted in the formation of dual-systems (as described in Chapter Five—*The Setting Up of New Relations*). The intraatomic system, the Z-system, of such a dual system is defined as life.

That the early, lifeless earth just before the first advent of life provided the conditions required by the theory, cannot be doubted.

Certainly, only the most simple of life-forms could result at first. However, concerning the problem of which appeared first, micro-organisms or larger specks of living matter, it would seem that the conditions which permitted the origin of one form likewise permitted the origin of the other form, and that therefore probably both forms arose simultaneously.

The theory is opposed to the idea that the origin of life is due to pansperm, or a peculiar life-element, or special "rays," etc. One does not need to deny the possibility or the probability that living germs might survive an interstellar voyage and, finding suitable conditions, might germinate, in order to hold that it is absurd to try to account for life on the earth on the hypothesis of an extraneous cause; since, according to my theory, a condition that undoubtedly was present on the early earth, *necessarily* had to result in the origin of life.

The theory, for the first time on the basis of science, gives a reasonable and well-founded concept of the origin of life on the earth.

XVIII. The view that life necessarily arises, or originates, whenever and wherever the conditions permit the formation of a dual-system, as described.

The same causes always produce the same effects, given the same factors and conditions.

The general view embraces the concepts (*a*) of the repeated origins of life on the earth; (*b*) of the simultaneous plural origin of forms; (*c*) of the necessity for the occurrence of pathological growths, given certain specific conditions following injury to various living cells; (*d*) of laboratory abiogenesis.

Someone may object: If life originates, as the theory asserts, whenever and wherever certain simple conditions are present, why are not new life-forms discovered today? The answer is: (1) Life has flourished for millions of years wherever it is possible for it to flourish. (2) There is nothing to show whether a speck of protoplasm is a newly arisen life or one that comes through an unbroken line of descent from a form that originated in the remote past. (3) Cancer and other neoplasms indeed are of all too frequent occurrence.

XIX. A working theory to guide research on experimental abiogenesis.

The question of experimental abiogenesis has been a delicate subject, because there has been no theory to guide the research. One recalls that Jacques Loeb said that no definite plan could be formed for the solution of the problem of transforming non-living matter into living matter, since nobody thus far had observed the transformation. (*See* p. 66.) Because of the utter lack of a theory of how non-living matter is transformed into living matter, Loeb said that "science will retain the idea of panspermia." Yet he urged: "There is no reason to predict that abiogenesis is impossible, and I believe that it can only help science if the younger investigators realize that experimental abiogenesis is the goal of biology."[16]

The theory for the first time states the general specific condition that must be provided in order to transform non-living matter into living matter in the laboratory; and thus for the first time furnishes a definite method of approach to the problem of experimental abiogenesis. (*See* pp. 117, 121.)

XX. The statement of the cause of cancer.

According to my theory of life, the general origin of cancer is as follows:

1. Normal cells.

2. Injury to a cell or a group of cells—tissue, gland, epithelial cells. The injury may be caused by a single trauma or follow prolonged "irritation"; it may be a local injury due to a mechanical, thermal, electrical, chemical, or biochemical cause; or the result of parasitic agency (such as the boring of a minute worm); or due even to autolysis.

3. Result of the injury: Indifferent cell material, that constitutes a solution of great chemical complexity and contains free ions, and in which *a critical*

[16] *Dynamics of Living Matter*, 223.

concentration of ions develops. There are no free ions in the normal healthy cell[17], but injury to the cell introduces the presence of free ions. Free ions would appear also following autolysis of a cell. There can be absolutely no doubt that *among the several possible conditions* following trauma or other injury is the specific condition which, according to the theory, *must* result in a neoplasm.

4. The critical ionic concentration condition leads to the establishment of a peculiar equilibrium in the formation of a dual system, as described in Chapter Five, *Theory of Life.*

5. A growth results: A cancer or other neoplasm forms. *Theoretically*, neoplasms would fall under two general groups: (*a*) One group of neoplasms would consist of cells that form a connected growth. (*b*) The other group would consist of cells or of less complex units that are more or less independent, that is, they do not form a connected growth. In some forms indeed the neoplasm would consist of a colony of highly individual units, which might be of almost unimaginable smallness.

XXI. A new theory of the origin of species. (*See* Chapter Seven.)

The difference between this theory and the current theory of the origin of species is apparent.

[17] *See* Wolfgang Pauli, *Kolloid Chemie der Muskelkontraktion.*

All the earlier sciences, on which the current theory of descent is built, ignored the actual life-process, intimately considered. Since my theory of the origin of species is inseparable from my theory of life, as an element of originality also may be named the contribution of a *new method* for attacking the problem of descent—introducing atomic physics.

The new theory makes necessary a general revision and restatement of the entire subject of organic evolution.

XXII. The theory that the germ-cells (ovum and spermatozoon, gametes) are ions; that is, ions in the specific sense in which the term "ion" is borrowed to designate a material carrier of an intraatomic (electrical) system.

This theory includes the theory of fertilization which describes the relation between ovum and spermatozoon that results in their union as one between "ion" and "ion."

All the phenomena would support this view. Here is a "ripe" egg that has its entrance zone. As Oskar Hertwig has shown (1875), only one spermatozoon is concerned in the fertilization of a normal egg. Before the egg is entered by one spermatozoon, countless spermatozoa may crowd around the egg. The movement of the spermatozoa here is not a darting about like that of the particles of which Perrin speaks in his *Brownian Movement and Molecular Reality,* and which the Tyndall cone reveals. The movement of the spermatozoa in this case is governed by the attraction of the egg. It is directed at the egg. To be told that the movement is "mechanical" or a positive chemotaxis, does not enlighten one. (It is well known that cytologists do not deem the cause of the uniting of the spermatozoon and the egg to be adequately stated by describing it as due to a "positive chemotaxis" or an accidental coming together or an undefined "attraction."[18]) I hold that the movement of the spermatozoon here is accounted for on the theory that the spermatozoon is an "ion" (with an *intraatomic* electrical system, as defined) that is attracted by another "ion" (the ovum). Obviously, according to this view of the germ-cells, fertilization is governed by very exact physicochemical laws. This must be borne in mind in interpreting the great variety of phenomena and factors (such as location of the egg, etc.) exhibited by the process. An "accidental" bringing together of spermatozoon and egg well may be necessary before the attraction between them can become manifest: two bodies constitutionally may have a very powerful attraction for each other, but whether this attraction is capable of operating is determined by absolutely definite and rigid

[18] *See* Edmund B. Wilson, *The Cell in Development and Heredity,* 406, 407.

laws concerning the distance between the bodies. It has been found (by McClendon) that fertilization increases the electrical conductivity of the egg. Why in fertilization the spermatozoon of one form will not activate the ovum of some other form, perhaps not even of some closely related form, is readily understandable on this view of the gametes. It may be recalled that in Loeb's experiments on artificial parthenogenesis it was found that the presence of certain ions permitted and of other ions inhibited the activation of the egg.

XXIII. My theory of heredity. (*See* pages 231–233.)

This theory for the first time gives a basic conception of heredity, and transfers, or reduces, the problem of heredity from morphology (chromosomes) to atomic physics.

XXIV. The statement of the cause of the difference in length between man's infancy and the infancy of the apes.

"Infancy" here means: the period from birth to physiological (sexual) maturity. This maturity waits on and accompanies a specific chemical condition in an organism. The phenomenon of man's long infancy, as compared with the ape's short infancy, represents *a retardation of the rate of progression of the chemical reactions, between birth and maturity, which* *result in maturity. And it is the cause of this retardation that must find its statement.*

Man is distinguished from the ape chiefly by his superior psychic powers that wait on his long infancy. That in a general way degree of psychic power corresponds to size or weight of the brain, is, of course, well known to everyone. At birth, man's brain and the brain of the great anthropoids have nearly the same weight. However, the ape's brain at birth already has attained two-thirds of its full size; whereas man's brain at birth weighs only about one-fifth of its adult weight. (On the brain and psychic properties *see* pp. 164, 165, 169–172.)

The superior psychic powers of adult man (according to the theory) indicate that the human brain carries a far greater and more complex Z-system than the ape's brain carries; and since the human baby at birth is utterly helpless, and entirely wanting in intellectual powers—its psychic powers developing gradually—it would follow that even as four-fifths of the brain-weight is added after birth, so most of the Z-system of the brain, the mind, is accumulated after birth.

The units that build up the Z-system of the brain are supplied primarily just as the "food" for all the rest of the dual system is supplied. We find then according to the theory not only that the common supply of food for the entire organism must meet this disproportionate demand of the human brain and its Z-system (demand determined by the constitution of the Z-system and conveyed by heredity), but also —and this is the significant thing—that the disproportionate, prolonged, increased demand of the brain and its Z-system *means a repetition of the reactions that are involved in supplying the demand.*

In the infant organism, a reaction that at any time is proper to the growing brain (and its Z-system) corresponds to a certain set of reactions in the rest of the organism. The exact relations that obtain within the complex organism (a unit), provide that *during the period of growth a certain degree of maturity or immaturity of one organ means the same, or a corresponding, degree of maturity or immaturity for all other organs of the system. It follows that the repetition of one kind of reaction of the growing brain and its Z-system would mean a repetition of the corresponding reactions in the rest of the infant organism.*

The repetition of reactions that necessarily attends the repetition of brain (and its Z-system) reactions, in that it multiplies the number of the same kind of reactions means the retardation of the rate of progression of the total series of reactions that are proper to the organism between birth and maturity. And the retardation of the progression of the series of chemical *reactions that result in the maturity of the organism, means a lengthened period of infancy.*

XXV. The theory of the cause of man's erect posture.

In connection with man's long infancy that is determined by his greater psychic powers, special mention must be made of one of man's outstanding peculiarities—his erect carriage. Utterly helpless as the human baby is for many months, when the little one finally learns to walk he raises himself to the upright position. The normal human walks erect.

It is my theory that the various peculiarities of any organism, including methods of locomotion and posture, are determined by the *dynamics* of the system. Man's normal erect carriage, then, is appropriate to the dynamics of the human organism. The cause of man's normal erect carriage, it would seem, is found in his great brain capacity; that is, man's erect carriage is due to the dynamics of the system that attend the greatness of the Z-system carried by his brain.

It is meaningless to say, as someone recently said: "A man-like tree-born primate became an earth-borne creature which from sheer necessity ultimately arose to man's estate. This meant the assumption of the erect posture." It is meaningless to say that man has the erect posture because he developed a great toe.

"Adaptation" and "habit" are not the primary cause of the erect posture of man. Man's erect carriage is a question of dynamics. The great toe is an effect, merely an accommodation to the demands of the system for equilibrium in the upright position. It had to develop to permit the posture that is appropriate to the dynamics of the system.

It is an exceptionable practice, and a mere exhibition of ignorance, to try to account for the peculiarities of man, such as his erect carriage, on mere "adaptation" and "habit." It is high time that this uncritical and slipshod method be abandoned. A beast is a beast on its fours *not* because it never formed the habit of walking erect, but because the dynamics of its system do not enable it to take the upright position. Man raises himself, and has the forward look because of the dynamics of his system that are bound up with the size of his brain and mind.

XXVI. The theory that the length of the period of infancy supplies a standard of measurement for rating the intelligence of a race.

The length of the period of infancy, that is (as defined), the time required to complete the series of chemical reactions that result in the physiological maturity of the organism, must be conceived—all other things being equal—to be a direct index of the size and complexity of the Z-system of the brain.

Size and complexity of the Z-system of the brain directly determine, or are an index of, the degree of psychic power proper to the individual. It obviously follows that the *length of the period of infancy* must be accepted as *a standard of measurement for rating the intellectual standing, the intelligence, of a race, or people.*

The various measurements that have been made heretofore in research on the problem of the difference in intelligence between one race and another race (comparisons of anatomical structure, cerebral convolutions, etc.) all admittedly have been unsatisfactory in that they have established no definite means for rating intelligence. One investigator, Franklin P. Mall, expresses himself thus: "Arguments for differences due to race, sex, and genius will henceforward need to be based upon new data, really scientifically treated and not of the older statements."[19]

The differences in the weight of the brain that are found to exist, thus far have been perhaps the chief means for rating the intelligence of races. The true value of this difference, however, has been lessened and obscured by the well-known fact that in individual cases the weight of the brain does not serve as an index to psychic power. Thus, as Keith points

[19] *American Journal of Anatomy*, IX, 1.

out, while "in the average Englishman the brain weighs 1,360 grammes; in Cromwell it is said to have been 2,231 grammes and in Byron 2,238 grammes. In Gambetta, the French statesman, it weighed only 1,294 grammes."[20]

"The brain-weight of the various races," Marion J. Mayo sets forth, "has been subjected to numerous measurements, with the result that important racial differences seem to appear. A relatively small brain-weight is found to be characteristic of the negroid races, and a relatively great weight of the white race, even when all other facts are taken into consideration. Now it has been found that while no certain correlation can be affirmed between the size of the brain and the degree of intelligence in individual cases, yet when large groups are considered some significance does seem to attach to the matter of size. . . . . From a study of the brains of 103 negroes and 49 American whites, Robert Bennett Bean reached the following conclusion: 'The brain-weight of the Negro is demonstrably smaller than that of the Caucasian.' "[21]

Another writer says: "The average brain-weight is:

Of Europeans, 49 ounces, or 1,390 grammes;
Of Negroes, 44 ounces, or 1,250 grammes."

[20] *The Human Body*, 33.
[21] *Archives of Psychology*, November, 1913.

To quote Mayo further: "Another important order of facts, which appears to have a significant bearing upon the subject of racial mental differences, is found in connection with the growth and maturing of individuals of different races. Early maturity is known to be related to climate, but it seems also to be related to race."

According to my theory, the early physiological maturity of the children of a race, when the early age represents a mean for a sufficiently large number of individuals, indicates, unmistakably and beyond a doubt, that the race has a smaller brain capacity and a lower degree of intelligence, or psychic power, than the races which arrive at physiological maturity later.

It hardly would need to be pointed out that the early maturity of a people which is a true index of degree of intelligence, is an unforced normal condition. The child marriages of the East Indians are determined by considerations other than fitness for marriage (as attested by engagements between infants), and therefore must be classed as without value as an index to the intelligence of the Indians. However, it is a significant fact that though the proud features of the Brahmin are stamped with the consciousness of age-long superiority, yet India contributes very little to the intellectual and scientific work of the day. The Nobel prize winner, Sir Rabindranath Tagore, and the great man of science, Sir Jagadis Chandra Bose, stand out in lonely greatness among the millions of their countrymen.

All modifying conditions that abnormally hasten or retard maturity, must be carefully considered. That climate has its effects in determining an earlier or a later maturity is well known, and must be taken into account. Temperature powerfully modifies the rate of progression of chemical reactions. Experiments on the fruit-fly (mentioned before) show that a lowered temperature prolongs the life of the fruit-fly.

A genuine earlier maturity and mental precocity would appear to belong to the negroid races, according to the conclusions and testimony of various observers. This fact of the earlier maturity, according to the theory, gives definite value to lighter brain-weight, and testifies to inferior intelligence. If then it should be established on sufficient data that the Negro with his "demonstrably smaller" brain-weight indeed reaches maturity earlier than the white races, that would need to be interpreted as establishing, demonstrating, his inferiority in intelligence, or psychic power.

The length of the period of infancy, that is, the length of time it requires to complete the series of chemical reactions that result in maturity, I repeat, according to my theory, is the index to degree of psychic power, or intelligence, and thus becomes a definite standard for rating the intelligence of races.

Measured according to this standard, what is the rating of the ancient Greeks?

As Benjamin Kidd said:

> "During the nineteenth century the opening up of many widely-different branches of research has brought a crowd of workers in various departments into close contact with the intellectual life of the Greeks. The unanimity of testimony which comes from these representatives of different spheres of thought as to the high average standard of intellectual development reached by this remarkable people, is very striking."[22]

The Greeks have a galaxy of illustrious names to their credit such as no other country or time can equal. In every department of intellectual activity they produced masters. They reveled in the elegancies of thought, in the audacities of speculation, in the profundity of philosophy, and the elusive witchery of poetry.

Galton asserts:

> "The Athenian race is, on the lowest possible

[22] *Social Evolution*, 252.

> estimate, very nearly two grades higher than our own; that is, about as much as our race is above the African Negro. This estimate, which may seem prodigious to some, is confirmed by the quick intelligence and high culture of the Athenian commonalty, before whom literary works were recited, and works of art exhibited, of a far more severe character than could possibly be appreciated by the average of our race, the caliber of whose intellect is easily gauged by a glance at the contents of a railway bookstall."[23]

It is important to take into account: As it was the Greek nation—a handful of people—that produced the highest intellectual development ever known on earth, so it was Athens which was the flower of this development. Athens was a city in which, Augustus Boeckh says, "in 445 B.C., according to Philochoras . . . . there were but 14,240 genuine Athenians. Four thousand seven hundred and sixty who had crept into the privileges of citizenship, were on that account, according to Plutarch, sold into slavery, but at all events, they were excluded from the rights of citizenship. Before that time, therefore, there were 19,000 acknowledged as citizens. . . . . The relation of the free population to the slaves may . . . . be assumed to have been 27:100 or about 1:4."[24]

[23] *Hereditary Genius*, 331.

[24] *The Public Economy of the Athenians*, 51, 55.

According to the theory, it will have to appear that the Greek people arrived at maturity later, perhaps two or three years later, than present white peoples do, in order to prove that their dazzling intellectual achievements were due to greater "brain capacity" and higher psychic power. Unless it can be shown that the Greeks were distinguished by a longer period of infancy than ours, their supposed superiority must be attributed merely to an unequaled devotion to education and culture.

XXVII. The theory for the first time shows that the problem of life itself is, not indirectly but directly, a physical laboratory problem.

Experimentally to establish the general law of the structure of living matter, and the fact of life as a quantity (given by the theory), falls to the lot of the physicist.

It is well known that the research of biophysics consists in the study of the biological effects of radium, and other rays; the measuring of the penetration of certain rays into protoplasm; determining the "absorption" and physiological action of rays in protoplasm, etc. (Most of the work in biophysics is done in connection with cancer research.)

However, the proposition: *Life is a quantity*, a quantity different from the quantity that is the body, but constituted of the same, that is, *like*, elementary units that constitute matter—this proposition does *not* enter any of the experiments in biophysics which have been made up to the present.

It would appear, then, that the theory (1) states the general law of the structure of living matter; (2) yields the definition (*a*) of life, and (*b*) of death; (3) elucidates obscure phenomena; (4) indicates new methods of approach to various problems; (5) directly leads to new laboratory research; (6) necessitates the rejection of the current theory of descent; and (7) subverts the present teaching of science about the soul.

CHAPTER SEVEN

The Origin of Species

AS EVERYONE knows, Darwin's *Origin of Species* (1859) constitutes the great landmark in the history of the concept of the evolution of species. In an address delivered at the University of Freiburg, on the occasion of the centenary of Darwin (1909), August Weismann said that Darwin's *Origin of Species* "raised a conflagration like lightning in a full barn."

The concept of the evolution of species had been a prolific idea long before Darwin; indeed, the concept was a familiar one to the ancient Greeks. Weismann reminded his hearers: "You know that Darwin was not the only one, and was not even the first, to whom the idea of evolution occurred." A writer in the *Biologisches Zentralblatt*, J. H. F. Kohlbruegge, asked: "Was Darwin an original genius?" and adduced about two hundred names to prove a negative answer correct.[1]

[1] *Biologisches Zentralblatt*, XXXV, Februar, 1915.

Aristotle (384–322 B.C.) was perhaps the first to teach descent, Empedocles (*ca.* 490–430 B.C.) earlier having taught succession from lower to higher forms of life.

As the real founder of the modern theory of the evolution of species one must name Jean Baptiste Pierre Lamarck (1744–1829); while Alfred Russell Wallace is known as the "co-discoverer" with Darwin of the theory. Weismann holds that "the credit for thus establishing the theory of evolution is shared with Charles Darwin only by his contemporary, Alfred Russell Wallace." Yet Charles Darwin, Herbert Spencer, and Ernst Haeckel form the great picturesque trio of the theory of descent—that dominating theory of the nineteenth century.

The late William Bateson pointed out that "the first full conception of the significance of variation we owe to Darwin." Evolutionary views held before the time of Darwin are presented by Henry Fairfield Osborn in his volume, *From the Greeks to Darwin.* A study of the evolutionary ideas of the Greeks is also found in an address by E. Zeller, delivered (1878) before the Akademie der Wissenschaften (Berlin), "*Über die griechischen Vorgänger Darwins.*"[2]

The general theory of descent always has involved the question of man's descent; since the problem of

[2] *Abhandlungen der königlichen Akademie der Wissenschaften,* Berlin, 1878.

human life, it appears, cannot be isolated from the general problem of life, as, for example, the extreme followers of Descartes attempted to do.

A very near "blood-relationship" between man and the apes has been established by certain reaction tests (made by Uhlenhuth, by Nuttall and others). Hugh K. Berkeley, of the University of California, in a paper on "The impossibility of differentiation between monkey blood and human blood," says: "It would seem impossible, then, to utilize antisera from the lower monkeys for the forensic differentiation of human from monkey serum."[3]

The manifest resemblance between man and the anthropoids served as sufficient ground in the sixties of the last century, the early days of the modern doctrine of descent, for the announcement that man evolved from the orang-outang.

Darwin taught that "the *Simiidae* then branched off into two great stems, the New and the Old World monkeys; and from the latter, at a remote period, man, the wonder and glory of the universe proceeded."

Today opinion is divided. Many still believe in the direct close relationship between man and the existing apes. Of these some—Felix von Luschan, Klaatsch, and others—incline to the belief that in a more or

[3] *University of California Publications*, II, 12.

less direct line of descent the white race is related to the chimpanzee, with its white face; the negro to the gorilla, having a black face; and the Mongolian to the orang. Others hold the opinion that man evolved from an ape-like progenitor, though not from any ape now in existence. Yet others insist that man and the anthropoids are descended from a common stock.

According to one interpretation, the several apes have retrograded from the common stock in various degrees. Richard Swann Lull, director of the Peabody Museum, Yale University, holds this view. According to Lull "all of these apes, the orang, chimpanzee, and gorilla, are degenerating from the higher condition of their common ancestor with mankind, the chimpanzee least, the gorilla most of all."[4]

The most critical students of the problem—Henry Fairfield Osborn and others—are inclined to push the assumed common ancestry of man and ape back to an indefinitely remote period. Gustav Fritsch, eminent anthropologist, deplores what he calls "the still widely made untenable assertion: 'Man is descended from the ape'."

Duckworth holds: "We must conclude that the existing anthropoid apes, constituted as they now

[4] *Evolution of the Earth and its Inhabitants*, 140.

are, did not figure in the ancestral history of man."[5] For on closer examination there is found lack of similarity between man and apes where, on the theory of descent or of near relationship, similarity should be found. Thus, for example: It is a remarkable fact that there is utter dissimilarity between the arrangement of the growth of hair of the human head and the head of apes.[6]

Again: The hand—next to man's superior brain, his long infancy and his erect carriage, his most characteristically human possession—resembles the hand of the ape, yet a comparison of finger-prints and hand-prints of man and ape has shown surprising dissimilarity between the human hand and the ape-hand. As everyone knows, the finger-tips of the human hand are marked with whorls. Experimenters found that the monkey-hand has the whorls on the mounds, and the finger-tips are marked with straight lines.

To say that the general theory of descent, including of course man's descent, today is commonly accepted by the world of science is but to state a well-known fact. One therefore might suppose that the foremost students of the problem hold the opinion that the

[5] *Morphology and Anthropology*, I, 238.

[6] *See* Gustav Fritsch, "Die Anthropoiden und die Abstammung des Menschen," *Zeitschrift für Ethnologie*, L, 1.

doctrine of descent in the form of Darwinism rests upon secure bases. However, such is not the case.

The entire theory of descent has been beset with formidable difficulties from the first; and these difficulties have not been overcome. The chief difficulties in the way of the theory have been (1) paleontological difficulties; (2) the evident fixity of species; and (3) the crudity of the conceptions on which the theory rests.

1. The paleontological difficulties are (*a*) the great gaps which exist in the geological record; and (*b*) the suddenness of the appearance of new and higher life-forms without record of intermediate forms to connect them with the earlier forms.

The older geologists spoke freely of the extinction of life, and the appearance of new species. As an eminent geologist of today, Charles Schuchert, of Yale, says: "Because of the long-enduring intervals of lost record, the subsequent faunas are not only very different, but appear as if suddenly or at least quickly evolved."[7]

Eduard Suess, famous author of the monumental work, *The Face of the Earth* (English translation from the German original, 1904–1908), states: "Whole groups, entire animal and vegetable populations, or, if I may so express myself, complete economic unities

[7] *A Text-Book of Geology*, 453.

of Nature appear together, and together disappear."[8] Suess, of course, like all other geologists of today, believes in the *unbroken* ascent, or evolution, of life, but he testifies to " . . . . the simultaneous appearance and disappearance over vast areas of whole communities, of whole economic unities; the same phenomenon which Heer long ago happily designated 'the periodical recoinage of organisms'."[9]

The older geologists, interpreting the evidence of the geologic record unhampered by any difficulty of theory, formed their estimate of the plural origins of life. Creation was the method assumed. Hence they were not concerned about the fact that these great geological epochs of appearance, disappearance, and new appearance of life would seem to indicate plural origins. They had only to say what they saw, without having to reconcile it with any theory.

This represents the general position of pre-Darwinian geologists; though some geologists indeed occupied themselves much with the problem of life as related to evolution. With Suess: "Let us glance over the period from 1849 to 1859. The doctrine of successive creations reigns everywhere. Each larger subdivision of the geological series is considered to denote an act of special creation."[10]

[8] *The Face of the Earth*, I, 11.

[9] *Ibid.*, 13.

[10] *Ibid.*, 8.

The older geologists fully recognized the magnitude and importance of the great continental and other changes suffered by the earth—cataclysmic, catastrophic, in character, as they described them. But after Darwin's book created its great furore and (championed by Fritz Mueller, and Haeckel—Haeckel foremost, with his fiery enthusiasm and his "life-tree"—and Huxley and Weismann) gained general recognition and wide acceptance for the theory of descent, including man's descent, the geologists showed a tendency to minimize or ignore the greatness of the several successive periods in the earth's history that over wide areas were destructive and inhibitive to land-life, the intervals that were followed by the comparatively sudden appearance of higher and ever more varied life-forms.

Of late these periods of convulsions have been receiving due attention, at least by some authorities. The vicissitudes suffered by the earth are vividly set forth by Pirsson and Schuchert[11] and by Suess.[12]

Of course, the fact that geology has not disclosed a complete life-series, is only a negative difficulty. All who hold the theory of descent believe that a complete geologic record would disclose an unbroken line of descent.

[11] *A Text-Book of Geology*, 450.
[12] *The Face of the Earth*, I.

Darwin himself pointed out:

"But just in proportion as this process of extermination had acted on an enormous scale, so must the number of intermediate varieties, which have formerly existed on the earth, be truly enormous. Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic change, and this perhaps is the most obvious and gravest objection which can be urged against my theory. The explanation lies, so I believe, in the extreme imperfection of the geological record."[13]

But so far as the theory of descent is concerned, the record of geology is as unsatisfactory today as it was when Darwin wrote. Suess admitted some years ago: "The fact remains that we do not find species varying gradually within the limits of single families or genera, and at different times."[14] (Surely, no one would venture to suggest that the great geologist forgot the "*Formenreihe*" of Waagen[15] and the change in the toes of the horse.[16])

2. The evident fixity of species, the evident observed persistence of type, always has been a diffi-

[13] *The Origin of Species*, Chapters IX and XII.

[14] *The Face of the Earth*, I, 13.

[15] *Die Formenreihe des Ammonites subradiatus.*

[16] *See* Henry Fairfield Osborn, *The Origin and Evolution of Life*, 266–269.

culty to the current theory of descent. Fixity of type of certain species, geological evidence shows, has persisted through millions of years.

Henry Fairfield Osborn writes:

> "Of the eighteen great orders of reptiles which evolved on land, in the sea, and in the air, during the long Reptilian Era of 12,000,000 years only five orders survive today; namely, the turtles (*Testudinata*), tuateras (*Rhynchocophalia*), lizard (*Lacertilia*), and crocodiles (*Crocodilia*).
>
> "The evolution of the members of these five surviving orders has either been extremely slow or entirely arrested during the 3,000,000 years which are generally assigned to Tertiary time; we can distinguish only by relatively minor changes the turtles and crocodiles of the base of the Tertiary from those living today. In other words, during this period of 3,000,000 years the entire plant world, the invertebrate world, the fish, the amphibian, and the reptilian worlds have all remained as relatively balanced, static, unchanged or persistent types."[17]

According to Jacques Loeb "the constancy of species, i.e., the permanence of specificity may therefore be considered as established as far back as two or possibly two hundred millions of years. The

[17] *The Origin and Evolution of Life,* 231.

definiteness and constancy of each species must be determined by something equally definite and constant in the egg, since in the latter the species is already fixed irrevocably."[18]

Bateson expressed the following opinion: "Without presuming to declare what future research only can reveal, I anticipate that, when variation has been properly examined . . . . the result will render the natural definiteness of species increasingly apparent."[19]

Since the authorities that have been quoted are numbered among the staunchest adherents to the doctrine of evolution, it is plain that the fact of the observed specificity has been soberly stated.

The experimental research that has been done on cross-breeding, etc., does not offset or nullify the difficulty that in geologic time certain species have remained constant for millions of years.

3. The greatest difficulty of the theory of descent is that it is built on insecure bases and superficial reasoning. (*See* p. 249.)

On close examination, the bases turn out to be exceedingly flimsy and insecure; consisting still, as they do, of the same vague generalizations, superficial inquiries, and loose reasoning from indefinite

[18] *The Organism as a Whole*, 43.
[19] *Problems of Genetics*, 21.

premises, which vitiated the early treatment of the problem of heredity and variation and the entire problem of the evolution of species as a whole. The most critical students of the problems that are involved in the doctrine of descent, are extremely dissatisfied with the alleged evidence on which it rests.

As Bateson states: "The advance has been from many sides. Something has come from the work of systematists, something from cultural experiments, something from the direct study of variation as it appears in nature, but progress is especially due to experimental investigation of heredity. From all these lines of inquiry we get the same answer; that what the naturalists of fifty years ago regarded as variation is not one phenomenon but many, and that what they would have adduced as evidence against the definiteness of species may not in fact be capable of this construction at all."[20]

Concerning the arguments employed in treating of the problem, Bateson writes:

> "A vast assemblage of miscellaneous facts could formerly be adduced as seemingly comparable illustrations of the phenomenon 'variation.' Time has shown this mass of evidence to be capable of analysis. The transformation of

[20] *Problems of Genetics*, 15.

masses of population by imperceptible steps guided by selection, is, as most of us now see, so inapplicable to the facts, whether of variation or of specificity, that we can only marvel both at the want of penetration displayed by the advocates of such a proposition, and at the forensic skill by which it was made to appear acceptable even for a time. In place of this doctrine we have little teaching of a positive kind to offer."[21]

It was the early assumption on inadequate evidence that a series of characters was successively evolved. Perplexing difficulty attends the later uncertainty of interpretation regarding the successive or simultaneous and independent evolution of such characters. (According to Eduard Seler, of the *Zeitschrift für Ethnologie*, the problem is receiving much attention. Felix von Luschan,[22] and others treat of it.)

A very great difficulty which attends the current theory of descent, a difficulty which is receiving wide and growing recognition, is the vagueness and crudeness of the conceptions of the causes and factors of heredity and variation which were current sixty years ago, and for which the later literature of the subject offers no satisfactory substitutes. For today,

[21] *Problems of Genetics*, 14, 248.

[22] *Zusammenhänge und Konvergenz.*

when the question of descent takes the form of inquiry into the causes and factors of heredity and variation, those best informed—after a half-century of Darwinism—profess only ignorance.

The utter unsatisfactoriness of the general situation in evolutionary inquiry appears in especially strong light when the indefiniteness and vagueness of it all is compared with the definiteness and exactness of the work done in chemistry and physics. That life-processes are characterized by the same precision of relations that always obtains in chemistry and physics is clearly indicated by specific lines of experimental research in botany and biology—cytology, heredity-investigations of the kind inaugurated by Mendel, and pursued by Raymond Pearl, Thomas Hunt Morgan and others, and experiments on artificial parthenogenesis (J. Loeb's and others').

To quote Bateson again:

> "As to almost all the essential features, whether of cause or mode, by which specific diversity has become what we perceive it to be, we have to confess an ignorance nearly total. . . . . When . . . . we contemplate the problem of evolution at large, the hope at the present time of constructing even a mental picture of that process grows weak almost to the point of vanishing. We are left wondering that so lately men

in general, whether scientific or lay, were so easily satisfied. Our satisfaction, as we now see, was chiefly founded on ignorance."[23]

Henry Fairfield Osborn admits: "We have no scientific explanation for those processes of development from within, which Bergson has termed '*l'évolution créatrice*,' and for which Driesch has abandoned a natural explanation and assumed the existence of an *entelechy*, that is, an internal perfecting influence."[24]

In passing, it must be noted: (1) The difficulties that beset the current theory of descent have been stated in the exact words of the men who are quoted; there has been no garbling or recasting of statements. (2) The criticisms are by representative leaders in science whose findings command respect. (3) These men are firmly convinced that evolution is a fact.

Some persons have understood these criticisms and similar expressions of extreme dissatisfaction with the current theory of descent (criticism within the ranks of science, by some of the ablest men of science) to mean that the general doctrine of evolution may be rejected. This, however, is an erroneous conclusion. It is not necessary here to adduce the various

[23] *Problems of Genetics*, 248, 97.

[24] *The Origin and Evolution of Life*, x.

reasons why men of science are almost as one man in their acceptance of the doctrine of evolution; but it is a fact that perhaps never before in the history of human thought has there been more complete unanimity of opinion on a debated question than the unanimity of men of science concerning the general idea of evolution. Galilei may have yielded to pressure and recanted his costly truth, but it is impossible for a man of science of today to renounce his belief in evolution.

This makes it plain that the problem of the origin of species is recognized as a *special* problem in evolution. Yet, while singling it out as a special problem, it may not be ignored that it is indeed the core of the problem of organic evolution. Therefore it is small wonder that the opponents of evolution consider the honest admissions of dissatisfaction with the theory of descent as extremely damaging to the entire doctrine of evolution.

The current theory of the origin of species, as everyone knows, is an effort to account for the successive appearance of higher and higher forms of life during geologic time. It teaches that all existing life-forms have descended in an unbroken line *from the first and lowliest form or forms of life* on the early earth. With the origin of life the theory is not concerned. The problem of the theory is *how* to account for the manifest variety and the observed specificity.

As everyone now recognizes it to be, the problem of the origin of species primarily is the problem of heredity, which involves the problems of specificity and of variation. Until recent years, the theory of organic evolution was only a quasi-scientific one; certainly, there was little inquiry into the actual life-process. But the problem of the origin of species undoubtedly is first of all a problem of life, a part of the general problem of life. Without being able to account for the fundamental life-process, to try to account for the ascent of life, for the observed specificity and for variety, necessarily is a pitifully futile and hopeless effort.

It would seem obvious that a knowledge of the process of the reproduction of life-forms is essential to an intelligent inquiry into the *causes* and *factors* of heredity. A brief review of the general facts about reproduction, therefore, may not be omitted.

Though there still is much to learn, today science can at least boast that it has a fair knowledge of the process of reproduction.

The study of the reproduction of life-forms is an elaborate study. Reproduction takes place in many different ways. The vegetable kingdom possesses a variety of methods for reproducing forms. In the animal kingdom the methods of reproduction range from the simple division of the apparently structureless speck of protoplasm, and next the cleavage of the nuclear unicellular organism, through numerous methods, up to the birth of the mammalian offspring, and to the coming of the human child into the home lovingly prepared for its advent.

However, as mentioned before (p. 50), fundamentally all methods and forms of reproduction are alike in that they represent the detachment of a part, or particle, of the parent organism, or of two organisms, which, given food supply and favorable conditions, grows into the likeness of the parent form. The close relationship that exists between nutrition and reproduction is well known to all students of the multitudinous phenomena of the reproduction of organisms.

Reproduction is asexual or sexual. In the lowest forms of life, reproduction is asexual. In some forms asexual and sexual generation alternate. In the higher animals reproduction is sexual.

Parthenogenesis—in the strict meaning of the word—seems to be entirely out of the question among organisms as high as the vertebrates. True, Dr. Leo Loeb (whose cultures of cells *in vitro* have been mentioned) found peculiar structures in the ovaries of guinea-pigs, which structures, he said, "must be interpreted as embryos developing parthenogenetically within the ovary of the guinea-pig."[25] Leo Loeb expressed the opinion that his observations "make it extremely probable that in a relatively large proportion of mammalian animals a spontaneous parthenogenetic development of ova takes place at some period during the life of the animal."[26] But this of course does not invalidate the statement that, strictly speaking, parthenogenesis seems to be out of the question among the higher organisms. And the general statement still holds though parthenogenesis has been caused in so high a form as the frog—by merely puncturing the frog's egg (first by Guyer, also by Jacques Loeb, and others); for normally the egg of the frog develops only when a spermatozoon enters.

As Jacques Loeb observed: "The reader knows that the eggs of the overwhelming majority of animals cannot develop unless a spermatozoon enters them."[27]

The differentiation of sex begins near the bottom of the scale of life. However, examples of intersexuality, that is, "the occurrence of examples intermediate between the normal male and female of the species" are cited from invertebrates (Dr. R. de la

[25] *Journal of Medical Research,* 1901.

[26] *Proceedings of the American Philosophical Society,* Philadelphia, 1911.

[27] *The Mechanistic Conception of Life,* 200.

Vaulx).[28] Also, Janda experimented upon a hermaphroditic worm, and found that "in a hermaphrodite both types of sex organs can be produced from body cells or from latent buds resembling body cells."[29]

The late E. A. Minchin said:

"The vital processes exhibited by the cell indicate a complexity and a minuteness in the details of its mechanism which transcends our comprehension and baffles the human imagination, to the same extent as do the immensities of the stellar universe. If such language seems hyperbolic, it is but necessary to reflect on some of the established discoveries of cytology, such as the extraordinary degree of complication attained in the process of division of the nucleus by karyokinesis, or the bewildering series of events that take place in the nuclei of germ cells in the processes of maturation and fertilization. Such examples of cell-activity give us, as it were, a glimpse into the workshop of life and teach us that the subtlety and intricacy of the cell-microcosm can scarcely be exaggerated."[30]

Concerning germ-cells, Edmund B. Wilson explains:

"In the lowest forms, such as the unicellular

[28] *Nature,* July 8, 1922.

[29] Jacques Loeb, *The Organism as a Whole,* 220.

[30] *American Naturalist,* 1916.

algae, the conjugating cells are, in a morphological sense, precisely equivalent. . . . . As we rise in the scale, the conjugating cells diverge more and more, until in the higher plants and animals they differ widely not only in form and size, but also in their internal structure, and to such an extent that they are no longer equivalent either morphologically or physiologically."[31] Again: In the higher life-forms "the gametes differ widely in form and function, the macrogamete or ovum being a very large, quiescent cell, while the microgamete or sperm is a very minute and usually motile cell, typically provided with one or more flagella or cilia."[32]

Jacques Loeb says that "only in respect to the chromosome constitution are egg and sperm alike, while they differ enormously in regard to the mass of protoplasm they carry."[33]

The spermatozoa are naked cells, that is, cells without membrane or protective covering. They are detached glandular cells, rod-shaped, motile, ciliated, of which each drop of seminal fluid may contain millions.

Of the millions of spermatozoa that press around the ovum only one enters the egg and effects fertiliza-

[31] *The Cell*, second edition, 229.

[32] *The Cell in Development and Heredity* (1925), 256.

[33] *The Organism as a Whole*, 251.

tion. (*See* p. 183 for the conception of the germ-cells supplied by my theory.) Experimental biology describes fertilization as the activation of the "ripe" egg, that consists in the initiation of adequate chemical changes in the egg. (Concerning "ripe," *see* p. 225.)

In sexual generation both parents provide each a single cell. Any variation from this—as, for example, one egg giving rise to two individuals—is an exception.

"Contact of the sperm," as Edmund B. Wilson describes, "calls forth a powerful and almost instantaneous reaction by the egg that is responsible not only for entrance of the sperm, but also for many other changes in the ooplasm."[34]

The fusion of the ovum and the sperm-cell is a process which involves a number of interesting and important phases.

Fertilization, impregnation, conception, having taken place, immediately the process of cell division commences. With the first division of the impregnated ovum, the growth and development of the new individual is begun.

A number of biologists obtained some very interesting results experimenting on fertilized eggs at the two-cell stage. Jacques Loeb put the eggs of the sea-

[34] *The Cell in Development and Heredity* (1925), 409.

urchin soon after fertilization into a solution which differed in specific points from sea-water, and found that "when the eggs are allowed to segment in such a solution the first two cleavage cells are as a rule in a large percentage of cases—often as many as ninety per cent—separated from each other, and when the eggs are put into normal sea-water (about twenty minutes after the cell division) each cell develops into a normal embryo."[35] Experimenting upon eggs of the frog, it was found—first by Hans Driesch—that if the first two cells of a dividing egg are separated, each cell develops into a whole embryo of half size. Driesch also found that by shaking a sea-urchin's egg in the four-cell stage, the four cells may be separated, and each one may develop into a complete embryo, "which only differs in size from the normal embryo."

In Jacques Loeb's words: "Roux destroyed one of the two first cells of a (fertilized) frog's egg with a hot needle and found that as a rule the surviving cell developed into only a half embryo."[36]

Again Loeb's words: T. H. Morgan "destroyed one-half of the egg (fertilized frog's egg) after the first segmentation and found that the half which remained alive gave rise to only one-half of an embryo, thus

[35] *The Organism as a Whole*, 137.

[36] *Ibid.*, 141.

confirming an older observation of Roux. When, however, Morgan put the egg upside down after the destruction of one of the first two cells, and compressed the eggs between two glass plates, the surviving half of the egg gave rise to a perfect embryo of half-size (and not to a half-embryo of normal size as before)."[37]

The interest that attaches to these monstrosities produced by experimental embryology, has been largely due to the fact that normally one egg gives rise to only one individual. However, these experiments are of extreme interest to my theory.

Concerning man: Necessarily, most of the facts known about the details of the process of fertilization have been gained through observation of, and experimentation with, lowly organisms. However, the human ovum and spermatozoon are structurally built on the same lines as the ova and spermatozoa of the animals which have been the subject of elaborate experiments. The human ovum (about 1/120 inch in diameter) is imbedded in the Graafian follicle, a vesicle about as large as a pinhead. Periodically an ovum ripens in one or the other of the two ovaries, and is then discharged from the ovary and carried to the uterus. Here, in the event of impregnation,

[37] *The Mechanistic Conception of Life*, 216.

the ovum gives rise to a new individual; otherwise it soon dies.

To repeat: Fertilization, conception, having taken place, immediately the process of cell division commences. With the first division of the impregnated ovum, the growth and development of the new individual is begun. Conception, fertilization, once having taken place (in normal fertilization that means when the spermatozoon has entered the egg), the egg passes into an irreversible condition. It may die, but if it does, it is the incipient new individual that dies. An unfertilized egg is a potential new individual; a fertilized egg is actually a new individual in its initial stage of existence. The beginning of the new individual dates from the moment of conception. (*See* p. 164.)

The mother supplies everything for the embryo but a single cell, the microscopic germ-cell supplied by the father in the fertilization of the ovum. Up to birth, the embryo is vegetal in its mode of obtaining nourishment: at an early stage what may be described as a stem-root of the embryo buries itself in the food supply of the egg or the placenta of the maternal organ.

This in fewest words outlines the process of sexual reproduction.

It is necessary now to note more closely the relation of the spermatozoon to the ovum in fertilization.

Some cytologists (thus O. Hertwig) defined fertilization as the fusion of the two nuclei, the nucleus of the sperm and the nucleus of the egg. But this definition had to be abandoned in the light of later experimental knowledge. All the successful experiments on artificial parthenogenesis disprove the idea that the fusion of the two nuclei is necessary to fertilize, or activate, the egg. In some experiments by Boveri, "an enucleated fragment of an egg was fertilized with a spermatozoon of a foreign species."

It was Boveri's conclusion, shared by many later authorities, that the centrosome of the spermatozoon is the essential organ that brings about division in the egg. However, it was found that this theory claims too much for the centrosome as an organ.

A flood of light has been shed upon the nature of the process of fertilization by Jacques Loeb's remarkable experiments on the artificial fertilization of echinoderms—sea-urchin and starfish.

Jacques Loeb has been quoted repeatedly; and here it may be noted that Dr. Loeb's brilliant and epoch-making work represents the highest point of experimental knowledge of life thus far attained by science. Needless to say, much work in this field of artificial parthenogenesis and of experimental embryology has also been done, with remarkable results, by not a few other distinguished investigators.

Jacques Loeb's work included a variety of elaborate experiments. But his crowning achievement was the demonstration "that eggs which naturally develop only when a spermatozoon enters, can be caused to develop artificially by certain physical and chemical means."[38]

Loeb is again quoted:

> "Experiments show that it is possible to completely imitate by physicochemical means the effect of the spermatozoon upon the sea-urchin egg."[39]

Again:

> "It may be mentioned that in the eggs of many animals the effect of the entrance of the spermatozoon manifests itself almost instantly by a characteristic change, namely, the formation of the so-called membrane of fertilization. . . . . In 1905 I succeeded in finding a method by which it is possible to call forth the formation of a membrane of fertilization without apparent injury to the egg. . . . . It was noticed that all the agencies which cause cytolysis also cause membrane formation."[40]

[38] Jacques Loeb, *Dynamics of Living Matter*, 165.
[39] *Ibid.*, 171.
[40] *The Mechanistic Conception of Life*, 129, 130, 132.

Again:

"I am inclined to believe that the direct and essential effect of the spermatozoon and the methods of artificial parthenogenesis is the starting of a definite chemical process, and that the formation of astrospheres is only a secondary effect of this. It is in harmony with this idea that the process of segmentation in the case of artificial parthenogenesis is entirely regular, and does not differ from that of fertilized eggs, provided that the right concentration and time of exposure are selected."[41]

It must be noted that in order that an egg may be fertilized, or activated, either by a spermatozoon or artificially, it must be in the specific condition described as "ripe." Loeb describes,[42] in the case of the egg of the starfish, that the nucleus must have become dissolved in the protoplasm.

It has been established, then, in numerous instances that in fertilization the life-activity of the spermatozoon can be duplicated by artificial means. As Loeb shows: "The objection raised that the phenomena are limited to a few species soon became untenable since it has been possible to produce artificial parthenogenesis in the eggs of plants (*Fucus*

[41] *Dynamics of Living Matter,* 172, 176, 178.

[42] *Ibid.,* 172.

according to Overton) as well as of animals, from echinoderms up to the frog."[43] Again: "The fact that the method which causes artificial parthenogenesis in the eggs of many animals acts in the same way in the case of the eggs of plants indicates the identity of this process in all living organisms."[44]

Concerning the egg, all the many successful experiments that have been made on artificial parthenogenesis, have demonstrated that fertilization of the egg can be effected by any means that can cause adequate "chemical" changes in the "ripe" egg. Anything that initiates certain specific changes in the egg, induces formation of the fertilization membrane and the development of the egg into an embryo. Experimenting on nereis, F. R. Lillie found that fertilization of the egg can be effected by a spermatozoon from which the tail, the middle-piece and part of the head has been removed.

As stated before, the mere piercing of the frog's egg resulted in the development of the egg and the production of an embryo that grew to maturity. Various physicochemical means have been successfully employed to cause the fertilization (activation) of the eggs of a variety of forms. Further, perhaps most interesting of all, the fertilization (activation)

[43] *The Organism as a Whole*, 123.

[44] *Artificial Parthenogenesis and Fertilization*, 279.

of eggs has been effected by exposing them to certain rays.

Jacques Loeb writes on the "activation of the unfertilized egg by ultra-violet rays": "The writer's previous experiments have shown that any substance which acts as a cytolytic agency can also produce artificial parthenogenesis. It was found, indeed, that the unfertilized eggs of the sea-urchin *Arbacia*, as well as those of the annelid, *Chaetopterus*, can be caused to develop by a short treatment with the Heraeus quartz arc lamp."[45]

One of the outstanding things brought to light by the experiments on artificial parthenogenesis, is that apparently "the egg is the future embryo."

Loeb says: "The idea that the egg is the future embryo is supported by the fact that we can call forth a normal organism from an unfertilized egg by artificial means; while it is apparently impossible to cause the spermatozoon to develop into an organism outside the egg."[46]

Loeb at one time had "seven parthenogenetic frogs over a year old, produced by merely puncturing the eggs with a fine needle." At a later writing he reported that "two more of the parthenogenetic frogs over a year old died. Both were males."[47]

[45] *Science*, November 6, 1914.
[46] *The Organism as a Whole*, 8, 9.
[47] *Ibid.*, 125.

Concerning the idea that the egg is the future embryo, Loeb says further: "The fact that the egg of so high a form as the frog can be made to develop into a perfect and normal animal without a spermatozoon—although normally the egg of this form does not develop unless a spermatozoon enters—corroborates the idea . . . . that the egg is the future embryo and animal; and that the spermatozoon, aside from its activating effect, only transmits Mendelian characters to the egg."[48]

The conclusion of biology, then, is that the egg is the future embryo. The egg is absolutely specific. The egg is the future embryo of an individual of the particular species to which its mother organism belongs. The species is represented by the egg, and reproduced by it.

The question of heredity is closely bound up with the fact that the egg is the future embryo.

(As Bateson points out, recognition of the significance of heredity is modern. That the idea of heredity in terms of blood—an idea sometimes suggested in common speech—has no foundation in fact, is obvious, since *every* organic individual starts his existence as a microscopic cell.)

A fertilized ovum that develops and grows to maturity of the embryo and of the adult form, always

[48] *The Organism as a Whole*, 126.

reproduces the leading characteristics of the species to which its parents belong. Heredity has to do with the preservation of traits, or characteristics, peculiar in general to the species and in particular to the progenitors of an offspring. The possession of special traits by an individual when assignable to heredity, may come as an inheritance from, or through, the mother or from, or through, the father.

It is well known that heredity does not generally manifest itself in a simple reappearance in the offspring of maternal traits plus paternal traits. Slight variations are the order; and these are not haphazard products. The classic work of Mendel and De Vries has demonstrated this experimentally. All the results obtained by these investigators were secured by means of artificial selection.

Especially to the point is the unquestioned fact that so far as the offspring is concerned, sexual selection operates irrevocably at the moment of fertilization. Hereditary traits can be transmitted only at the time of fertilization. Thus fertilization (when a spermatozoon is involved) is unthinkable apart from heredity, and heredity is unthinkable apart from fertilization.

In fertilization, the spermatozoon then plainly has the dual rôle of initiating specific changes in the egg (which lead to cell division and growth), and of conveying hereditary traits. It is Jacques Loeb's finding: "The analysis of the process of fertilization by the spermatozoon shows that we must discriminate between two kinds of effects, the hereditary effect and the activating or developmental effect."[49]

Biologists today are generally agreed that the factors, or carriers, of heredity are the chromosomes, bodies, or structures, that are found in the nucleus of the egg and in the head of the spermatozoon; and which may be identified under suitable conditions.[50]

"Chromosomes" are thought to be the carriers of individual hereditary traits; individual hereditary traits being distinguished from the general traits of species heredity.

As the name itself indicates, chromosomes furnish a purely morphological conception of heredity; and, of course, no biologist supposes that visible structures can supply an ultimate conception of heredity. (*See* pp. 258 and 259.)

Henry Fairfield Osborn (the famous paleontologist who has been freely quoted) some years ago urged an "energy" conception of heredity—"and away from the matter and form conceptions." Osborn said that "we may imagine that the energy which lies in the

[49] *The Mechanistic Conception of Life*, 158.

[50] *See* August Koehler, *Zeitschrift für wissenschaftliche Mikroskopie*, XXI, 129; W. T. Bovie, *Journal of Medical Research*, XXXIX, 247.

life-germ of heredity is very great per unit of mass of the matter which contains it."[51]

In heredity numerous specific and pronounced paternal traits are transmitted to the offspring through the medium of a single cell, so small that one drop may contain millions of them. That the human child inherits psychic qualities and traits from the two parents, is a widely held view. Thus, Eugen Fischer, director of the Kaiser Wilhelm Institute for Anthropology, recently stated that "the question as to the hereditary transmission of mental endowments must be answered absolutely in the affirmative." It is plain that morphology, physiology, and chemistry cannot throw much light upon the problem of *how* ultimately this is possible.

My theory of heredity is an integral part of my theory of life; it results directly from the basic conception of life and the life-process which the theory gives.

The germ-cells themselves, the activation of the egg in fertilization, and the entire series of changes initiated by the entrance of the spermatozoon into the egg or (in artificial parthenogenesis) by certain physicochemical means—all must be conceived in the terms of the theory.

According to the theory, the sex-cells (like all other

[51] *The Origin and Evolution of Life,* 12.

living matter) consist of two systems, a Y-system and a Z-system, as described. And it is the constitution, the organization, the pattern, of the Z-system of the germ-cell—not the chemical constitution of the matter (the Y-system) of the germ-cell, nor anything else connected with the germ-cell—which *primarily* determines that given the egg of a Planorbis, only a Planorbis can result.

The egg of any organism never by any possible chance develops into anything but an individual of the same kind as its parent. This phenomenon of specificity cannot be accounted for except on the view which here is briefly stated; on the other hand, specificity, such as is actually observed, inevitably must characterize the process and product due to a germ-cell that is constituted as the theory describes it.

Suitable conditions predicated, it is *the pattern of the grouping* of the elementary units that constitute the Z-system of a germ-cell that *determines what series of reactions can take place*; one series leading to another, and that to the next; and so on, until the limit of reactions proper to the organism (always a dual system), as determined by the germ-cell, has been reached. Obviously, the determinants of the series for any one of the higher organisms lie packed in the microscopic germ-cell. This fact finds its simple interpretation in the terms of the theory. The fanciful idea that the germ-cell contains the miniature organism or a rudimentary organism, of course has no place in my theory. The theory requires only that the Z-system of the germ-cells be organized into a specific pattern, that pattern which (following activation of the egg) through the series of successive reactions that are determined by it, *results* in a new organism that is like the parent-form.

The theory thus offers the concept that (suitable, normal conditions predicated) *heredity*, including (1) the reduplication of kind, (2) the recurrence of traits, (3) the limits of possible variation, (4) the limit of possible development, (5) the limit of possible growth, and (6) the length of the average life-span of the organism, and *also* including (7) *the specificity of species, is determined by the constitution (pattern) of the Z-system of the detached particle of the parent organism, or sex-cells*, by which particle heredity is conveyed.

The new theory of life treats of *the origin of species*, of specificity and variety, and the successive appearance of higher and higher forms of life on the earth, as follows:

The formation of the dual-system, the origin of life, occurs granted only a limited set of conditions. No particular complexity is required: The life-forms that arise are correspondingly simple.

The series of reactions that is possible to life-forms is determined (1) by the specific condition that determines the origin, or formation, of the dual-system (without which condition it cannot form); and (2) *by the degree of complexity of the factors that combine to make the conditions.* The "conditions," the "factors" and the "complexity" here referred to, of course all are physicochemical.

It is obvious that *the degree of complexity* that obtains at the formation of a dual-system is a most important factor in determining the series of reactions that may be completed by the system, and thus in determining the life-form itself.

But only a limited series of reactions is possible to the organism, considered as a dual-system that consists of a Z-system and a material system, as the theory defines it. It is absolutely impossible that these should be exceeded. The possibilities of variation are simply and solely those which are permitted by these exact limitations. Always the *ultimate* determinant is the constitution and complexity of the Z-system.

The specificity of the relations that govern the life-process (basically considered) is such that it seems extremely improbable that the earliest life-forms on the earth could have developed into the later higher life-forms.

Geological records clearly show that the earth passed through at least several great periods of well-nigh general upheaval and changes of continental surfaces. The end of every one of these great epochal periods provided a maximum of the conditions which according to the theory are necessary for the initiation of life.

A critical concentration of ions always develops whenever the conditions permit; and the formation of dual-systems, according to the theory, always occurs whenever the conditions permit.

As it has been shown, geology indeed testifies that following the several great periods of upheaval which were attended by destruction (seemingly verging on extinction) of life on land, *new* and *higher* life-forms made their relatively abrupt appearance.

The cause of the successive appearance of higher and higher life-forms on the earth during geologic time is found, I hold, in the fact that each succeeding time in the earth's history which was favorable to the wholesale origin of life provided greater complexity of conditions (physicochemical conditions) than the preceding times.

In extensiveness some of the great occasions that were favorable for the repeated wholesale origin of life, approach that of the early earth. But without a doubt, each succeeding occasion had greater complexity. Geologists and paleontologists (Walcott, Schuchert, Osborn) allow about eighteen million years to archeozoic time. During these millions of years organic matter began to accumulate, even then greatly increasing the complexity of physicochemical conditions.

Whether or not the early earth had direct light from the sun, and whether or not the ocean was salt from its beginning, both sunlight and salt have played an almost inestimably great rôle in the later history of life on the earth.

Whatever the constitution of the early atmosphere may have been, it has changed greatly during geologic time. To realize the importance of this one factor, one needs only to call to mind the fact that any considerable modification of the present atmosphere would result in the death of the human race.

As students hold, it does not seem likely that the average temperature has varied very greatly since life first appeared on the earth, that is, when and where life flourished; for the peculiar life-process can take place only within a very narrow range of temperatures. The presence of glaciers and glacial action, prolonged and over wide areas, necessarily has meant absence of life.

The present adjustment between temperature and atmosphere and the highest life-forms on the earth, is of very recent establishment—very recent, that is, compared with the total of the many millions of years that geologic history covers.

The increase in complexity (physicochemical complexity) of conditions on the earth, broadly viewed, has been a gradual process; though great upheavals and cataclysmic changes indeed have occurred at intervals, some have fancied, with almost rhythmic regularity.

The increased physicochemical complexity that obtained at each succeeding time in the earth's history that provided the conditions which (according to the theory) must have meant the repeated, very general origin of life-forms, *higher life-forms*, registering the increased complexity, then, was due to several causes. These are:

1. The accumulation of organic substances. The great modifications caused by the presence of organic substances are described by geologists and geochemists.

2. Changes in the atmosphere, the great "turbulent sea" of gases that lies above the earth.[52] That the atmosphere has undergone great changes is pointed out by Arrhenius[53] and is fully recognized by all writers on the subject of life on the earth.

[52] *See* William Ramsay, *The Gases of the Atmosphere.*

[53] *Das Schicksal der Planeten,* 51.

3. The change from (probable) faint light or, perhaps, mere heat from the sun to direct sunlight.

How completely the presence of life on the earth is dependent upon the sun, is known to everyone. Since, as now known, the sun pours torrents of electrons upon the earth, and sunlight exerts actual pressure,[54] the enormity of this change is evident.

All these causes, of course, are interrelated and were interactive.

4. The great periods of convulsions and upheaval with their changes of the earth's surface.

The untold significance of these times as mighty factors in determining the possibility of the appearance of higher life-forms, remains to be realized.

Heretofore it has been thought and taught (by those who believe that all existing life-forms are descended from the first and lowliest forms of life on the early earth—by practically "everybody") that life advanced in spite of these disturbances. Of course, all pelagic and bathybic forms were unaffected by changes of continental surfaces, and flourished as temperature conditions permitted. Undoubtedly "many new forms have appeared (or 'evolution has gone on') in the sea." Possibly numerous surviving forms, through adaptation to changed environments, suffered modifications because of these disturbances.

[54] J. H. Poynting, *The Pressure of Light.*

But according to my theory, the immediate and direct means whereby the appearance of higher life-forms was made possible were the times which over wide areas meant changes of the earth's surface and the interruption of the life-process on land, times that were followed by conditions which were suitable to the new origin of life.

It is a matter of common observation that life flourishes in every nook and cranny that will support it. When then at any one of several periods in geologic history, the earth was crowded with the highest forms of life which up to that time had appeared (and with lower forms), not much further advance was possible until there was opportunity for a new beginning. The conditions that necessarily followed the great upheavals and changes of the earth's surface provided this opportunity. Each great advance to higher life-forms was made possible by a new beginning.

Necessarily each succeeding recurrence of wide-spread conditions suitable for the origin of life did not, could not, provide these conditions uniformly throughout, but only uniformly in a general way; and since every slightest difference in constituents or conditions necessarily is reflected, or registered, in corresponding variation, there must have arisen great varieties of forms which, on culmination, exhibited much general similarity and much diversity in detail. Always, of course, earlier, lower life-forms persisted as conditions permitted, "adapting" themselves to the limit of possibility. The possibilities of adaptation, however, necessarily were limited. "Adaptation" as a factor in evolution has been greatly exaggerated. That the life-forms which escaped destruction when the wholesale loss of life, with extinction of many species, occurred, had any part in the evolution of *higher* forms that followed these destructive periods, seems most unlikely. Most, if not all such surviving forms in all probability had become distinct forms long before the disturbances set in. And, according to my theory, *a "species"* (such as the life-forms, mentioned by Osborn, that remained static for millions of years—*see* pp. 207, 208) *must be conceived to be the end of a series; not a step, or link, to higher forms.*

A dual-system such as the theory conceives every life-form to be, is a strictly limited system, a system *limited by its own constitution.* Any occasion, every occasion, that gave rise to life, gave rise to life-forms that were strictly limited as to possibilities of development, and of variability. Inevitably, when the limit of these possibilities was reached, sooner or later in geologic time, the "pattern" became rigid, no further development, or evolution, being possible.

Reproduction then became a reduplication that faithfully copied the parent form, the succeeding generations showing only such variations as attend the transmission of hereditary traits from two parents. Cross breeding, when possible, generally resulted in sterile offspring. The form was fixed. (*See* p. 138.) *As a fixed form of this kind I describe a species.* And thus the theory accounts for the fixity, the specificity, of the species of geologic times which, Osborn and Loeb have said, persisted for "from two to possibly two hundred millions of years." (*See* p. 207.)

One can conceive the possibility or probability of one incipient form, if sufficiently complex, giving rise to a variety of forms that ultimately resulted in separate species. Also some forms would remain less rigid than others, and these might produce a series in which the successive generations developed specific characteristics; or these less rigid forms through interbreeding would result in slight or pronounced variations. There is the famous example of the evolution of the horse, described by Henry Fairfield Osborn,[55] the other of the *Formenreihe* of Waagen;

[55] *The Origin and Evolution of Life,* 266–269; "Recent Advances in our Knowledge of the Horse," *Proceedings of the American Philosophical Society,* XLIII (April, 1904), 156; "The Evolution of the Horse," *Report British Association for the Advancement of Science,* 1905, pages 607 and 608; "The Continuous Origin of Certain Unit Characters as Observed by a Paleontologist," *Harvey Society Volume,* seventh series, November, 1912, pages 153–204.

and hybrids and "intergrades" are numerous. However, it is necessary to exercise extreme caution in assigning similar species to a common ancestral form.

My theory brings about a curious reversal: The current theory of descent grants almost unlimited possibilities of evolution, demanding only the primary, single origin of life. To account for the origin of life was thought to be impossible. According to my theory of life, the origin of life is a phenomenon that is bound to take place granted only a very limited set of physicochemical conditions. But the possibilities of evolution of any forms that arise—these, it appears, are strictly limited.

It would seem that most existing species could not be other than specific and fixed in their essential characteristics, the limit of their development (evolution) having been reached long ago. Specificity fixity of species, then, may not be conceived in the sense of something fatal that was impressed upon a life-form; but must be understood to mean merely that the limit of the reactions that by reason of its constitution were made possible to any newly-arisen life-form (the reactions that represent an organism of a certain definite species), was reached long ago. The average limit of possible reactions of any form having been reached, the form necessarily became rigid.

The pattern having become rigid, succeeding generations demonstrate the "fixity of species."

At several great periods in the earth's history, according to my theory, countless separate life-forms could originate, doubtless did originate at the same time. In each case, the process of development (evolution) inevitably continued until the form became rigid. Eventually, then, each of these different forms necessarily resulted in one or more separate species.

That these conclusions have direct bearing on the problem of man's descent is obvious. The doctrine of man's descent is no stronger than the weakest link in the general descent theory. But that absolute specificity rules in all life-processes as in all other processes, cannot longer be doubted by anyone who is familiar with atomic physics.

Therefore, emphatically, the painful crudity, the vague generalizations, and the inexactness of the old forms of expression relative to the facts of the diversity of life-forms and their causes, which have been current in most of the evolutionary literature of the fifty and more years after Darwin, must be rejected utterly. High-sounding generalizations, however plausible, are absolutely meaningless to a physicist or a physical chemist. He knows only exact quantities and quantitative relations and their results. The current general theory of descent is not compatible with the very specific, rigid, and exacting laws of atomic physics.

And thus it comes about that the finding of the other, earlier, more general sciences concerning man's descent is reversed: The new verdict is that it would seem almost certain that the strain which resulted in "man" was a separate one from the beginning. It is extremely improbable that there should have developed a common ancestor from which (as many think, at a late date) both man and the apes evolved; and the idea that apes degenerated from an ancestral stock from which man evolved, is pure fancy.

The reasons for rejecting the current doctrine of man's descent are:

1. The same reasons which apply to the general theory of descent; and

2. Specific reasons which arise from a comparison of man and ape.

My theory of the origin of species, and of the cause of the successive appearance of higher and higher forms of life on the earth during geologic time, then, is diametrically opposed to the current theory of descent, which teaches that all higher organisms now existing have descended through an unbroken line, and have advanced by insensible gradations or sudden mutations from the *earliest, the lowest, forms of life that appeared on the planet.*

It would appear that geology fully grants the facts that are necessary to the new theory.

The concept that has been given of the origin of species, of the fixity of species and limit of variability, is that of my theory interpreting the *natural process unmodified by artificial methods.* It is a peculiar fact, however, and one that must be carefully noted, that the life-process as conceived by the theory is such that it must be assumed not only that definite, fixed, species necessarily arose in geologic time, but also that artificial methods and cross-breeding easily should succeed with various life-forms in achieving the experimental transmutation of species. For, remembering the definition of "species," it is plain that the problem of transmuting a species into something else consists merely in disturbing or breaking up a specific state of equilibrium. In experimentation, various sets of conditions (physicochemical and other conditions) are carefully arranged and regulated in the deliberate effort to bring about a desired result. In this way conditions can be secured which, according to the theory of chance, might never have occurred in the natural state. Thus, for example, various luscious hybrid fruits now commonly enjoyed, probably never would have been produced unaided by artificial methods. Most notable are the experiments (of H. J. Muller, of the University of Texas, T. H. Goodspeed and A. R. Olson, of the University of California, W. C. Curtis, of the University of Missouri, and others) in which by exposing living organisms to powerful beams of X-rays that were just below fatal intensity, a large number of mutations, or "sports," were produced in the third generation. Various life-forms—fruit-flies, mice, hen's eggs, jellyfish, tobacco plants, etc.—have been subjected to this treatment with X-rays, and similar effects were found. Numerous other experiments that have been made also support my view.

Chapter Eight

Why Was This Theory of Life Not Stated Before?

THE theory offers a solution that seems so simple and obvious that the only wonder of it is that it was not stated before. However, many of the facts on which it is based, and without which it could not be formulated, have been brought to light only recently. Biology itself is a very young science, and atomic physics is still younger.

Modern biology may be said to date from the discovery of the cell. (Von Mohl, Schleiden and Schwann.) It was in 1839 that Schwann discovered that the human ovum is a cell, and recognized that animals and plants are built up of cells. And as a writer pointed out on the occasion of the centenary of Schwann's birth (Dec. 7, 1910), "the first years of Schwann's scientific activities fell within those happy days when it was still possible, in the words of Henle, 'by scraping with the blade of a scalpel or with the fingernail over an animal membrane, to make fundamental discoveries.'"

Following the revolution of all former conceptions of life caused by the discovery of the cell, for about fifty years emphasis in biology was almost entirely placed on morphology. Concerning the cell, early views deemed the cell wall as hardly less important than the "contents" of the cell. It was by no means known that the apparently simple cell constituents really are "incredibly complex," and that the cell is a unit which, as since shown by cytologists, exists in most various degrees of complexity.

The conception of the cell as very close to the origin of life, and the idea of the importance of the cell wall, has been lingering. Thus it only a decade ago (1916) found expression by an authority in geology (Thomas Chrowder Chamberlin[1]) when among the conditions that might be considered favorable for the origin of life on the early earth, was mentioned the probable presence of cell-like, comb-like formations. Bütschli thought he discovered a comb-like structure in gels, but the "discovery" was discredited by Wolfgang Pauli. Naturally then, to be able to produce an artificial "cell," hollow chamber, membrane, was thought to be a very high goal. However, it has been found that artificial cells (Wilhelm Pfeffer's and Moritz Traube's) after all do not contribute much toward the solution of life.

It is well known what importance the evolutionists

[1] *The Origin of the Earth*, 250–261.

of the second half of the nineteenth century attached to form and structure, to the neglect of causes save for vague ones such as "function," "use," and "disuse." There was incessant and almost exclusive appeal to comparative anatomy, embryology, and paleontology—all morphological.

Henry Fairfield Osborn finds: "The old paths of research have led nowhere, and the question arises: What lines shall new researches and experiments follow?"[2] Osborn urged an "energy conception" of the origin and evolution of life.

If one were asked today to state the trend in biology, one could answer in a word: away from morphology. Of course, the word "morphology" is used in its obvious sense, as it has been used since Goethe first coined the term "*die Morphologie*"; for, certainly, it is true, and guaranteed by atomic physics, that (as P. P. von Weimarn insists) amorphic chaos can be found nowhere in "nature."

Modern colloid chemistry has been making its rapid strides only within the lifetime of the present workers. Only within the last few years have demands been made that it, one of the branches of physical chemistry, be ranked as a separate science. A German reviewer referred to Bechhold's *Die Kolloide in Biologie und Medizin* (English translation

[2] *The Origin and Evolution of Life*, 10.

and second German edition 1919) as pioneer effort. Wolfgang Ostwald, in the volume which embodies his lectures delivered in 1913 and 1914 before some of the leading universities in the United States, calls colloids "the world of neglected dimensions," and insists that "just as normal causal biology must be edited—must be rewritten in fact—in the terms of colloid chemistry, even so must pathology be rewritten."[3] Ostwald indeed called colloid chemistry "the promised land of the biological scientist."

It is well known that the employment of physicochemical methods, especially in the hands of Jacques Loeb, was crowned with brilliant results. The successful substitution of physicochemical means for the life-activity of the spermatozoon of certain organisms, the work of Jacques Loeb on artificial parthenogenesis (mentioned repeatedly), has been the decisive factor in working a revolution of conceptions about life which stands out as the most conspicuous thing in biology since the discovery of the cell. Concerning these experiments, Loeb himself said: "I consider the chief value of the experiments on artificial parthenogenesis to be the fact that they transfer the problem of fertilization from the realm of morphology into the realm of physical chemistry."[4]

[3] *Theoretical and Applied Colloid Chemistry,* 171.

[4] *The Mechanistic Conception of Life,* 123.

Besides Loeb's work and the work of others on artificial parthenogenesis, much other work also has been done which indicates that morphology is of only secondary importance. Thus, for example, as Wolfgang Pauli insists, the concept of a *boundary phase* has to do service in the absence of histologic evidence of a membrane between different tissue constituents. Then there are the experiments on the growth and form modifying tropisms of plants (J. Sachs), and of organs of certain animals (Loeb[5]). One also may recall Brown-Sequard's classic experiments and theories on sex-gland transplantation (1888), and the earlier (1849) experiments of Berthold, who found that a hen into which the testicles of a young cock had been transplanted, developed secondary sex characteristics—masculine voice, love of combat, etc.

But the trend away from morphology in biology, and the substitution of the methods of physical chemistry for those of morphology, is not the end. Life, the organism, cannot be interpreted adequately in terms of physical chemistry any more than in terms of morphology. This does not mean that, depending on the method of approach, the organism may not be described as a series of chemical reactions, the rate of progression of which, in some organisms

[5] *Forced Movements, Tropisms, and Animal Conduct.*

at least, can be definitely accelerated or retarded by changes in the temperature in which the organism is kept;[6] or as an aggregate of cells; as like a galvanic cell—transforming chemical energy into electrical energy; or (the higher organism) as a mechanical engine, as Arthur Keith describes it in his volume *The Engine of the Human Body*, and De la Mettrie (b. 1709) pictures it in his *Man a Machine*. Each description is true but inadequate, as were the five different descriptions which the five blind sages of India gave of an elephant.

It would seem that physical chemistry in the service of biology already is about exhausted—of course not as to countless possible experiments that never yet have been made, but rather so far as concerns any further great fundamental contributions towards the elucidation of the problem of life. The one capital contribution which physical chemistry has yet to furnish, experimental abiogenesis, has been an impractical line of research in the absence of a working theory of the origin of life. (*See* p. 180.) Therefore, although experimental abiogenesis is seen as the challenging goal of biology, not a few of the leading representatives of science retain the idea of panspermia. And this in face of the fact that no evidence for panspermatism ever has been discovered.

[6] *See* Jacques Loeb, *Scientific Monthly*, December, 1919.

The hypothesis has been put forth gratuitously, as the ancient Greeks put it forth, in the absence of a definition of what constitutes life and determines the origin of life.

That life cannot be interpreted adequately in the terms of physical chemistry is plain from the definite limitations of physical chemistry. In the division of labor, which alone now divides one science from another, it is allotted to physical chemistry to work with the chemical atom, the molecule, and the ion. When then, for instance, membrane permeability is interpreted in terms of ions of positive or negative sign, in pointing out the ion (the element) and its sign as the active agent, physical chemistry reaches its limit. Unaided, it can go no further. But today no one thinks of the chemical atom and the ion as ultimate units. It bears repeating: Concerning the chemical elements, it is an indisputable fact now firmly established, that they are not simple but compound, and not only compound, but trebly complex; and further, that all their qualitative properties are determined numerically. Elucidation of the constitution of matter, basically considered, is furnished by theoretical (mathematical) and experimental physics. How then, reasonably, can one expect physical chemistry to perform for biology what admittedly it cannot do and is not expected to do in the realm of the inorganic—yield fundamental concepts?

Soddy teaches: "The chemical analysis of matter is, even within its own province, superficial rather than ultimate."[7]

In order to get at the inner constitution of matter, "ordinary" inorganic matter, physics has devised, has had to devise, methods a million million times more sensitive than ordinary chemical analysis. *How can one expect the secret of living matter to reveal itself to methods too clumsy for the inorganic?* One cannot expect to get results by using a tool comparable to a mile measure when what is needed is one corresponding to an inch. Therefore in biological inquiry, even when physical chemistry points out and describes causes and effects, such as identifying certain changes as of rate of action, with change of electrical sign of a specific ion, the demand for a further reduction of the terms cannot be suppressed. The terms to which the atom and ion and their activities must be reduced of course are the terms of atomic physics. This is obvious, since the chemical elements which are present in organisms and involved in life-processes, are like the same chemical elements found in the inorganic, fundamental conceptions of which are supplied by atomic physics. Jacques Loeb, whose

[7] *Nature*, July 19, 1917.

investigations into the effects of ions led him to the successful employment of physicochemical methods in research on artificial parthenogenesis, later conducted experiments on diffusion, in which he interpreted the action of the ion in terms of atomic physics.

Wolfgang Pauli believes:

> "There can be little doubt that out of the study of the physicochemical properties of the colloids there will spring a new bud of physical physiology in which the application of the modern teachings of electricity will play a primary rôle. The physiology which recognizes in the neighboring sciences of physics and chemistry that profound revolutionizing influence of the newer electrical investigations, which do not stop before even the most sacred and fundamental conceptions of this subject, must consider it as a next most worthy task to guarantee itself its share in the new conquests of scientific knowledge."[8]

The terms of physical chemistry then admittedly are utterly inadequate to express the ultimate relations which obtain among the phenomena of life, or the organism. It comes to this: Life, any and all life-phenomena and the organism as a whole, cannot

[8] *Physical Chemistry in the Service of Medicine,* 155.

be interpreted adequately in the terms of physical chemistry for the simple reason that the inorganic cannot be interpreted adequately in these terms.

There seems to be no reason for accepting as the final word in biological research an analysis which is not accepted as the final word concerning the inorganic, unless the mere circumstance that an experiment is related to problems of life-processes constitutes reason why the matter and electricity involved should not be reduced to the terms of atomic physics. Of course, this latter idea is absurd. To insist that the interpretation of the organism in terms of the electron and of atomic physics is legitimate, is merely to insist in a specific way on the relationship which exists between the organic and the inorganic on which many—Helmholtz at the age of twenty-five, Ernst Mach to the rounding-out of his scientific career, Jacques Loeb, Wilhelm Ostwald, Sir Jagadis C. Bose, and many others—forced by overwhelming evidence, have insisted. Indeed, a large number of students see an "all-embracing unity," and therefore, with Wilhelm Ostwald, insist on "a doctrine which excludes all double-entry bookkeeping, which removes all barriers, hitherto regarded as insurmountable, between inner and outer life, between the life of the present and that of the future, between the existence of the body and that of the soul, and which comprehends all these things in a single unity, that extends everywhere and leaves nothing outside its scope."[9]

A strong plea for the stating of the facts of psychology in the general terms of science is made by the psychologist, J. B. Watson, formerly of Johns Hopkins University: "The key which will unlock the door of any other scientific structure will unlock the door of psychology. The differences among the various sciences now are only those necessitated by the division of labor. Until psychology recognizes this and discards everything which cannot be stated in the universal terms of science, she does not deserve her place in the sun."[10]

Thus Jacques Loeb:

> "The physical researches of the last ten years have put the atomistic theory of matter and electricity on a definite and in all probability permanent basis. We know the exact number of molecules in a given mass of any substance whose molecular weight is known to us, and we know the exact charge of a single electron. This permits us to state as the ultimate aim of the physical sciences the visualization of all phenomena in terms of groupings and displacements of ultimate particles, and since there is no dis-

[9] *Monism as the Goal of Civilization*, 5, 6.

[10] *Psychology from the Standpoint of Behavior.*

continuity between the matter constituting the living and non-living world the goal of biology can be expressed in the same way."[11]

Wolfgang Ostwald declares:

"Like the chemistry, so must the physics of organized substance be analyzed into unit processes and through gradual rebuilding from these be resurrected into a synthetic biology."[12]

Of the admitted legitimacy then of interpreting life in terms of atomic physics there can be no doubt. How far from the goal biology has been, appears from the fact that heredity is interpreted in terms of chromosomes. (*See* p. 230.) To be sure, especially when one reflects that the scientific conception of heredity only dates from Herbert Spencer, heredity in terms of chromosomes is seen as a marvelous advance over heredity in terms of "adaptation." As Bateson points out: "The absence of any definite progress in genetics in the last century was in great measure due to the exclusive prominence given to the problem of adaptation. Almost all debates on heredity centered in that part of the subject."[13]

However, concerning the unsatisfactoriness of the morphological interpretation of heredity, Ralph S. Lillie, in a paper on *The Place of Life in Nature* (read

[11] *The Organism as a Whole*, 1.
[12] *Theoretical and Applied Colloid Chemistry*, 170.
[13] *Problems of Genetics*, 187.

before the Royce Club, Harvard University), expressed himself thus:

> "Most geneticists regard chromosomes as the bearers of hereditary qualities in organisms. But in the physiological sense no such theories of heredity can be regarded as ultimate; if chromosomes (e.g.) determine the appearance of certain special characters in organisms (as now appears almost certainly to be the case) what determines the appearance of the special qualities possessed by a given set of chromosomes themselves? Surely not a second set of chromosomes—i.e., similar physiological units of a lower order? Evidently these would require a third set of determinants, and so on *ad infinitum*, like the fleas in Swift's epigram. But the facts of physical science forbid any such *regressus* since limits to divisibility are set by the atomic or electronic constitution of matter."[14]

Atomic physics enables a refinement of *definite* concepts to a degree until recently deemed impossible. But the thorough establishment of modern atomic physics is of most recent date. As yet comparatively few persons are thoroughly conversant with the facts of the new atomic physics and the labors (including the early labors of Kaufmann, Laue, other

[14] *Journal of Philosophy, Psychology, and Scientific Methods*, XVII, 38.

German students, the Braggs, and Henry Moseley) on which it is built. Nevertheless, how general the acceptance of the fundamentals of atomic physics is, may be stated in the words of R. A. Millikan: "Today there is absolutely no philosophy in the field other than the atomic philosophy, at least among physicists."[15]

The facts of atomic physics are absolutely indispensable to the comprehensive interpretation of life, the organism. In the absence of much-needed data, then, it was impossible for the would-be interpreter of the organism to frame an adequate theory of life. Surely that was his misfortune—blame for the tardiness of the development of physics may not be heaped upon him. Lawrence J. Henderson (in 1913) sketched "the painful advance of physics and chemistry into the domain of biology," and pointed out "how progress is beset with well-nigh insuperable obstacles." He concluded: "Thus it is that biological thought has never attained to that finality which appears, at least by contrast, to characterize the greater body of opinions in physical science."[16]

However, the needed facts are now available. And to neglect to make use of *all the facts of atomic physics* predestines any "theory" of life to certain failure.

[15] *The Electron*, second edition, 10.

[16] *The Fitness of the Environment*, 282.

The mere recognition of the electron or of the discrete nature of matter and electricity does not take one far. *The mere reduction of the units of physical chemistry—the atom and the ion—to the electron, does not solve the problem of the organism.* Plainly, it does not advance our knowledge of the organism in any way that would make possible a statement of the difference between life and non-life, the organism and inorganic matter, in terms of atomic physics. In fact, the mere reduction of the atom and the ion to the electron does not shed even a ray of light on the specific questions about the organism that physical chemistry cannot answer. The bare idea that an immensely large number of atoms, that themselves are built up of a large number of elementary units, constitute a cell or are contained even in chromosomes or chromatin, and therefore permit of the forming of rich and varied "mosaics," is like the idea that a very great number of cells that build up an organism—one estimate has it *twenty-six million million* cells in the human body—account for the organism. Neither idea contains anything that in the least would indicate the relationships among these units that result in the larger living aggregate.

In connection with the fact (as I hold it to be) that life, that is, the living organism, cannot be interpreted comprehensively without taking account of *all* the facts of atomic physics, it is of very special interest that a department of biophysics has been established in a number of large institutions. The work is in the field of X-rays, of radium, and of ultra-violet light brought into relation with living matter. (*See* p. 196.) Seemingly it is only a short step from the much-pursued study of the effects of X-rays and of radium on animal tissue and particularly on cancer, to the study of atomic physics and biophysics, yet the establishment by a great institution of a department of biophysics marks the official recognition of the most significant advance in methods since physical chemistry was first employed to elucidate life phenomena.

The hour of physics is striking. However, when a textbook by an eminent physiologist (D. Noel Paton[17]) still makes the assertion (emphasizing it with italics) that "the science of life has become the science of the chemistry of protoplasm," it is, after all, small wonder that a theory of life based on atomic physics was not formulated before.

[17] *Essentials of Human Physiology*, fifth edition, 3.

Chapter Nine

On Proof

CONCERNING the theory of life that has been submitted (Chapter Five) it may be urged:

1. The theory is in entire accord with the accepted findings of atomic physics.

2. The peculiarities of organic matter, that is, the peculiarities of the carbon compounds, or combinations (*see* pp. 91, 92) would support well the author's contention that in the dual atomic-intraatomic system of living matter, the atomic (material) system is the secondary system; i.e., the arrangement of atoms to form molecules in and during the living state is directly or indirectly determined by the intraatomic system, the primary system of the dual system.

3. The theory adequately accounts for the phenomena of life *basically considered.* It accounts for the peculiarities of the organism that distinguish life from non-life.

4. There are no known facts to invalidate or discredit it.

5. All pertinent facts find their ready interpretation, that is, classification; and with its aid stubborn difficulties are readily solved.

Thus, for example, the cause of man's *long infancy*, as compared with the ape's short infancy, finds its easy statement when the problem is viewed in the light of the new theory. (*See* pp. 185–188.) Anatomically man and the great apes are similar; physiologically and chemically there is an extremely close relationship between them; yet the period of time required to reach physiological maturity, in which *the same sets of organs and the same functions* are involved, in the case of man is several times that required in the case of the ape. Why? The cause of man's long infancy, it appears, simply cannot find its statement by science on any other theory than this theory of life based on atomic physics.

Someone said: "He has not adduced proof until he has adduced a fact which is compatible with no other explanation than his own." Such a fact having been adduced, has not *proof* been adduced?

If the exigencies of a theory require that to be true a certain given set of phenomena must be found present under certain specific conditions; and if this set of phenomena is found unmistakably to exist under the specified conditions; and if, furthermore, the facts, or phenomena, for which one is searching as necessary to the theory—in the present case, lengthened infancy with increase of psychic powers—are facts which themselves have been vainly seeking classification (by science) on any theory whatever, and have remained utterly inexplicable: the combination amounts to *proof* for the theory.

6. It is a *complete* theory, in that "the truly psychical" is included and fully accounted for—accounted for, that is, to the same extent to which anything else may be said to be accounted for. (*See* p. 151.)

7. The theory calls in no unknown agencies. It shows that there is absolutely no more need for postulating pansperm, a peculiar "life-element," a pre-existing soul, "life entities," etc., to account for life and all life-phenomena than there was for the many kinds of elementary "atoms" which the Greeks postulated to account for matter. As a theory of life, *the theory is both sufficient and necessary.*

Further, it appears that certain rigid demands which the theory makes, are met by answering facts of observation.

One of these demands is that given *certain specific conditions* which beyond a doubt follow many injuries, inevitably a neoplasm, cancer or other growth, must result. (*See* p. 181.) And surely, no critical but impartial reader will underrate the significance, or corroborative value, of this agreement between demand of theory concerning neoplasms and the phenomena of cancer—the phenomena of both the abnormal "proliferation" of cells, as which (for want of a closer definition) cancer has been described by some pathologists, and of those cancers which, according to some researchers of unquestioned ability, show the presence of minute organisms.

Thus it would appear that while the theory states the cause of cancer, the phenomena of cancer constitute a striking *proof* of the theory.

Another demand of theory concerns specificity of species. This demand of theory is met by the fact that "species" appear to be constant. (*See* Chapter Seven.)

The theory makes several demands of geology. (*See* Chapter Seven.) The easy harmony that is found to obtain between these demands and the pertinent facts of the geologic record, not improperly may be said to be in the nature of *proof* of the correctness of the theory.

The theory then, plainly, is well supported. Yet there remains the imperative demand for direct experimental proof. This is simply because to the trained, critical mind, absolute conviction in matters of science which may be referred to the laboratory can come only through positive and conclusive proof that is furnished by the laboratory. And in view of the wealth of corroborative evidence of various sorts that supports the theory, it is apparent:

1. *The demand for direct physical laboratory proof of the theory is a demand that may not be denied.*

2. Physical laboratory experiments to test the theory will be not only *crucial as concerns the theory*, but, since the theory treats of the basic problems of life, *the research will be fundamental* as well, designed to solve the primary problem of the nature of life.

3. This crucial and fundamental research will prepare the way and serve as a basis for much other work, since the theory opens up the entire field of inquiry into life phenomena to the quantitative method.

4. The necessary expenditure of time and money for whatever extensive and costly laboratory research is required to test the theory is well warranted.

5. *Only the physical laboratory can supply the required proof.*

A mathematical demonstration, that is, *proof*, of the theory is impossible in the present state of our imperfect knowledge of the atoms that are involved. Concerning the Bohr (or the Rutherford-Bohr-Sommerfeld) atom, on which the theory is based, it is, of course, well known that it was not established mathematically, but was, as Sommerfeld put it, "*intuitiv erfasst.*" However, that the "Bohr atom" is signally successful in interpreting the spectral lines of the atoms and the chemical behavior of the elements, is evident to everyone who is familiar with the problems that are involved. The modified Bohr atom today is accepted by most if not by all physicists and chemists. Nevertheless, it is true that the precise relations—positions and motions, of the orbital electrons of the atoms of nitrogen, oxygen, sodium, etc., are not yet known. The negative electron, thanks especially to the exact measurements of Millikan, is a known constant; the value of the positive electron, too, Millikan has stated. Planck's constant has its definite value. The ratio of charge to mass is readily determined. But the normal orbits of the electrons that revolve about the nucleus of the atom are still unknown, and thus the changes caused in these orbits by the relations of the atom with other bodies are unknown; therefore the exact values of the electron that depend on position and velocity, are undetermined. Mathematical proof of the theory, then, plainly, is not possible yet. Any mathematical work lacking this knowledge of exact quantitative values, in its skillful use of variables and factors might be a thing of art, and in the ease of its presentation a veritable mathematical poem, but it could not be proof.

Fortunately, the theory does not depend on mathematics but on the laboratory for proof; it does not need to wait for proof until the basic data required by mathematics are determined, but it is directly amenable to crucial laboratory test. It sometimes happens that data that are lacking and that are indispensable to mathematics, are not necessary to proof by the laboratory. Thus, today the existence of the cell is one of the best-known basic facts of biology; but von Mohl's and Schleiden and Schwann's "cell-theory" never was a problem of mathematics but, of course, was established by direct experimental research.

The exact manner of the formation of a system and *the fact of the existence of that system are two different things.* It probably would not be questioned that, though the exact paths and speeds of the orbital electrons of the atoms cannot be pointed out, and therefore certain quantitative values of even the first positive and negative electrons that collide and unite at critical positions and—pursuing a new and independent path—through further collisions and unions form a new and different system (life), cannot be pointed out, the theory is none the less valid.

And after all, desirable as mathematical "proof" is, it is the boast of science that most of our modern knowledge rests upon direct evidence of the laboratory; and only the laboratory can furnish absolutely decisive, unequivocal, and final proof on so revolutionary a theory as this one that asserts that *life is a quantity.*

What constitutes the general problem that is involved in the question of laboratory proof of the theory, is obvious. The theory involves two essential hypotheses for which there is as yet no laboratory evidence: (1) There is a type of combination of positive and negative electrons which is distinct from the types at present recognized by physicists and chemists; (2) this new entity is an essential constituent of living matter.

Thus *the core of the theory is the general law of the structure of living matter.* It is the affirmation that all living matter is dual, atomic-intraatomic, in composition. The stability of the organism that means the living state, is determined by an intraatomic system.

The intraatomic system—necessarily described as *not* belonging to the configuration of the atoms within which it is found, but as an immaterial quantity, that is, a quantity the units of which are not grouped after the pattern of the elements, but are organized after a different pattern, with qualities peculiarly its own—was identified as life.

Together with the general law of the structure of living matter, then, are given the propositions:

1. The stability, or state of living, of the organism is due to an intraatomic system (life, or the soul).

2. The organism is a dual (atomic-intraatomic) system.

3. Life, or the soul, is a quantity—a quantity different and separable from the quantity which is the body.

4. Death is the rupture between, and the separation of, the two quantities.

Obviously, these concepts either do or do not answer to the facts. And the general problem of physics that is involved in the question of proof, is to establish the correctness or the erroneousness of these several propositions.

The theory concerning the law of the structure of living matter is directly amenable to test. Whether it is a fact that the organism is a dual system, as described, can be experimentally determined by laboratory test. It is not a mathematical proposition that cannot be tested. Inquiring into the question of direct proof, then, it appears that amenable to laboratory test are:

1. The general law of the structure of living matter—the description of the organism as a dual atomic-intraatomic system.

2. The definition of life—at least, so far as the description of life as a quantity is concerned.

3. The definition of death, which describes death as the severance of the intraatomic quantity, "life," (which determines the living state of the organism) from the matter (or body) of the organism.

With this law and these definitions established by laboratory test, it would seem that proof of the theory would be complete. For, clearly, the law of growth, the involved theory of the origin of species, and the other conclusions which are offered, all follow from the simple law of the structure of living matter, when the details of this law are carefully considered and interpreted in keeping with the established facts of atomic physics.

Of course, it may be urged that since the theory affirms the specific general condition that is necessary to initiate life, that is, to transform non-living matter into "living matter," and supplies a more or less definite picture of the transition from non-life to life, the question of proof of the theory concerning the *origin* of life must include experimental abiogenesis.

Proof of the theory as related to experimental abiogenesis, obviously can come only from the physical chemistry laboratory. The physical chemist, as such, is the only person who is qualified to try to transform non-living matter into living matter in his laboratory. In his hands, the research should not be too difficult.

It would seem plain that *the general law of the structure of living matter and the definition of life and of death* are amenable to proof in the laboratory of the *physicist.* But because the problem of the structure of living matter (no less than the problem of the structure of inert matter) ultimately is a problem of atomic physics, the physicist is the only one who has the tools, or who, finding his tools inadequate, can contrive tools, to test for the law and the definitions. Of all who heretofore have testified concerning the problem of life in one or another of its aspects, not one has the tools for this investigation. This question of direct experimental proof of the theory then cannot be answered by the paleontologist (whose facts in every way satisfy the demands of the theory), the comparative anatomist and the embryologist—who have been the chief witnesses on the question of descent; nor by the physiologist, nor the cytologist, nor the psychologist, and by neither the biochemist nor the physical chemist. The biologist, as such, does not have the means of approach to the problem involved in this question of proof. Proof can be supplied only by the physicist.

The work required certainly is not less difficult, but perhaps is more difficult, than any that yet has been done in physics. That living matter presents peculiar difficulties to direct research is, of course, well known.

Biophysics has been engaged for some years in experimentation on living matter, especially in connection with cancer research, and particularly on the effects of various rays on living matter. Thus, there is no difficulty in causing the destruction of cancer cells—where they are accessible to treatment—by X-rays or by radium rays; the difficulty consists in not also causing injury or death to normal cells. Of the *fact* of the difficulty of research on living matter there is no doubt. But *why* living matter should behave so utterly unlike non-living matter, except non-informatvely to assign "the state of living" as the cause, no biophysicist has attempted to say; and there then has been no clue to the *cause* of the peculiar difficulties of research on living matter.

The first of these is the difficulty that all experimenters on protoplasm have recognized, the difficulty, namely, of keeping living matter alive under experimentation.

> "Following life in creatures we dissect,
> We lose it, in the moment we detect."

The *cause* of this difficulty is found in the fact (asserted by theory) that living matter is a dual system, the constituent systems of which are in a state of delicate equilibrium, which equilibrium is easily upset. Any attack upon the dual system that *destroys* the equilibrium to a degree that recovery of equilibrium is impossible, necessarily causes the separation of the two systems, or the dislodgment and escape of the Z-system, from the Y-system, that is, death.

The difficulty of research on living matter, according to the theory, is due, first, then, to the idelicacy of the equilibrium between the two constituent systems of living matter.

The second difficulty is that the Z-system (the intraatomic system, life) corresponds to undetermined wave-lengths, which wave-lengths, however, would be found to lie outside the range of wave-lengths associated with matter. (*See* X-rays.)

The third great difficulty of research on living matter is owing to the fact (of theory) that in the living state the Z-system is screened off by the Y-system. This screening, as the theory conceives it, of course, is *unlike* the screening off of the nucleus, as the center, or core, of an atom, by the K-shell and other shells of the atom, yet roughly comparable to it, in that, as n research on the atom, the inner constituents of the atom cannot be made to register by the same methods that suffice for the atom as a whole, so the Z-system cannot be made to register by the same methods as the Y-system. It is a question of responding to different wave-lengths, or wave-numbers. The Y-system then screens the Z-system, but screens it merely by reason of registering more readily (more readily, that is, according to present methods of research).

These are the chief difficulties that according to the theory are inseparable from research on protoplasm, and that definitely limit experimentation.

However, concerning the problem of proof: It is plain that if the theory of life that has been presented is true, that is, answers to the facts, then at death the escape of the Z-system (life) from the Y-system (the body) must take place. For—once more—as life is defined as the immaterial, intraatomic system, of the organism, so death is defined as the separation and escape of this quantity from the organism. Therefore, to determine conclusively whether *life is a quantity*, as the theory describes, requires research upon living matter, or an organism, at the moment of death. For if the death of an organism indeed means the separation of a definite *quantity* from the organism, then that quantity can be made to register, at least at the moment of death, by adequate means. The crucial experiment (a biologist, physiologist, having prepared a suitable subject) consists in causing death, and testing for and measuring the Z-system, the quantity life, that according to the theory, becomes separated from the body, the atomic system, the Y-system, at the moment of death. The experiment to be decisive, at first may be only a rather rough one—relatively speaking—and merely to establish the fact of *life as a quantity*. Nevertheless, the research is extremely difficult. The main problem consists in *devising a method for registering a quantity* (as which the theory conceives life to be) *that corresponds to an undetermined but exceedingly small wave-length*, or a very great wave-number. The research, of course, presents a number of other difficulties, such as, for example, the necessity of distinguishing carefully between the quantities of electricity that an organism may give off, due to being alive, quantities that vary according to state of health, etc., and the quantity, asserted by theory, that *is life*.

Obviously, the research that is indicated is entirely different from research on the changes caused in the body by death. It is well known, and has been known for many years, that the body does not behave towards electrical stimuli in the same way after death as before death. Thus, one of the recognized means of distinguishing death-like trance from actual death, is the persistence of the excitability of the muscles to electrical stimuli. Numerous experiments have established the fact that death causes changes in the body in respect to excitability and resistance to the electrical current.

Obviously, too, the measurement of life that is proposed, is entirely unlike the experiments that have been made in "weighing the soul." The experiments of a Dr. Duncan MacDougall (of Haverhill, Mass.) who "weighed the soul," consisted in weighing the *human body* immediately before and after death. He found a difference in weight of about six to eight ounces, and from this concluded that he had "weighed the soul." That at the moment of death, with the exhalation of the last breath, the body should lose slightly (some ounces) in weight, would seem likely from physicochemical considerations. However, the loss that is registered on a scale that weighs "matter" certainly is not the loss of the quantity which the theory describes as life, or the soul. One might with equal propriety and with equal hope of success weigh a wire after the current has been shut off, to determine something about the quantity of the current, as to weigh the human body before and after death to determine something about life, or the soul.

All experiments in connection with death heretofore have been on the body; on tissue, nerve, muscle; on matter. There has been no research to determine whether or not death is the severance, the subtraction, of an immaterial quantity from the organism; because not a few leading men of science have been holding and dogmatically asserting the opinion—strange to say, unwarrantedly, without any pertinent experimental data to support it—that "nothing leaves the body at death." However, it is true that never before was there a basis or warrant in science for research such as the new theory of life, based on atomic physics, is under the necessity of demanding.

Evidently, the *quantitative* measurement of life hat may be expected as the result of this research, will disclose nothing of *life-qualities*, as a scale in a market only registers pounds without indicating whether it is a man or a barrel of flour that is weighed.

The question may be raised whether, in the event that the laboratory establishes the fact of death as the separation of a quantity from the body, the quantity that leaves the body really constitutes life.

Of course, if any one chooses to postulate "vital force" or "life entities" to account for life, nothing will prevent him. But it is a generally accepted principle that it is unscientific to seek a more difficult "explanation" when a simple one suffices, or to call in unknown factors when known factors answer fully.

It would seem that the fact of death as the separation of a quantity from the body demonstrated by laboratory test, will amount to conclusive proof that the quantity that escapes *is life*, because the establishment of this fact is the last link that is needed in the chain of evidence that supports the theory. The peculiarities of the organism, including the "truly psychical," would seem to be accounted for on the theory. The burden of proof will rest upon him who would affirm something else needed.

That the physical laboratory *can* establish the propositions of the theory experimentally—if they correctly state the facts—is not open to doubt.

That physical laboratory research *will* supply the direct experimental proof of the theory that is demanded, reasonably may be expected; since it would appear that the theory is in entire accord with and fully supported by all known facts.

Appendix

Glossary

Abiogenesis. The production of living matter from non-living matter.

Absolute Temperatures. Temperatures measured from *absolute zero.* (Absolute zero is reached at $-273°$ centigrade, at which point the molecules are motionless.)

Acids. Acids change the color of certain indicators, dissolve metals, combine with bases, neutralize alkalis, etc. Acids are defined as compounds that in aqueous solution suffer electrolytic dissociation with formation of hydrogen ions. Some acids are highly ionizable; many acids are not highly ionized in ordinary solutions. A very extensive literature treats of hydrogen ions. The accumulation of data is so great that, Dr. Leonor Michaelis says, no one person can master the entire field. *See* Electrolytic Dissociation and Metal.

Adsorption. The action of a substance in condensing and holding another substance by surface condensation (as of colloids in taking up dissolved substances).

Analysis (*Chemical*). The determination and (or) estimation of the constituents of a compound or mixture is termed *chemical analysis.* There are several branches of chemical analysis: (1) *Qualitative analysis,* the process of detecting what elements are present in a compound or mixture. (2) *Quantita-*

tive analysis, the process of determining the amounts of the elements present in a compound or mixture. (3) *Proximate analysis*, an analysis for the purpose of detecting and estimating the presence of certain compounds in a mixture. (4) *Ultimate analysis*, the determination of the elements in a compound. (5) *Organic analysis*, the qualitative and quantitative analysis of organic compounds, involving the determination of carbon, hydrogen, nitrogen, sulphur, and the halogens (iodine, chlorine, bromine, and fluorine). (6) *Combustion analysis*, a method of analysis of organic compounds for the determination of carbon, hydrogen (and oxygen by difference), and nitrogen. (7) *Electroanalysis*. This method employs the electric current to effect the separation of the constituents of a compound or mixture. (8) *Spectrum analysis*, the detection of elements by means of their characteristic spectra.

Ångström Unit. A unit for measuring the wavelengths of light. It is equal to one ten-thousandth of a micron. *See* Millimicron.

Aphelion. The point in an orbit (as of a planet) farthest from the sun (*helios*). By extension, in the theory of the planetary atom, the point in the orbit of an orbital electron that is farthest from the nucleus of the atom. Opposed to *perihelion*.

Archeozoic Era. The oldest era of geological history. The era of the earliest life-forms.

Atmospheric Pressure. *See* Pressure, Atmospheric.

Atomic Weight. The weight of an atom of a chemical element as compared with the weight of an atom of hydrogen. The value 1 was arbitrarily assigned to the weight of the hydrogen atom because hydrogen is the lightest of all the elements. On the basis of hydrogen equals atomic weight 1, oxygen—found to be sixteen times heavier than hydrogen—equals

16. Because most of the elements form analyzable compounds with oxygen and few with hydrogen, oxygen = 16 was adopted as the more convenient standard. (Taking 16.00 as the atomic weight of oxygen, it was later found that the atomic weight of hydrogen is 1.008.)

Autolysis. The disintegration of tissues caused by the action of their own ferments.

Avogadro's Constant. The number of molecules in a gram-molecule. (Symbol N.) $N = 6.062 \times 10^{23}$. It is the famous rule of Avogadro (stated in 1811) that given the same temperature and pressure, equal volumes of all gases contain equal numbers of molecules.

Bacteria. Microorganisms. Bacteria were first discovered by the Dutch naturalist Anton van Leeuwenhoek in the last quarter of the seventeenth century. About a hundred years later the Danish investigator Müller made further observations. In 1838 Ehrenberg, who discovered iron bacteria, described a large number of bacteria. The study of bacteria now ranks among the most important subjects of research from several approaches. The results which crowned the experiments of the pathologists Robert Koch, Pasteur, and Metchnikoff, have made the widest possible appeal. Special interest also has centered in the *nitrifying bacteria*, which became known chiefly through the investigations of S. Winogradsky. Many hundreds of different bacteria are known and described. Bacteria are found in the alimentary canal of animals, and distributed in the air and in water, etc. Those that are injurious to the health of animals and plants are termed *pathogenic.* Most infectious diseases are due to bacteria; as diphtheria, to the bacillus of diptheria; typhoid fever, to the bacillus of typhoid fever, etc. Some bacteria are able to survive extreme cold. Paul Becquerel kept bacteria for many hours at a temperature of 253°C. below zero, and yet they retained their vitality. Some bacteria or the poisons generated by them, according to E. O. Jordan, may survive *boiling*. Morphologically, bacteria are rod-shaped (*bacilli*); or in shape like twisted rods (*spirella*); or spherical (*cocci*). Methods that make possible the examination of the structure of living bacteria have been available since, some years ago, J. E. Barnard, the English optical physicist, discovered methods whereby to secure a useful magnification of 3,000 diameters, that is, the magnifying of an object twelve and one-half million times, showing detail. (Ultramicroscopes of even greater power have since been perfected; one by F. F. Lucas, with a magnification to 9,000 diameters, and one yet more powerful by W. G. Guthrie.)

Bathybic Life-forms. Life-forms that inhabit the deep sea.

Brownian Movement. The constant rapid and oscillatory motion of fine particles of a substance suspended in a liquid. Named for the botanist Dr. Robert Brown, who first treated of the phenomenon in 1827. Brownian movement is also exhibited by the molecules of a gas. *See* Kinetic Theory of Gases.

c. Symbol for the velocity of light. *See* Velocity of Light.

Cancer. "Any malignant growth."

Catalysis. The phenomenon in which many reactions that otherwise proceed very slowly have their velocities increased in the presence of certain substances, which latter in most cases themselves remain chemically unchanged. In some cases reactions are retarded.

Catalyser (*Catalyst*). A chemical substance which by its presence is capable of influencing the reactions between certain other substances, while remaining chemically unchanged itself.

Cathode Rays. A stream of electrons emitted from the negative pole (cathode) of a vacuum tube.

Centrosome. An organ of the cell that is found at the center of greatest activity in the processes of cell-division.

Chemical Action. The process in which atoms unite to form molecules or molecules are broken up into atoms. Generally, in chemical processes molecules are both formed and decomposed. Chemical action always is accompanied with changes in energy.

Chemical Affinity, "the force which binds the atoms together in their combinations as molecules," is measured in terms of energy. The quantitative relations between the free energy change (change in the energy which can be obtained in the form of work) and the total energy change of a reaction in condensed systems is expressed in *Nernst's Heat Theorem.* The amount of heat liberated or absorbed in a chemical reaction between given quantities of substances is termed the *heat of reaction.* The *heat of formation* is "the amount of heat liberated or absorbed in the formation of one gram-molecule of a compound from its elements." *Hess's Law* states the amount is the same whether it is formed in one or more reactions. The *heat of combustion* is "the total heat liberated by the complete oxidation of a given quantity of an element or compound." And so on. (*See* Heat of Solution.) The idea that chemical affinity is electrical in nature, has been entertained since the days of Sir Humphry Davy (Bakerian Lecture, 1806) and of Berzelius (1812). Faraday said that the forces of chemical affinity and electricity are the same.

Chemical Analysis. *See* Analysis, Chemical.

Chemical Changes and Radioactivity, The Difference Between. In chemical changes molecules are formed or decomposed; in radioactivity atoms are disintegrated. In chemical changes the nuclei of the atoms that are involved remain unaltered in constitution; in radioactivity the nucleus of the atom suffers the loss of one or more constituents. In chemical changes the atoms (elements) remain unchanged; in radioactivity the element is changed, transmuted, into another element. The energy liberated in radioactivity is millions of times greater than any energy liberated in chemical changes.

Chemotaxis, Positive. The property possessed by certain living cells (that are capable of spontaneous motion) of moving towards certain substances.

Chromatin. The minute granules that constitute the chromoplasm (the readily stained parts) of a cell-nucleus.

Coagulation. The precipitation of a colloid. In some colloids the disperse phase is separated from the dispersion medium by heat, in others by the addition of a small quantity of an electrolyte, etc. *See* Disperse Phase and Dispersion Medium.

Compton Effect. In a very interesting and difficult experiment, involving the scattering of X-rays (of molybdenum) by free electrons, the shifting of a characteristic spectral line from blue to red, indicating the change of the "waves" from a shorter to a longer wave-length, or a higher to a lower frequency. This effect is produced as the result of the collision of "light-quanta" with *free* electrons, in which collision the light-quant transfers some of its energy to the electron, and thus with a smaller energy is changed to a lower frequency, which latter registers as a shifting of lines. The experiment was designed and carried out in 1923 by Arthur H. Compton, of the University of Chicago, to test the hypothesis of localized light-quanta. Since X-rays resemble light, the scattering of X-rays is a phenomenon comparable to the reflection of light. Compton proceeded on the assumption that a collision between a "light-quant" and a *free* electron should be governed by the general law of the conservation of energy and Newton's law of the conservation of momentum. The actual shifting of lines, and the amount of the displacement that resulted from the scattering of X-rays by free electroms, were approximately those which Compton predicted from these laws and the values belonging to a light-quant (energy hv, velocity c, etc.) and a "free" electron. The Compton experiments have been repeated and confirmed by P. A. Ross, of Stanford University, and others. (W. Duane, who repeated the experiments, failed to secure the Compton effect, and secured an effect—now known as Duane's effect—that is distinct from the Compton effect. Duane therefore at first held that the Compton effect did not exist. But both effects have since been found on the same photographic plate.) The Compton effect demonstrates the existence of localized "light-quanta," and thus is a direct proof of Einstein's theory. Sommerfeld holds that the Compton effect promises to become the *experimentum crucis* between the wave-theory of light and the quantum theory. He places the Compton effect "among the fundamental experience facts," and says "it is perhaps the most important discovery that in the present state of physics could have been made." *See* Spectrometer, Energy, Quantum, and X-rays.

Coolidge Tube. A high-power cathode ray tube. According to Dr. Coolidge, the tube is capable of operation up to 900,000 volts.

Coulomb's Law. The law that "the mutual force exerted by two charged bodies is directly proportional to the product of their charges, and inversely proportional to the square of the distance between the bodies."

Crystalloids. A name given by Graham to substances that in solution diffuse readily through a parchment membrane or some other septum.

Dialyze. To separate crystalloids from colloids by dialysis. (In *dialysis* the crystalloids diffuse out through a membrane into the surrounding solvent, the colloids remaining behind.)

Dielectric Constant. A term to denote the capacity of a substance for transmitting electrical forces or effects to another body or substance by virtue of the mere proximity to it.

Disperse Phase. The *dispersoid* in a *disperse system;* that is, the *colloidal particles* that are suspended in a medium. *See* Phase and Disperse System.

Disperse System. A colloidal system.

Dispersion Medium. The *continuous phase* in a *disperse system;* that is, the medium in which the colloidal particles are suspended. *See* Phase and Disperse System.

Electricity and Life, Early Knowledge of. That electrical phenomena abound in life is knowledge of long standing. An early number of the *Philosophical Magazine* (Vol. V, Oct., 1799) contains an article entitled: "Observations on Animal Electricity, and particularly that called spontaneous." The writer, J. J. Hemmer, observes: "We are taught by many instances, both ancient and modern, that men, as well as other animals, have exhibited evident signs of electricity; although the ancients, who mention these instances, did not know to what the phenomenon was to be ascribed." That the human body conducts electricity was discovered by Stephen Gray; electricity in plants was discovered by Sir John Burdon-Sanderson (nearly sixty years ago). So-called "animal electricity" has received much attention, with names such as Galvani, Peltier, Du Bois-Reymond, Tigerstedt, Ewald Hering, and Augustus Waller identified with the investigations.

Electrochemistry. One of the branches of physical chemistry. It treats of chemical changes that determine or are determined by electrical processes or phenomena.

Electrokinetic. Relating to or caused by electricity in motion.

Electrolysis. The decomposition of a chemical compound by means of an electric current.

Electrolyte. A substance (acid, base, salt) that, when present in solution, conducts the electric current.

Electrolytic Dissociation. The dissociation of an electrolyte into ions when it is dissolved in water or certain other liquids. *See* Electrolyte.

Electrolytic Solution Pressure. A term used to designate the force by virtue of which metal ions pass into solution when a metal is immersed in pure water. The metal is negatively charged and the solution positively charged. At the interface, or boundary of the metal and the solution, a layer of positive and negative charges (electrical double layer) is formed.

Electron, The. Historical. The first instance on record when electricity was thought to be atomic is that of Thales of Miletus (*ca.* 600 B.C.) who observed the effect of the rubbing of amber. Benjamin Franklin, to whom we owe the terms "positive" and "negative" to designate the two kinds of electricity, was perhaps the first in modern time to advocate the view that electricity is atomic. In 1871 Wilhelm Weber wrote of positive and negative electrical particles. In 1873 J. Clerk Maxwell, in referring to Faraday's experiments (which showed that the quantity of electricity carried by an atom in electrolytic conduction is exactly proportional to the valency of the atom), spoke of a "molecule of electricity," but deemed it "extremely improbable" that the "theory of molecular charges" would be retained. In his Faraday lecture at the Royal Institution (1881) Helmholtz expressed the belief that electricity is atomic on the basis of Faraday's discoveries. However, Helmholtz did not feel prepared to embrace all electrical phenomena in his atomic view. Faraday himself did not use his own remarkable data to further an atomic theory of electricity. Dr. G. Johnstone Stoney did use the facts of ions in solutions brought to light by Faraday as his starting point, and, in 1874, developed clearly the theory of the atomic nature of electricity. He even estimated the value of the elementary electrical charge, and his estimate shows a surprising approach to the later accurately determined values. Stoney also, in 1891, first suggested the word "electron" (Greek *elektron*, amber) as a name for the "natural unit of electricity."

Much theoretical work was done on the electron, notably by Sir Joseph Larmor and by H. A. Lorentz. The discovery of cathode rays for the first time in history revealed pure negative electricity. "Before we had found only electrical bodies," said P. Lenard, "but never electricity itself." But in 1897 the great Lord Kelvin, though expressing his preference for "an atomic theory of electricity," still admitted the possibility that electricity might be "a continuous homogeneous liquid."

Then, crowning a long series of painstaking experiments, Sir J. J. Thomson at the Cavendish Laboratory in Cambridge, discovered the negative electron, and measured its mean statistical charge. The work of Sir J. J. Thomson easily claims first attention. There is, as Sir Arthur Schuster says, "no doubt that Sir J. J. Thomson's experiment will be looked upon in the future as a landmark in the advance of science." Sir J. J. Thomson's epoch-making work in 1898 consisted in the experimental demonstration of the existence of units of negative electricity, whose mass is nearly 2,000 (1845) times smaller than the mass of the hydrogen atom, the lightest atom known.

And, finally, Robert Andrews Millikan in Ryerson Laboratory, the University of Chicago, *isolated the electron* and measured the unit electrical charge. (1909.) Dr. Millikan determined the ionic charge, compared it with the frictional charge; determined the charge carried by a beta particle or the cathode ray—all have the same value. (This value is stated in the text, p. 119.)

Energy, Physics. Whatever the form of the energy, potential energy, kinetic energy, electric energy, etc., energy always means "capacity for performing mechanical work"; that is, the capacity for accomplishing motion against the action of a resisting force. According to Einstein's *Theory of Special Relativity*, a quantity of energy represents a mass; active energy represents momentum. The mass is equal to the energy divided by c^2. Einstein says: "Mass and energy are therefore essentially alike; they are only different expressions for the same thing." *See* Quantum.

Faraday's Law of Electrical Equivalence. In electrolysis, the amount of a substance deposited by the same quantity of electricity always is proportional to the equivalent weight of the substance, and is the same for all electrolytes. This quantity (termed a *Faraday*, or the *Faraday constant*, symbol F) is equal to 96,494 Coulomb, or 9,649.4 C. G. S. (or absolute electromagnetic) units.

Flocculation. "The coalescence of the suspended particles of a disperse system into particles or aggregates of much larger size which settle out." *See* Disperse System.

Gamete. The germ-cells that unite in fertilization.

Gas Law. The law that at constant temperatures the product of the pressure and volume of a given quantity of gas is a constant. The volume varies inversely as the pressure. (Boyle's Law.) For the same change in temperature, the change in volume is the same for all gases. (Charles's Law. The Law of Gay-Lussac.) *See* Osmotic Pressure, van't Hoff Factor *i*, and Avogadro's Constant.

Gibbs's Phase Rule. A general law that governs equilibria in heterogeneous systems. It states that "the number of degrees of freedom of a system is equal to the number of its components plus two, minus the number of phases in which it exists." It was enunciated in 1874 by Josiah Willard Gibbs.

Gland. An organ the function of which is to remove specific constituents from the blood, either as an excretion or as a secretion (as the kidneys, the liver, the sebaceous and gastric glands, etc.). *Ductless glands* (as the thyroid gland, the suprarenal body, etc.) resemble true glands.

Gram-atom. The atomic weight of an element stated in grams.

Gram-molecule. The molecular weight of an element or compound given in grams. *See* Molecular Weight.

Heat of Ionization. The heat absorbed or set free by the electrolytic dissociation of a compound in water. *See* Electrolytic Dissociation.

Heat of Solution. The amount of heat absorbed or set free when a given quantity of a substance is dissolved in a solvent. The amount depends on the substance, the solvent, and quantity.

Heliotropic. Characterized by or relating to heliotropism. *See* Tropism.

Hertzian Waves. "Wireless" waves. Very long electric waves. Electric waves lie below the region of the heat waves. The wave-length of the longest Hertzian waves is over a mile. They are named for their discoverer, Heinrich Hertz.

Histologic. Concerned with the minute structure of tissues. *See* Tissue.

Hydrolysis. A reaction between water and another compound (as salts of weak bases or weak acids) in which the second compound suffers chemical decomposition and the water splits up into H and OH, one of the decomposition products combining with H and the other with OH.

Hysteresis, Chem. A term used to denote a lag or retardation in passing into a stable condition.

Hysteresis. Physics. "The tendency of a magnetic substance to persist in any state of magnetization."

Isomerism. The condition of two or more (organic, or carbon) compounds of having identical molecular formula (i.e., the same chemical composition) but exhibiting different physical properties, and in many cases different chemical properties. Compounds thus characterized are termed *isomers* or *isomerides.* Organic chemistry shows a great many cases of isomerism. Several special types of isomerism are recognized; as, stereoisomerism (isomerism due to the different arrangement in space of certain groups), structural isomerism, dynamic isomerism (tautomerism), etc. *See* Tautomerism.

Isotopes. The name, proposed by Soddy, for all elements that are inseparable by chemical processes. Isotopes have identical chemical properties, and the same valency. They differ in atomic weight by small amounts. The radioactive isotopes always differ in radioactive properties.

Karyokinesis. Indirect cell-division. Also the series of changes exhibited by the nucleus in such cell-division.

Kinetic Theory of Gases. The kinetic theory teaches that each individual molecule of a gas is endowed with motion, the velocity of which is different for the different molecules (different elements), and which varies with the temperature. The kinetic theory of gases is the theory according to which all the phenomena exhibited by gases are accounted for by the motion of their constituent molecules.

Kinetic Energy. The energy that belongs to a body in motion. *See* Energy and Quantum.

Metabolism. A general term that comprises both *anabolism* and *catabolism*, and designates the changes undergone by the food taken into the animal body. In the limited sense of chemistry it means the process of the building up of more complex substances from simple substances (anabolism), or the breaking down of complex substances into simpler ones (catabolism). In the wider view of biology it means the process of the change of the food constituents into living matter (anabolism), or the process by which living matter is broken down into simpler products within a cell or an organism (catabolism).

Metal. Chem. Any element that forms a *base* by combining with oxygen. (A *base* is a compound that in aqueous solution gives hydroxyl ions [HO].) Bases combine with *acids* and form *salts*. *See* Acids and Salt.

Millimicron. One-thousandth of a micron. (A *micron* is equivalent to one-thousandth of a millimeter, or one-millionth of a meter.) A unit for measuring light-waves.

Molecular Weight. The sum of the atomic weights of all the atoms in the molecule of a compound or element.

Molecule. Chem. Two or more atoms that are bound together chemically constitute a molecule. The power of atoms to unite with other atoms to form molecules is termed their "valency." The atoms of all the elements except the rare gases (helium, argon, neon, krypton, and xenon) enter into combination with other atoms to give molecules. When two or more atoms of the same element are united, they form a molecule of an element. When the combining atoms are of different kinds, they form a molecule of a compound. A molecule consists of the smallest number of atoms that will form a given chemical compound. Thus it is *the smallest particle of a substance, or compound, that can have an independent existence and retain its composition and properties*. The molecule of most inorganic substances is light, and consists of only a small number of atoms. The molecule of most organic substances (carbon compounds) is extremely heavy. Thus, according to Julius B. Cohen, probably few proteins have a molecular weight of less than 10,000. The minimum molecular weight of hemoglobin (the solid coloring-matter of red blood-corpuscles) is estimated at about 16,000. A molecule, an *octadecapeptid* (18 amino acid molecules combined), having a molecular weight of 1213 has been built up by the German chemist Emil Fischer. This is the largest molecule ever produced by synthetic methods. The polypeptides synthesized by Fischer, according to E. J. Holmyard, are very similar to the first decomposition product of the proteins, the peptones. C. W. Porter says that "no doubt this compound would have been classed as a protein if it had been discovered in nature instead of appearing as a synthetic preparation." *See* Chemical Action and Molecular Weight.

Molecule. Physics. The structural unit in the kinetic theory. To the alteration of the position or relation of molecules all *physical* changes (freezing, evaporation, etc.), as distinguished from *chemical* changes, are due.

Neoplasm. A new growth resulting from a pathological condition.

Nereis. A sea-worm.

Nulvalent. Without chemical combining power. The rare gases are nulvalent.

Ooplasm. The cytoplasm of the egg; i.e., the protoplasm of the egg as distinguished from the egg-nucleus.

Osmotic Pressure. *See* Pressure, Osmotic.

Oxidation. The process or state of the chemical combination of an element or compound with oxygen. Several types of reactions are covered by this term. Oxygen enters into chemical combination with most elements.

Paleontology. The branch of biology that treats of fossil plants and animals.

Panspermia (Cosmozoa), Hypothesis of. The hypothesis that life-giving seeds are drifting about in space. They encounter the planets, and fill their surfaces with life as soon as the necessary conditions for the existence of organic beings are established. As held by Arrhenius it teaches that when conditions on the earth had become favorable to life, life originated from the action of life-sperms, or germs, which, eternal in nature and able to survive the extreme cold of interstellar space, came from space, transported largely by means of radiation pressure.

The view, like most other views, is related to some similar ideas of antiquity. The modern hypothesis of panspermia was advanced in 1865 by H. E. Richter. It was accepted by Helmholtz, by Ferdinand Cohn, and many others.

Parthenogenesis. Reproduction without sexual union.

Pelagic Life-forms. Life-forms that inhabit the surface of the ocean far from the land.

Perihelion. The point in an orbit (as of a planet) nearest to the sun. By extension, in the theory of the planetary atom, the point in the orbit of an orbital electron that is nearest to the nucleus. Opposed to *aphelion.*

Phase. Physical Chem. In a heterogeneous system, a uniform solid, liquid, or gas, or a mixture, a compound, or solution, that is one of the physically distinct and mechanically separable portions of the system.

Photoelectric Effect. The emission of electrons caused by the influence of light. Knowledge of the photoelectric effect dates from Heinrich Hertz (1887). According to Ernest O. Lawrence and W. J. Beams, of Yale University, electrons are ejected from a metal in less than three-billionths of a second after a ray of light strikes it.

Photosynthesis. A synthetic reaction brought about by the influence of light.

Planorbis. A pond snail.

Pressure, Atmospheric. The pressure of 14.7 pounds per square inch exerted by the atmosphere at sea-level.

Pressure, Osmotic. If a solution is separated from the pure solvent by a semi-permeable membrane, the solvent will diffuse through the membrane into the solution, a process termed *osmosis.* The volume of the solution will then increase and its level will rise, thus setting up a hydrostatic pressure, termed the *osmotic pressure. Chem. Dict. See* van't Hoff Factor *i.*

Protoplasm. The accepted name for "living matter." It was so named by von Mohl, and called by Huxley "the physical basis of life."

Quantum. The quantum of action. It is known as Planck's constant or Planck's element of action (symbol h). The sum and substance of the quantum theory is that *radiant energy* (sunlight and similar forms of energy) *is emitted and absorbed by a given source only in units.* The value of this unit is equal to hv, in which h, Planck's element of action, ($=6.547 \times 10^{-27}$ ergs) is the same for all sources, and v is the frequency of the source, varying with the source. All leading physicists now recognize h to be a universal constant.

The quantum theory dates from Dec. 14, 1900, when Max Planck, professor of physics in the University of Berlin, presented his thesis on energy quanta before the *Deutsche Physikalische Gesellschaft.* Planck was led to his conclusion that the emission of energy is a discontinuous process, through his exhaustive study of black-body radiation. Five years later (in 1905) Einstein formulated the theory that light itself consists of "light-quanta," units having the value hv. Einstein evaluated the work necessary to lift an electron out of its bond in an atom of metal in the photoelectric effect. This value was purely theoretical. But in 1914, R. A. Millikan, as the result of elaborate experiments on the photoelectric emission of electrons, designed to test Einstein's equation, obtained results that proved Einstein's equation correct. Meanwhile Niels Bohr, in developing his now generally accepted theory of the atom, computed the value of the energy that is lost when an electron in an atom jumps from one state to another, in terms of $h\nu$. The results of certain experiments by W. Duane and his collaborators corroborated this equation. A. Sommerfeld extended the laws of the distribution of quanta in atomic systems. (Of the formula which Sommerfeld worked out, Planck holds that it "is an accomplishment in every way comparable with the famous discovery of the planet Neptune, whose existence and position had been calculated by Le Verrier before it had been seen by human eye.") Millikan and Bowen's work on stripping valence electrons from atoms included the furnishing of proof of Sommerfeld's formula. With the aid of the quantum theory, and on the basis of the Bohr theory of orbits, P. Epstein and K. Schwarzschild were able to compute the value of the energy changes caused in the orbital electrons of atoms by a strong electrical field. (The so-called "Stark effect," discovered by J. Stark in 1913.) This brilliant theoretical work also was thoroughly confirmed by the spectroscope. Other verification—by J. Franck, G. Hertz, Paul D. Foote, K. T. Compton, R. W. Wood, and others—has come from the field of optics, the experiments having to do with the determination of the energy values in ionization and radiation phenomena. In the X-ray field, too, experiments by De Broglie and Ellis, and other experiments by D. L. Webster supplied further proof. A wealth of experimental work thus has proved Planck's element of action to be indeed a universal constant. However, though the quantum theory so far as *h* is concerned has been generally accepted as fully established, not many have been ready to accept Einstein's "extreme quantum theory" of discrete, or corpuscular, "light-quanta." Recently (1923), direct and, it would seem, convincing proof of Einstein's theory of light-quanta has been furnished by the Compton effect. But serious difficulties remain, and must be cleared up before various phenomena that have been accounted for on the wave-theory can be harmonized with the quantum theory. *See* Energy, Photoelectric Effect, and Compton Effect.

Radical. Chem. A group of atoms which enters into chemical combinations, acting as a single element, and that can pass unchanged through many chemical transformations.

Salt. Chem. A compound that is produced when the hydrogen of an acid is replaced by an electropositive element or radical. *See* Acid, Electrolyte, and Electrolytic Dissociation.

Simiidae. An African and Asiatic family of apes.

Sols. Colloidal solutions.

Solution. 1. The term is generally understood to refer to the liquid phase, but solutions may also exist in the solid, and gaseous phases. A solution is "a single homogeneous phase made up of two or more components and whose compositions may vary within certain limits." In the liquid phase the liquid is known as the *solvent*, and the substance dissolved in it, as the *solute*. 2. The process of dissolving a substance in a solvent.

Sorption. A general term denoting all cases involving more than one of the factors, adsorption, diffusion, absorption, chemical reaction, electrical effects, surface tension, hydrolysis, double decomposition, and formation of solid and colloidal films.—*Chem. Dict.*

Spectrometer. A spectroscope (i.e., an optical instrument for producing and analyzing spectra) that is fitted with special appliances for the measurement of wave-length of spectral lines, etc.

Spontaneous Generation. Until about the middle of the seventeenth century, besides the belief in the doctrine of special creations, the belief in the spontaneous generation of various life-forms, which was handed down from antiquity, was very general; in the church as well as without. When, about 1660 A.D., Francesco Redi, an Italian court physician, demonstrated that the maggots of flies grow from eggs, and not spontaneously from putrefying matter, it was—to use the words of a writer in *Man*—"the accepted notion, that scorpions were generated by sweet basil, that frogs were brought by heavy rain, that cabbages brought forth butterflies, and that a mulberry tree could engender silkworms." But experiments to prove or disprove spontaneous generation continued to be made for two hundred years. All these experiments, however, merely had to do with sterilization. Pasteur (+1895) was foremost among the men who finally disproved the old ideas. When perfect sterilization had been secured, the belief in spontaneous generation was discarded for the belief: *Omne vivum ex vivo.*

Surface Tension. The tension of a liquid caused by the attraction exerted upon the surface molecules by the molecules lying underneath, and manifesting as the tendency of all liquids to contract to the minimum area and to act as if they were surrounded by a very thin membrane.

Tautomerism. A term introduced by Van Laar, and used to indicate that a compound can react in two different ways. *See* Isomerism.

Tetragrammaton. The four letters J H V H (or a variant of them) that in Hebrew texts represent the ineffable name of Jehovah.

Tissue. Biol. An aggregation of similar cells and fibers that shows a definite structure and is a constituent part of an organ.

Trauma. A wound.

Tropism. The inherent tendency of an organism to respond in a specific manner to an external stimulus. Thus a *heliotropic* organism, unless illuminated evenly on all sides, moves either toward or away from the source of light.

Tyndall (Optical) Effect. In a highly disperse system, the suspended particles are of a size too small to be visible under the microscope when they have diameters of the order of about 10^{-3} cms. If a powerful converging beam of white light, termed the Tyndall cone, is passed through the disperse system, the suspended particles if viewed at right angles to the direction of the beam, become visible through the light reflections of the individual particles. This is called the Tyndall optical effect. True solutions do not reflect the light.

Ultra-violet Rays. Light-rays that register beyond the limit of the visible spectrum. Ultra-violet rays are the actinic, or chemically active, rays. Ultra-violet rays exert a beneficial effect on living beings from the region of the limit of the violet to about 2,900 Å; rays of wave-lengths 2,990 Å to 2,100 Å (the middle ultra-violet) have a bactericidal action.

Urease. A ferment that decomposes urea.

Valence Electrons. Those outer electrons of an atom through the direct agency of which the atom combines with other atoms.

Van't Hoff Factor i. Van't Hoff found that for many very dilute solutions the osmotic pressure is the same as the gaseous pressure which the substance in solution would exert in the gaseous state, at the same absolute temperature and occupying an equal volume. Van't Hoff's *law of osmotic pressure* states: "Equal volumes of different solutions, at the same temperature and osmotic pressure, contain equal numbers of molecules of dissolved substances." Electrolytes, because of their dissociation into ions, give greater osmotic pressures than non-electrolytes. To bring these anomalous osmotic pressures into harmony with the general finding, van't Hoff introduced the factor *i*, the value of which is "the ratio of the total number of ions and molecules to the total number of molecules if no dissociation had occurred." *See* Osmotic Pressure, Electrolyte, and Avogadro Constant.

Velocity of Light (symbol *c*). 186,173 miles a second. (Albert A. Michelson's new figures.) All other known velocities are less than that of light; and it is held to be impossible that material velocities can exceed the velocity of light.

Viscosity. That property of gases, liquids and semi-fluids by reason of which they resist displacement, or change of the arrangement, of their constituent parts.

X-rays, Roentgen Rays. Rays that are sent out when a stream of cathode rays (electrons) strikes the opposite walls of a vacuum tube. X-rays are similar to light. "Today," says Sommerfeld, "we speak of Roentgen-light, and distinguish it from visible light only through its greater hardness (penetrability).” (Great hardness means short wave-length, or high frequency; soft rays mean greater wave-length, or lower frequency.) According to Millikan, the hardest X-rays have a wave-length of 0.1 Å. It has been shown by Barkla that every element when made the anti-cathode in a discharge tube, will emit its own characteristic X-rays. These can be photographed by employing a suitable spectrometer, and the photographic plate will show lines that are characteristic for the element, and that are analogous to the spectral lines in an ordinary spectrum. The “hardness” of the X-rays increases with increase in the atomic weight of the element. Much brilliant work has been done in research upon X-ray spectra. The work of Laue, who (in 1912) introduced the use of the crystal grating, is a landmark in the study of X-rays. The Braggs—Sir W H. Bragg and his son W. L. Bragg—stand out for their spectrometer and their determination of the wave-lengths of the X-rays of various metals. Notable work has been done by Siegbahn, De Broglie, W. Duane, A. W. Hull, D. L. Webster and Harry Clark, and many others. Henry Moseley’s study of the wave-lengths of the characteristic X-rays of most of the elements, resulted in his classic demonstration (1912) of the arithmetic progression in the natural series of the elements. With the aid of the modified Bohr theory of the atom, the spectral lines of the elements are slowly being deciphered, A. Sommerfeld leading in this extremely difficult research.

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