THE UNITARY PRINCIPLE IN PHYSICS AND BIOLOGY

By the same author

ARCHIMEDES, OR THE FUTURE OF PHYSICS

CRITIQUE OF PHYSICS

THE NEXT DEVELOPMENT IN MAN

EVERYMAN LOOKS FORWARD

LANCELOT LAW WHYTE

THE UNITARY PRINCIPLE IN PHYSICS AND BIOLOGY

Effectus *non* aequat causam.

C'est la dissymétrie qui
crée le phénomène.
P. CURIE

NEW YORK: HENRY HOLT AND COMPANY

Printed in the United States of America

First Printing

CONTENTS

PREFACE

THIS WORK springs from a conviction of the unity of nature, expressed here in a single principle.

In its earliest form this conviction was merely the sense of a hidden unity of form in nature, which the intellect had not yet identified. At that stage it had little value, except in creating the need to find a rational justification for the arational feeling.

Soon I realized that the discovery of a universal form of process was hindered by the intellectual separation of the processes of subjective experience from those of the external world. It was necessary to bring into closer relation the scientific conception of the forms of external nature and the subjective sense of the forms of experience.

This in turn led to the recognition that the methods of exact science had paid inadequate attention to the irreversible or *one-way* character of process, which is unmistakable in the subjective realm, but is also evident in many inorganic and organic processes, such as those in which form is developed. I expressed this view in a sketch of the outlook of the sciences, entitled *Archimedes, or the Future of Physics* (1927).

The next step was the observation that one principle only could account for the development of regular spatial forms: the principle *that asymmetry decreases in isolable processes.* This concept of one-way process appeared to me to be the most general conception of spatial process conceivable at the present time, so that all other types of process should be capable of being represented as special cases. I called it the *Unitary Principle* and determined to use it as the basis of a comprehensive scientific method.

With this in mind I surveyed the basis of contemporary physical theory, on the assumption that the time was ripe for a radical revision. But no constructive results followed, and in *Critique of Physics* (1930), which reported this survey, the unitary principle was only briefly mentioned.

During the subsequent years the decay of Europe drew my attention from special scientific problems, and the belief grew in me that civilization could only be saved through the discovery of a universal method of thought providing the basis of a unified humane science. Moreover I could not escape the conviction that the unitary principle must provide the basis for that universal method of thought.

This was the theme of *The Next Development in Man* (1944),* where I used the unitary method to interpret the present human situation. Though essentially a speculative essay in the philosophy of history, that book defines the historical context which renders the present scientific work both possible and necessary.

In the Appendix to *Next Development* it was stated that certain elements were required to complete the unitary system of thought. The present volume is an attempt to supply a first outline of one of these elements, the unitary theory of organism, and to indicate the lines along which another, the unitary theory of physics, must be sought. I found that it was necessary to cover part of the field of physics in a preliminary manner in order to provide a basis for the approach to a theory of organism. This work therefore includes both a general introduction to the unitary method and a more detailed application of the method to the problem of biological organization.

The two books are thus intimately related, but I wish to point out that an eventual confirmation of the unitary theory of organism, or of the unitary method in exact science, would not of itself give objective authority to the general historical interpretations of the earlier work.

The outline of a general theory of organism presented here is provisional in the sense that it is neither developed with mathematical rigor, nor contrasted with alternative theories in relation to particular sets of facts. But it is not an essay in speculative philosophy or in merely terminological synthesis, since it is open to further development and to experimental test in relation to special problems. The reader is invited to consider this work as defining a line of advance; the next stage will require mathematical formulation and detailed application to particular problems.

In other circumstances it might have been preferable to wait until the unitary principle could be justified by exhaustive application to one restricted problem, such as the biochemistry of protein synthesis. But I have decided to publish this general

* Published in the United States in 1948 by Henry Holt and Company.

theory of biological organization as a draft, so that if it proves of value I may be able later to issue a revised, definitive formulation.

I regard this book as part of a co-operative and convergent movement in all the sciences, which is now at full flood. Apart from the emphasis on the unitary principle there is probably little new in it, and its dependence on much recent work, particularly in biology, is obvious. Owing to the wide range covered it is impossible to give references in the manner appropriate to specialized scientific studies. But I cannot forbear to mention those who for me have thrown most light on the foundations of exact science: Bohr, Bridgman, Broad, Curie, Eddington, Einstein, Heisenberg, Henderson (L. J.), Mach, Planck, Russell, and Whitehead. Nor those who have been my main teachers in biology: Adrian, Astbury, Child, Coghill, de Beer, Herrick, Huxley (J. S.), Jennings, Lashley, Lillie, Needham, Pauling, Seifritz, Waddington, Weiss, and Woodger. In § 5, I have given the most important references to those whom I consider as predecessors or collaborators on the main path toward unitary science. I wish also to thank M. R. A. Chance, M. W. Goldblatt, C. C. L. Gregory, M. Newfield, J. Stern, L. V. Bertalanffy, and finally my wife, for valuable personal help, and to place on record my debt to the friendship of the late H. T. J. Norton.

During the past few weeks, since the text of the book was completed, I have had the great pleasure of receiving from Prof. A. Sellerio * of Palermo and Dr. P. Renaud * of Paris

* The relevant papers, to which I wish to call the attention of those interested in fundamental physical principles, are:

A. Sellerio. (1) "Entropia, Probabilità, Simmetria." *Nuovo Cimento.* May, 1929. (2) "Les Symétries en Physique." *Scientia.* (Fr. Transl.) 1935, 58, p. 69. (3) "Il Concetto di Simmetria nella Fisica." *Rivista di Fisica, Matematica, e Scienze naturali.* July, 1936.

P. Renaud. (1) "Sur une Généralisation du Principe de Symétrie de Curie." *Comptes Rendus.* Paris, 1935, p. 531. (2) *Analogies entre les Principes de Carnot, Mayer, et Curie.* Exposés. Hermann, Paris, 1937. (3) "Expression analytique du Principe de Curie généralisé." *Revue Générale des Sciences.* Paris, Dec. 1939.

Two of these (Sellerio 1935 and Renaud 1935) were already known to me and are referred to in § 5.

I wish also to recommend for an introduction to the theory of symmetry: (a) Curie's classic paper (see § 5); (b) F. M. Jaeger, *Lectures on the Principle of Symmetry,* 1917; and (c) H. Ollivier, *Physique Générale.* 1921-3, Vol. I, last chapter.

copies of two important series of papers on the principle of decreasing asymmetry in mathematical physics, extending the work of Curie on the symmetry properties of physical phenomena. These papers cannot be discussed here, but a preliminary study and comparison with the present volume shows that during the last twenty years three workers have independently reached certain identical conclusions regarding this principle, while differing in other respects. Though some of the results must be regarded as tentative and as still awaiting adequate expression, the range of agreement is striking and provides support for the argument of this book. Moreover, the ideas of Sellerio and Renaud should aid progress toward a final reconciliation of the unitary principle with mathematical physics.

London. February, 1948. L. L. W.

INTRODUCTION

Science is in need of a new foundation establishing unity and order in knowledge. Specialized research has long outrun synthesis and during this century has entered realms lying outside the scope of earlier fundamental principles. Only the discovery of a theoretical principle more comprehensive than any of the past can reveal the significance of the facts which are already known.

The need is equally great in physics, in biology, and in psychology, though for different reasons. Physics has had a reliable foundation, but has outgrown it. The problems with which physical research is now occupied require fundamentally new conceptions, but these have not yet been found, and theory has to make do with Newtonian ideas, modifying them to meet situations for which they are unsuited. The result is not surprising: the axioms of physical theory are now abstract formulae without immediate physical significance, fundamental theory has become embarrassingly complex, and the mathematics used is often intractable. These are signs that new methods are necessary.

The position in biology is different. We may here neglect the vitalistic and overteleological schools of thought which have rightly emphasized the working unity of the organism, but have made little contribution to exact knowledge. Apart from these the modern science of biology rests mainly on foundations supplied by physics. But a critical moment has been reached. Theoretical biology now faces the task of explaining the general properties of organisms, such as synthesis, differentiation, cyclic function, self-regulation, and adaptive modification, in terms of the structural patterns of living protein. The problem of the relation of organic properties to physical structure must now be solved, if biology is to advance.

Yet here there is a curious situation. At the very moment when exact biology has come into a closer relation to physical theory than ever before and has a special need to clear physical principles, physics has lost its own fundamental clarity. Biology looks to physics, but physical theory cannot give an adequate lead, for it is occupied in a basic reorganization and does not yet see its own way ahead.

However, this coincidence of two crises may be a favorable sign. Many biologists have suspected that the foundations of classical physics lack some element which is essential to biological theory, for the value of every physical model has sooner or later been exhausted, and the nature of biological organization still remains obscure. It is therefore possible that the crisis in physics is related to the crisis in biology, and that both sciences must now move together on to a new common foundation.

In psychology there is a similar but more complex situation. Psychological theory has so far lacked a unified foundation, and has relied on ideas drawn mainly from three sources: subjective experience, biological theory, and the methods of exact science. These methods of approach emphasize three aspects of man: the subjective and teleological, the functional and adaptive, and the physical and quantitative aspects respectively. Each aspect is necessary, and psychological theory continues to use ideas drawn from these three independent sources.

This confusion of concepts is now obstructing progress. Yet the different aspects of human psychology which are covered by the subjective, biological, and physical approaches cannot be combined into a single theory, because of the conceptual dualism of mind and body. Both the practicing psychiatrist and the psychological theorist are aware of the need of concepts which avoid the distortion inherent in the dualistic language. Yet the transformation to a single view cannot be accomplished by a movement within psychology alone, for the relations of psychology to biology and to physics are also deeply involved.

It seems that what is required is not the discovery of a new fundamental law lying within the present field of any one of the three major sciences, but the identification of a principle underlying all three, and providing a new foundation for the whole of science. The new unifying principle must go beneath the shaken foundations of physics to find a broader basis for a unified science.

That is a legitimate aim for research. But how can theoretical inquiry be guided toward it?

In facing the unknown the theorist has one weapon: his conviction that nature is simple, that a universal order awaits discovery. This conviction can only be justified by its results, and its source must lie in the property of mental processes whereby they tend to establish simple relationships within complex phenomena. Nature is to all appearance so complex that no reasonable man would spend himself in exploiting the assumption that nature is simple, unless he were already convinced of its truth. The conviction may be an illusion, but it is indispensable to theoretical endeavor, and it has borne fruit in the past. Without this conviction nothing can be achieved; with it everything is possible—if it is exploited to the full.

If the aim is a simple unified science, the standard of simplicity must be set as high as the imagination can reach. We can express this severe standard by demanding that the unified theory shall display the highest *universality, immediacy,* and *elegance,* in addition to the *power of prediction* which distinguishes scientific from philosophic theory. The significance of these terms must be explained.

Universality means validity in all fields. *All processes are to be represented as variants of one universal process.* The aim is to reduce all causal processes to special cases of one general type of causal process. But provisionally we shall neglect what are called the processes of consciousness, and deal only with observable processes manifestly set in space and time. Mental processes will be excluded from explicit treatment in this work, as a principle of strategy rather than a limitation of ultimate aim. But to protect this flank of the argument, and to maintain liaison with those who will ultimately be disclosed as our allies in the field of psychology, we shall briefly indicate (in § 10) the bearing of the argument on mental processes.

Immediacy means possessing direct intuitive significance, and is the opposite of abstractness. More precisely, immediacy in a theory implies that *the formal relationships expressed in its fundamental axioms must be recognized as corresponding to directly experienced or observed relations.* This applies not only to the concepts underlying the theory, but also to its procedures. The fundamental concepts must be based on relations such as the perception of spatial symmetry and asymmetry and the awareness of temporal succession, which represent components of immediate experience. In addition, the actual course of any process must correspond to an evident logical and causal necessity. We shall see that this means that the law governing all isolable processes must possess a unique character which can be seen to follow from the condition that they must be capable of isolated treatment.

Mathematical elegance was interpreted by Henri Poincaré as *"elements harmoniously arranged so that the mind can without effort take in the whole without neglecting the details,"* and this may be taken as indicating the nature of all elegance, whether aesthetic, theoretical, or functional. In a universal theory elegance implies the highest self-consistency and simplicity—all phenomena, large and small, complex and elementary, being revealed as expressions of one comprehensive principle. For example, an elegant theory of organism must display the functional elegance of living systems whereby all their parts co-operate to maintain all the properties of the whole.

The conviction of the causal unity of nature carries with it the view that any theory possessing this high degree of comprehensiveness and simplicity will also possess the predictive power necessary to a scientific theory. For that conviction implies that nature is so profoundly one that any theory which fails to recognize its unity must somewhere lead to incorrect predictions. The aim is not a merely terminological synthesis or verbal unification of theories, but a reinterpretation based on more comprehensive principles and leading to new predictions distinguishing the synthesis from the earlier partial theories.

No theory has hitherto satisfied these four criteria in respect of the contemporary field of scientific knowledge, and it is important to appreciate their significance. The normal procedure of theoretical advance consists in the passage from narrower to wider generalizations, and does not involve any prejudice either to the validity of existing foundations or to the scope of research. But a sudden transformation of the whole of scientific theory on to a new foundation satisfying these criteria implies a revolution leading to a phase of completed theory and of full theoretical understanding, within the limitations set by the contemporary techniques and capacities of the scientific intellect. It means, for example, that the fundamental laws of quantitative physics will be finally established, being not only confirmed experimentally, but also derived theoretically from deeper lying principles. Fundamental physics would thus, for a time at least, become a closed subject without either theoretical or experimental problems inviting further research.

It is unnecessary to consider in detail the consequences of this situation, but since it would follow from a successful development of the method here proposed, one observation is relevant. There are some who consider the possibility of complete knowledge, even within limited fields, as so absurd or so distasteful as to lead them to resist any attempt to prepare for a comprehensive synthesis. This attitude may have its advantages for the individual who adopts it, but it is alien to the spirit of science. Research must go forward in every possible direction; it cannot renounce its task today lest it should discover tomorrow that it has completed a part of that task. A universal theory would only tend to stifle experiment in so far as experiment itself had confirmed the validity of the theory.

But once again, how can theoretical research proceed? The aim is a theory of highest universality, immediacy, and elegance. How does the formulation of that aim guide the advance? A new conception may arrive by a sudden happy intuition, but it will be of little value unless a compelling argument can be found which leads to it from earlier ideas. Where can that argument be found?

A hint can be gained from the history of physical thought. The advance from narrower fundamental principles to those of greater generality is always achieved by the consideration of issues which had previously been regarded as so general as to lie outside the realm of science proper. For example, about 1860 the conceptions of matter and of motion in the absolute space-time frame were regarded by many as beyond the range of scientific analysis. Yet fifty years later these conceptions had been brought within the realm of exact analysis and observation, and had been transformed into the electrical theory of matter and the relativity theory of motion.

This method of advancing by a critical analysis of the assumptions implicit in earlier conceptions is as old as human thought, but it has recently come to be known as the epistemological method, particularly in relation to the recent speculative theories of Eddington and Milne. For example, Eddington attempted to derive a fundamental theory of the physical universe from the single assumption that measurements of certain kinds are possible.

This theory is the latest application of an ancient and legitimate method, and if it satisfied our criteria there would be no call for further theoretical research. But Eddington's theory displays the following limitations: (1) It is not universal in a full sense, for it is restricted to the metrical aspects of physical processes, and neglects both formative processes and the phenomena of biology and psychology. (2) It lacks immediacy, its fundamental concepts displaying a fantastic degree of abstraction. (3) It lacks elegance; for example, the interrelationships of electromagnetic, quantum, and gravitational phenomena remain obscure. (4) It does not lead to new lines of research. Eddington's *Fundamental Theory* provides an example of the brilliant application of inadequate criteria. In assuming that physical theory is concerned only with results of measurement it remains essentially within the Newtonian foundations, and therefore fails to provide new fundamental concepts.

To discover the new conception which is required it is necessary to go even deeper into the roots of physics and of science as a whole. We must use the principle that an analysis of the nature of any particular kind of knowledge, including the way in which it is obtained, must, if properly carried out, throw light on that knowledge. Since the aim is a universal science we have to discover the needed universal conception by considering the general nature of scientific knowledge. So long as it is assumed that all scientific knowledge expresses the quantitative result of a process of measurement we remain within the old foundation; if a radical advance to a unified science is desired a wider conception of scientific knowledge is necessary. To recover unity we must discover the indispensable criterion of scientific knowledge, the most general assumption which could provide the basis for a science. Only in this manner can universality be attained.

This point is of crucial importance. The search for a universal foundation has become an inquiry into the nature of science. It is necessary to discover the minimum requirement for a science, the most general possible kind of scientific causality. Every arbitrary restriction is to be eliminated. The universal science must be the most general possible science conceivable to twentieth-century minds compelled to think in terms of three-dimensional space and temporal succession.

The inquiry must open with the question: What is the reliable inference which can be drawn from any observation, if all existing scientific concepts are suspect as containing arbitrary restrictions? Bertrand Russell has given one part of the answer: *it is only structure which we can validly infer from perceptions, and structure is what can be expressed by mathematical logic, which includes mathematics.* (See § 5.) More precisely structure is a complex of relations possessing certain logical properties. A relation is said to be *asymmetrical,* if it is incompatible with its converse; for example, if *a* is the husband of *b*, *b* cannot be the husband of *a*. *Husband of, greater than, later than,* are examples of asymmetrical relations. Again, a relation is *symmetrical,* if it implies its converse; *spouse of, simultaneous with,* and *equal to* are symmetrical relations.

These logical properties are of great importance, but while mathematical logic is concerned with logical structure, science is interested in *causal or space-time structure.* Any particular model of physical structure may contain unnecessary elements or actual errors; what we can be certain of is only the immediately observed space-time relation-structure. Our inquiry must therefore be into the relation-structure underlying physical structure, and we have to formulate the most general possible causal relation-structure that can provide the basis of a science. For only in this way can universality and immediacy be insured.

This approach through the logic of relations leads at once to the observation that the asymmetrical relations of scientific theory are more general than the corresponding symmetrical relations, in the sense that the latter can be represented as limiting cases of the former. Here one example will suffice. If an event B is later than an event A, this asymmetrical relation *later than* can cover an extensive series of different temporal separations of the two events. This series has a unique limit, or limiting case, in which the asymmetrical relation discriminating the earlier from the later event can no longer be identified, and A and B can be regarded as simultaneous. Thus the symmetrical relation of simultaneity can be defined as the limit of a series of asymmetrical relations of succession. But the reverse procedure is not possible, for the symmetrical relation of simultaneity does not discriminate between the two events, and is inadequate to define an order of temporal succession between them. The asymmetrical relation is logically more general than the symmetrical relation, and the latter can be treated as a logically degenerate (i.e. less complex) special case of the former.

This higher generality of the asymmetrical relations characterizes all the fundamental spatial and temporal relations of scientific thought: the relation *greater than* is more general than *equal to,* succession is more general than simultaneity, and spatial asymmetry than spatial symmetry. It follows that the science of the asymmetrical relations of space-time phenomena is more comprehensive than the science of symmetrical space-time relations. For example, the theory of one-way processes is more general than, and can contain as a special branch, the theory of reversible or cyclic processes.

The task, as now seen, is to discover a single principle representing the observable, causally necessary relation-structure of all one-way processes. For only thus can elegance be combined with universality and immediacy.

This argument will be retraced in greater detail in Chapter I. But it can be seen at once that the application to the basis of exact science of the Russellian concept of relation-structure opens up a new field of theoretical inquiry: the study of the asymmetrical relations inherent in observable phenomena, and their relation to the symmetrical relations which have constituted the effective content of all exact concepts from Galileo, Kepler, and Newton, to Heisenberg, Schrödinger, and Dirac (excluding only the concept of entropy).

Unitary Theory is the result of applying these criteria and methods to the facts and theories of contemporary science. There is reason to believe that it expresses the most general kind of theory conceivable today, and it may therefore prove to be of wide scope, even if the special applications attempted here should prove mistaken. Particular applications are subject to personal error, but the method is more comprehensive than the classical and opens a new realm to the scientific intellect, for here at last the limitations of Newtonian quantitative concepts are wholly overcome. The aim is now a theory of tendency containing the theory of conservation and quantity as a special branch, a calculus of one-way processes including the limiting case of quantitative physics.

As presented here unitary theory is a method in course of development, for it is not yet mature. The reader may therefore regard this volume as a draft formulation submitted for his criticism and co-operation, with a view, first, to checking and improving the present argument, and second, to developing it further. In the present state of knowledge a first formulation of a comprehensive theory must be provisional, for the vast range of science can no longer be comprehended by one mind. The more completely a specialist is master of his own field, the less likely is he to see the whole of science in balance; while the more free a speculative thinker is from the limitations of any field, the more probable is it that, even if his theoretical intuition is valid, he will apply it wrongly to particular facts. The synthetic thinker must be daring in his general aim, but modest in respect of special knowledge. The co-operation of synthetic theorist and practical specialist is indispensable, and this work, it is emphasized, is a draft submitted for comment.

The *Unitary Principle,* which is the key to the new method, is introduced in Chapter I. In order to provide an adequate basis for the subsequent argument the principle is at once brought into relation to physical, biological, and mental processes. While the treatment of the last two is provisional, the analysis of physical theories and concepts leads to a program of research in theoretical physics. This chapter presents the general foundation of the unitary method.

Chapter II is devoted to the development of certain *unitary concepts* of wide scope, which arise in the application of the principle to special situations. This provides an introduction to unitary theory as a nonquantitative system of inference applicable to space-time processes.

In Chapter III unitary theory is applied to interpret the chief properties of living protein as the main constituent of *the physical basis of life.*

The unitary *Theory of Organism* is then developed in Chapter IV. Here the aim is to formulate the necessary and sufficient basis for a general theory of biological organization, excluding heredity and evolution. The common characteristic of all living systems is identified in a *formula* *for organism,* first in the special form applicable to animal organisms, and then in the contrasted forms covering green plants and primitive organisms. In this chapter the most important general characteristics of animals, plants, and primitive organisms are shown to represent variants of one general formula for organism. The chapter ends with suggestions for research.

Since this work is an introduction to a theory in course of development, methods are used which would not be appropriate to a definitive, rigorous formulation. Terminological pedantry has therefore been avoided, and current terms are used wherever this is possible without undue risk of misinterpretation, even though their meaning may be slightly modified under the unitary principle. Every sentence carries the implicit limitation, "under the unitary principle," except where that is obviously excluded. For example, "necessary" refers to logical or causal necessity under the principle and within any stated conditions.

The supreme condition, which is implicit throughout this work, is that the simplicity of nature is evident in the universal validity of the unitary principle as representing the causal relation-structure of all isolable one-way processes. We must now set out to examine what this implies.

THE UNITARY PRINCIPLE IN PHYSICS AND BIOLOGY

CHAPTER I

THE UNITARY PRINCIPLE

1. Causality

THE AIM of scientific theory, on which all the applications of science depend, is to represent with increasing comprehensiveness the universal order of nature. This is achieved by selecting from the complex totality of process simpler processes which can be represented separately as if they were isolated. The method of selection is regarded as successful if it leads to a simpler representation of observed phenomena in which many different processes are shown to be variants of a single form.

If scientific theory becomes unduly complex this may be the result of an inappropriate method of selecting individual processes for separate representation. It is then necessary to examine the method in use, and to consider what alternative is available. The complexity of contemporary theory may be due to the continued use of a method of selection which is inappropriate to the present scope of science.

The basis of exact science has not yet been adequately examined from the point of view of the criterion used for selecting isolable processes. For example, the principle of causality has been extensively analyzed, but the value of interpreting it as *a rule for selecting isolable processes* does not appear to have been recognized. In relation to scientific theory the principle of causality and the principle of sufficient reason are equivalent; they both assert that every effect must have a cause. (The recent breakdown of the four-co-ordinate quantitative determination of individual atomic events in quantum statistical theory is here provisionally neglected, since the unitary theory of one-way processes aims at providing a causal description which does not assume metrical co-ordinates, but derives them when special conditions are satisfied.) This implies that a particular process can only be represented separately from the rest of the universe while it is causally self-contained, so that every effect can be traced back to an internal cause as far as some selected starting point.

Thus the principle of causality is a general condition which must be satisfied in selecting isolable processes: those processes are isolable for the purpose of scientific representation which display internal causal continuity. If any process displays at some moment an arbitrary feature, in the sense of a characteristic which cannot be traced to an earlier cause within the process, then the process cannot be represented in isolation, for the external cause must be included. Internal causal continuity means absence of the arbitrary appearance of new characteristics, and there must be internal causal continuity in any isolable process.

This condition cannot, however, be applied in a critique of the fundamentals of exact science until it is clarified by an analysis of the nature of the relation between cause and effect. The precise significance of causal continuity is not evident until we are clear what is meant by tracing an effect to a cause. An arbitrary feature is one which cannot be traced to an earlier cause within a particular process. But what is the exact condition which must be satisfied in this tracing of causal continuity? What kind of cause is necessary to account for a given effect? Until this question is answered in respect of each science we do not know what criterion that science is using for the selection of isolable processes. The most fundamental characteristic of any science is the type of cause-effect relation which it assumes, and the class of systems which it thereby selects as isolable.

The simplest, though not the most general, assumption is that *the cause equals the effect*. On this view, the causal continuity of an isolable process is to be traced in a perpetual sequence of equal causes and effects constituting an aspect of unchanging permanence within the changing appearance. The rational link between earlier and later states is to be found in a principle of permanence, and in quantitative science this method acquires precision in the principles of the conservation of particles, of mass, and of energy. Process is to be understood by abstracting from it an invariant which is itself timeless. On this assumption the cause-effect relation is symmetrical; the relation between the earlier and later states of any process is symmetrical in respect of the causal factors which determine its course. The particles and the total mass and energy are the same in earlier and later states.

The assumption, that cause equals effect, dominated the later phases of Greek philosophic thought and determined the entire development of exact science. Plato asked "How can that be real which is never in the same state?" Aristotle held that "in pursuing the truth one must start from things that are always in the same state and never change." Greek atomism and, until recently, modern atomic theory found the real basis of nature in permanent and unchanging constituent units. Quantitative physics abstracted ideal reversible processes from observed phenomena and constructed quantitative energy-functions which were conserved in the processes which is treated as isolable. J. R. Mayer based his formulation of the principle of the conservation of energy on a general law of the quantitative indestructibility of causes.

So remarkable has been the success of this assumption that few have noticed that it is an assumption, and fewer still have seen grounds to question its adequacy. Some have expressed the view that scientific method can only cover the permanent and quantitative aspects of phenomena. Others have even suggested that the human intellect is biologically so conditioned that the intrinsic character of process must for ever escape rational comprehension. We shall see that these views are wrong. The causal continuity which relates earlier and later states in any process may itself be a form of process, a universal pattern of one-way change which recurs everywhere. The invariant factor in process need not itself be timeless, but may consist in a universal tendency toward a defined end-condition. The clue to the order of nature may not be a principle of permanence, but a universal pattern of process displaying an invariant one-way tendency. For it is not change, but only arbitrary change, which eludes the rational intellect.

2. *One-Way Causation*

THE AIM of this inquiry is to develop a more comprehensive scientific method which includes the classical method as a special case and thus can account for its partial success. Since the classical method was based on the equality of cause and effect, we require to find a more general cause-effect relationship which includes equality as a special case. The new method must therefore be based on *the inequality of cause and effect.*

Inequality is a more general relationship than equality, in the sense that it covers a wider field and approaches equality when the inequality becomes vanishingly small. This is an example of the fact that the field of an asymmetrical relation, such as *greater than,* often includes the corresponding symmetrical relation, here *equal to,* as a special limiting case. Thus the field of inequality includes equality, nonsimultaneity includes simultaneity, and spatial asymmetry includes spatial symmetry, each as a logically degenerate limiting case of a wider field of relations. The asymmetrical relations of quantity, time, and space (*greater than, earlier than,* etc.) are more general than, and can be used to define the corresponding symmetrical relations (*equal to, simultaneous with,* etc.) which form the basis of quantitative physics. The science of inequality, succession, and asymmetry—which has still to be created—is more comprehensive than the science of equality, reversibility, and symmetry, and can include the latter as a special branch. The science of quantity and equations is a part of the more general science of order.

We have therefore to discover the most general possible relation of inequality between cause and effect which can provide a basis for science. This is equivalent to discovering the necessary and sufficient characteristics of scientific causality.

The principle of causality requires that those processes alone are isolable in which there is no appearance of new arbitrary features, i.e. of features which cannot be traced to earlier causes within the process. But we have seen that this formulation does not indicate what conditions must be satisfied in tracing an effect to an earlier cause, and a closer analysis is necessary.

In an isolable process, if two components, A and B, are in every respect equivalent at any one moment, they cannot subsequently lose that equivalence. Every effect must have a cause, and by definition no internal cause which could produce a distinction between A and B existed previously. It would therefore be arbitrary for either A or B to be discriminated from the other by the appearance of some new distinction. Every distinction present at any one moment must be traceable back to earlier distinctions. If a balance is true and the weights are equal, the arm cannot swing either way; there would be no sufficient reason for it to do so.

But these illustrations of the principle of causality still do not reveal the essential characteristic of causal relations with sufficient precision for the purposes of exact science. For this it is necessary to replace such expressions as the "tracing of distinctions" by a more exact terminology expressing the character of the actual process of reasoning used by the exact scientist in his fundamental analysis of any phenomenon.

The fundamental intuition of the physicist and the first (necessary) characteristic of causality are expressed in the *principle of symmetry:* the symmetry of causes must be repeated in their effects, and any asymmetry of effects must therefore be present in their causes. The degree of symmetry of an isolable process cannot decrease; new asymmetries cannot arise in an isolable process. The underlying conception in this principle is that a new asymmetry would be arbitrary, and contradict the principle of sufficient reason. Expressed in more general terms this means that the procedure of nature must operate on existing distinctions, it cannot produce new distinctions where none existed before. (Even the quantitative indeterminacy of atomic events cannot infringe this principle, which lies deeper than the process of measurement.)

The reverse is *not* true, however. In isolable processes new distinctions cannot arise, but earlier distinctions can disappear. For example, temperature differences vanish in diffusion processes, and structural asymmetries disappear as symmetrical structures are formed. Causal continuity must be traceable *one-way* in the temporal succession, from earlier to later states; it need not necessarily be traceable the other way, from later to earlier states.

This all-important fact is self-evident when it is clearly formulated. There is nothing in the principle of causality or in the principle of sufficient reason, properly understood, to exclude the decrease and vanishing of earlier distinctions or asymmetries; it is only the arbitrary emergence of new distinctions or asymmetries which would frustrate reason. It is sufficient if the causal continuity of processes can be traced one way, from past to present and future, i.e. from earlier to later states; it need not be traceable from later to earlier.

Though its far-reaching consequences have not yet been appreciated, this fact has long been known. In 1873 Clerk Maxwell pointed out that in diffusion processes prediction is possible, but past states cannot in general be inferred from present ones, since past distinctions may have disappeared without trace. We can predict that hot and cold fluids when mixed will reach a uniform temperature, but from this end-result we cannot infer the original difference of temperature. "The prophetical problem is always capable of solution, but the historical one, except in singular cases, is insoluble."

In 1894 Pierre Curie stated the same principle more generally as an intrinsic characteristic of physical causality: *an asymmetry in causes may disappear in their effects, so that* *the symmetry of the effects may be greater than that of their causes.* The number of elements of spatial symmetry cannot decrease, but it may increase, in an isolable process. The nature of physical causality leaves open the possibility of a one-way process in which cause and effect are not equal, later states being more symmetrical than earlier states.

Thus the first characteristic of causality, as expressed in the principle of symmetry, is necessary: symmetry is preserved in isolable processes. But the second characteristic of causality, as at present understood, is only permissive or hypothetical: asymmetry can decrease in isolable processes.

Here is the opportunity to broaden the foundations of science while retaining the necessary character of causality. Unitary theory converts this logical possibility into the axiom of a causal science of one-way processes. Just as the conservation of symmetry constituted the fundamental intuition of the quantitative physicist, so the decrease of asymmetry in isolable processes represents the fundamental intuition of the unitary scientist.

3. The Unitary Principle

THE SEARCH for a wider foundation for science is guided from two sides. On the one hand, an examination of the character of scientific causality shows that asymmetry *can* decrease in isolable processes. On the other hand, the argument will show that in a wide range of processes some asymmetry, gradient, or difference *does* in fact decrease. Thus analysis of scientific method and induction from observed processes both lead in the same direction, toward a science of decreasing asymmetry.

Moreover, this science is more comprehensive than classical physics. For if asymmetry decreases in isolable processes, there may be processes in which this decrease is vanishingly small and the observed phenomenon is therefore adequately covered by the conservation of total asymmetry. In such limiting cases effect equals cause, there is no one-way development, and conservation principles can be applied. Conserved quantities, such as ordinary energy, can be treated as special cases of decreasing or increasing quantities, such as available energy or entropy, while the reverse is not possible, for conservation principles alone cannot discriminate between earlier and later states. A science based on a principle of decreasing asymmetry is broader than, and can include, the science of the conservation of asymmetry. Theoretical analysis and induction from observations both lead toward this wider foundation.

There is therefore ample ground for considering, as the axiom of a potentially universal science, the *Unitary Principle:*

Asymmetry tends to disappear, and this tendency is realized in isolable processes.

In this formula *asymmetry* means an observable deviation from some type of three-dimensional spatial symmetry latent in a system, or in a finite part of a system. (In this work we are mainly concerned with the asymmetry of fundamental molecular structures.) *Symmetry* is invariance of finite parts of a structure with respect to rotations or translations, i.e. by the regular repetition of equivalent spatial elements. The *latent symmetry* of a system, or of a part, is the symmetry toward which it tends, in so far as it is isolable. The *tendency* of a system is the one-way process (of decreasing asymmetry), which occurs in the absence of external factors. *System* and *process* are equivalent terms. The *character* of a system or process refers to the elements of symmetry which are present, absent, and latent or developing. The principle is called *unitary* because it aims at representing all processes as variants of a single form.

The unitary use of the term asymmetry must be distinguished from the "asymmetry" of enantio-morphic (left- and right-handed) forms, which following Kelvin and Eddington will be called *chirality*. A chiral pattern is one whose mirror image cannot be brought into coincidence with itself.

Every asymmetry can be represented by a direction with sense located in the system, i.e. by a sited and oriented arrow, defining the observable deviation or distortion of the system from a specific type of symmetry. The fact of the decrease of some asymmetry may be observable when it is not possible to *measure* the asymmetry. But for convenience the asymmetry may be regarded as a vector quantity, the unitary theory of measurement being postponed for treatment elsewhere.

The unitary principle represents the isolable phase of a given process, in which the distortion due to some wider system of which the process was previously a part, is progressively eliminated as the system in question separates itself out and perfects its characteristic symmetry. Isolable systems are those which are in course of isolating themselves, and they are only observable while this process is incomplete.

Unitary science is concerned with the identification of this tendency toward symmetry in all fields. This work covers the field of physics in a provisional manner and the problem of biological organization in greater detail. In order to give the unitary principle a preliminary justification some of its applications in fundamental physics will be cited at once.

The formative tendency, or decrease of asymmetry, is present in all cases of the development of symmetrical patterns or of the genesis of regular order, whether of position or orientation. The most obvious examples are the growth of crystals, the formation of symmetrical molecules, the extension and multiplication of specific molecular patterns, and the formation of complementary patterns. In these cases specific patterns are formed and extended. A more fundamental, but less well-known class of examples are those processes in which elementary physical vectors tend to take up states of identical or regular orientation, as in the interaction of electron spins, polar valencies, and dipole axes; the induction of electrical polarization; etc. These cases illustrate the development of states of ordered orientation.

In yet another class of examples a polar distortion of an existing structure tends to decrease. We shall suggest that this general class includes all cases of the decrease of electrical potential energy, such as the approach and neutralization of opposite electrical charges. Complementary to and overlapping with these are the cases of the decrease of magnetic potential energy, in which it appears that angular distortions (of orientation) tend to decrease.

Wherever states of minimum potential energy possess a corresponding element of spatial symmetry, as is often the case, the tendency toward minimum potential energy illustrates the unitary tendency toward symmetry. But even this wide class does not exhaust the physical applications of the principle. Wherever there is a tendency toward uniformity of distribution, or equipartition, of some scalar quantity, such as temperature, there is also present a tendency toward symmetry. But in this case the scalar usually represents the average state of distortion of the fundamental structures present in any small region. The unitary tendency then appears as the elimination of an asymmetry of distribution caused by some previous external factor, and the process may be represented as the decrease of the gradient of a statistical scalar (diffusion processes, increase of entropy, etc.).

These examples require exact treatment before the unitary principle can be of service to physical theory. They are referred to here solely to justify a preliminary analysis of the logical and descriptive, i.e. nonquantitative, properties of the unitary principle.

In a vague sense the principle appears self-evident, but what is not evident at once is the remarkable comprehensiveness which results from its high logical generality.

4. Significance of the Unitary Principle

The unitary principle defines a universal method of selecting causally simple processes within the complexity of nature. It may thus be regarded equally as a proposed law of nature or as a rule for selecting isolable processes. It defines a general form of causal process of which all isolable processes must be shown to represent special cases.

The principle combines in the simplest possible formula the minimum spatial and temporal relations that are required by any general theory of process. It achieves this by using asymmetrical relations which include the corresponding symmetrical relations as limiting cases, and thus reveals finality as the most general form of causality.

In the conception of decreasing spatial asymmetry, the spatial asymmetry of observed forms is correlated with the temporal asymmetry of experienced succession. This correlation is achieved by identifying the asymmetrical relation of greater to less spatial asymmetry with the asymmetrical relation of temporal succession. No simpler or more general causal axiom can be conceived.

Asymmetry is treated as the cause of change, and symmetry as the basis of stability. Instability implies asymmetry, and stability symmetry. These interpretations carry a stage further the reduction of physics to geometry.

Mayer's indestructibility of causes is replaced by the principle that causes are eliminated by the processes which they initiate.

The tendency for asymmetry to decrease is the formative principle necessary to account for the development and stability of regular forms. In elementary isolable processes the tendency culminates in the development of stable symmetrical patterns, while in certain more complex situations it results in the rhythmic process patterns of the organic realm. This tendency covers all processes in which theoretically separate entities appear to co-operate so that form is developed, whether in the "co-operative" phenomena of the inorganic realm, or in the organic processes which were supposed by some to reveal the operation of a nonstructural entelechy. The unitary principle may be regarded as a fusion of entelechy and structure underlying all phenomena.

The principle defines a continuous phase of isolable process extended over a finite range of space and time. Each isolable phase of process begins at a threshold (§ 14) and ends at a terminus, when the asymmetry characterizing the process has vanished.

Moreover each isolable phase of process consists in the decrease and vanishing of an asymmetry originally forming a component of some more extensive process. Thus the phase of process from the initial threshold to the final terminus may be regarded as the progressive elimination of a distortion due to external factors operating prior to the threshold, when the process was not isolable.

Each isolable step consists in the separating out of a characteristic symmetry. A process is isolable in so far as it constitutes the process of isolation of a system from its setting. Symmetry is the limit which is approached as the degree of isolation of a system increases, but it is never absolute, for no isolation is complete.

Conservation principles apply to the limiting case of isolated systems and their cyclic changes. The unitary principle is more comprehensive, because it describes the process of isolation.

Moreover it describes this process both in external nature, and in the human mind applying the principle. Thus the unitary principle represents the process, both in nature as a whole and in that part of nature which we call the mind, whereby a system or its mental representation is separated out from its setting.

The complete unitary process is unobservable, because it represents the process of a system becoming unobservable. When symmetry is perfect and unchanging, it cannot be observed. But the unitary process is observable in the sense that the tendency of the system can always be identified.

The task of unitary theory is to display the unitary process everywhere. To recognize the causal development of any system it is necessary to identify the particular type of decreasing asymmetry which characterizes it.

If an existing symmetry disappears in the course of any process, that process is not isolable, and must be treated as a component of some more extensive process. If in any process a characteristic asymmetry does not wholly disappear and the corresponding latent symmetry never becomes explicit, this again must be shown as due to some larger process of which the first is a component. Finally, if new patterns arise in any process, as in biological differentiation, this must be displayed as the result of the interplay of existing patterns. All novelty must be traced to the interaction of existing forms, and all interaction must be interpreted as the development of symmetry in the extensive process comprising all the interacting constituents.

All forms of specific interaction which discriminate between systems of different structure, from the steric correspondence of chemical groups, and the formative and selective activity of antibodies, genes, and virus, to the correlation of stimulus and response patterns, express the development of a characteristic symmetry. Selective specificity always expresses a developing symmetry character in the system composed of the two interacting entities.

The unitary principle is structural; it applies to the ultimate structure of nuclei, atoms, molecules, and more extensive patterns. The properties of large-scale systems and their processes are normally to be treated as indirect consequences of the application of the principle to their ultimate structure. The principle applies in all fields, but it only applies directly to ultimate structure; statistical and macroscopic phenomena represent the indirect results of the universal operation of the principle. Thus many large-scale processes may seem, on a superficial analysis, to contradict the principle, and it is the task of unitary theory to resolve this paradox in each case.

The greatest paradox of all is that asymmetry tends everywhere to decrease, yet neither the universe nor any of its parts reaches a static end, for no system is ever completely isolable, nor isolable in any respect for ever. Every system tends to perfect its own inner symmetry, but as a component of more extensive systems it tends also to develop its symmetry in relation to its neighbors, and so to conform to the general state of the universe. But the universe is in a condition of finite asymmetry, instability, and disturbance, and every local system therefore partakes in the general state of disturbance. Every isolable system tends toward its symmetrical state, but no system remains isolable indefinitely. Nature is a disturbed system of systems, and there is never anywhere a final end to process.

Much is claimed here for the unitary principle, but no more than it is believed will be justified in the immediate future. Yet how can so brief a formula hold such power?

Because it expresses a pervasive simplicity which has hitherto been neglected. What appears simple may be merely familiar, and true simplicity may appear strange. The methods based on conceptions of permanence are familiar, but far from simple in their application to a world of process. The unitary principle is simple, but as yet unfamiliar. To minds accustomed to conceptions of permanence it must appear strange, for it selects as the invariant in change a persisting tendency. In that strange simplicity lies its power.

5. History of the Principle

The transition to the unitary basis from the foundations of exact science laid by Galileo, Kepler, and Newton implies an abrupt step forward into a more comprehensive realm of theory. The facts remain unchanged, but the scientific description of them is subject to a sudden adjustment in accordance with the new perspective. Every scientific concept has in some degree to be reinterpreted, and there is no halfway house between the old and the new.

This element of intellectual discontinuity is inherent in a fundamental revision, yet it is desirable to recognize the wide field of continuity which exists between the old and the new in order that the integrity of the scientific tradition may not be prejudiced. It is possible to understand a specialized theory without knowledge of its history, and logical clarity implies the elimination, at some stage, of any concern with vague or mistaken conceptions which may have played a part in the development of a theory. But the sudden adjustment which is necessary in passing from the quantitative axioms of classical physics to the unitary principle penetrates deeply into the scarcely conscious assumptions of scientific thought. This produces an intellectual disturbance which will not be entirely harmless until the whole of quantitative physics has been developed on a unitary basis.

In the meantime it is important to look back and observe how closely the new method links up with certain earlier observations which were not adequately covered by the basic axioms of classical physics.

A comprehensive principle cannot crystallize without extensive preparation. Many of its specialized applications will have been noticed, though without recognition of their connections and common origin, long before the principle is expressed in its most general form. The new formulation throws light in many directions because it reveals these apparently distinct phenomena as special cases of a common principle.

The following aspects of the unitary principle have already been recognized: the vague conception of a formative process; the view of process as a movement from instability toward stability; the interpretation of instability as due to differences and the association of stability with symmetry; the possibility of one-way causation; and the importance of asymmetrical relations. Each of these has been discussed separately during the last hundred years, but it is only through their fusion in one constructive principle that their full significance becomes evident.

The idea of a formative process is latent in ancient thought, but was perhaps most clearly expressed by Aristotle, who conceived the world process as a striving after form. His conception of the realization of potential form is also relevant, though limited by its special philosophical context. These vague suggestions of a formative tendency reappear two thousand years later, and acquire increasing precision in Goethe's conception of the *Gestalt,* Blumenbach's *Bildungstrieb* (nisus formativus) of the organic realm, Haeckel's and Roux's formative process, the morphogenetic studies of recent exact biology, and the orienting forces involved in the formation of molecules and crystals and in organic synthesis and organization.

In the succeeding sections we shall refer to this vague conception of a formative process as the "development of form" in order to distinguish it from the precise concept expressed in the unitary principle.

The conception of process as leading from instability toward stability is implicit in Leonardo da Vinci's observation that motive forces seek rest and act in being themselves consumed. Similar views became widespread during the second half of the nineteenth century after the discovery of the Second Law of Thermodynamics. Spencer recognized a widespread tendency to equilibrium. Fechner suggested that every system moves from unstable to stable states. Petzoldt placed great emphasis on this idea, and expressed his conviction that "the principle of the tendency to stability is the most general law of process; it displays all process as directed." The tendency for instability to develop toward stability is from one point of view self-evident, and in this vague form the conception has little constructive value.

Mayer suggested that instability is evidence of the existence of differences. He called these differences "forces," and regarded the various kinds of physical forces as due to the presence of differences of various types. Mach called attention to Mayer's ideas, and to similar suggestions by Avenarius and Hering, and himself held that "without differences nothing ever happens."

But an important element was lacking in these conceptions of a one-way process leading toward the elimination of differences in a stable end state. Mallard was possibly the first to associate stability with spatial symmetry: *"Cette tendance vers la symétrie est une des grandes lois de la nature inorganique. . . . Elle n'est d'ailleurs qu'une manifestation de la tendance plus générale de la Nature vers la stabilité."* Mach expressed this idea independently and even sought to demonstrate that certain classes of stable systems must necessarily possess elements of spatial symmetry. Though his argument is open to criticism, Mach's discussion of the problem and his interest in symmetry and asymmetry mark an important advance toward the unitary principle.

Another critical step forward was made by Pierre Curie, though apparently he did not realize the import of his own observation. In 1894, in a classic paper on the symmetry of physical magnitudes, he formulated the general methodological principle that effects can be more symmetrical than their causes without infringing the principle of causality as required by exact science.

If Curie unknowingly pointed the way, Russell cleared the road. His emphasis on space-time relation-structure as the only valid inference from perceptions banished at one stroke the prejudices of centuries, and his work on asymmetrical relations as the source of serial order invited its application in science.

By 1920 the ground had been prepared. The formative tendency, the movement toward stability, the linking of stability with symmetry, the possibility of a one-way causality, and the conception of relation-structure as underlying physical structure—all these ideas began to converge within a new scientific outlook: the study of process as a pattern of changing relations. A great current of thought, culminating in Bergson and Whitehead, had established for many the primacy of a historical or one-way process. But this one-way process still awaited scientific definition.

The first hesitant crystallization of the new principle was achieved by W. Koehler, who in 1924 called attention to the observations of Mach and Curie, and formulated the conception that "in an isolated process asymmetries disappear as a constant state is approached." This idea, in the vaguer form of a tendency toward the development of simple configurations, provided the basis for the Gestalt school of the psychology of perception. But Koehler's formulation of the unitary principle did not bear fruit, except in encouraging the next attempt.

In 1866 Haeckel had asked: "Where are the morphogenetic laws of nature?" and the question was equally relevant in physics, biology, and psychology. It seems that the method by which the answer must be sought was defined in 1931 when the unitary principle was first asserted as a comprehensive rule. The general *problem* of morphogenesis was transformed by converting it into an *axiom*: if any general rule exists covering the production of symmetrical patterns it must have the form: more symmetrical follow on less symmetrical states. But at that time no use was made of the new principle.

The next known publications dealing with similar ideas are by Sellerio * and Renaud *, who in 1935 independently called attention to Curie's paper. Renaud reformulated Curie's observation with greater generality and precision. Sellerio went further and sought to bring two great principles of tendency, Curie's formal principle and the entropy principle, under one rule of "the increase of the structural symmetry of an isolated system." Sellerio's cautious analysis aided the development of the unitary principle during the subsequent years.

REFERENCES

to the more important known publications relevant to the history of the unitary principle.

Date of first publication		
1862	H. Spencer	*First Principles.* Ch. XXII.
1873	G. T. Fechner	*Einige Ideen zur Schöpfungsgeschichte.* (See L. J. Henderson. *Order of Nature,* 1917, p. 229.)
1874	J. R. Mayer	*Die Mechanik der Wärme.*
1880	E. Mallard	Quoted in F. M. Jaeger. *Lectures on the Principle of Symmetry,* 1917.
1884	P. Curie	*Oeuvres,* p. 119. *Journal de Physique,* 3, 407, 1894.
1891	J. Petzoldt	"Über Maxima, Minima, und Oekonomie." *Vierteljahrschrift für wissenschaftliche Philosophie,* 1891. *Das allgemeinste Entwickelungs-Gesetz,* 1923.
1896	E. Mach	Passim. *Principien der Wärmelehre,* pp. 381-6. *Science of Mechanics,* 1919 Edition, p. 395. *Populärwissenschaftliche Vorlesungen,* 1910, p. 499.

1903	B. Russell	*Principles of Mathematics,* Ch. IIc. *Introduction to Mathematical Philosophy,* 1919. *Analysis of Matter,* 1927, Ch. XXIV.
1924	W. Koehler	*Die physischen Gestalten in Ruhe und im stationären Zustand,* pp. 257-9.
1931	L. L. Whyte	*Critique of Physics,* p. 140. *The Next Development in Man,* 1944, Ch. II and Glossary.
1935	A. Sellerio *	"Les Symétries en Physique." *Scientia.* 58, p. 69.
1935	P. Renaud *	*Comptes Rendus.* Paris, p. 553.

6. Physical Processes

If the unitary method is to provide the basis for a unified science, it must be possible to see in principle how it might simplify the foundations of the three great sciences of matter, life, and mind, and so clarify their relationships. The principle asserts that it is possible to identify a formative process of decreasing asymmetry throughout all realms of science. What does this imply for physics, biology, and psychology, and for their role in a unified science? The next five sections attempt a provisional answer to these questions, as a preliminary to the further development of the method.

The problem is not only technically most difficult in the field of physics, but also most obscure even to specialists, since fundamental physical theory has hitherto neglected the formative aspect of physical processes. The growth of crystals and the formation of stable molecules of regular structure are two of the best known phenomena in which a formative process is clearly at work, but this aspect is not explicitly represented in fundamental theory. Such formative processes have been regarded as adequately covered by

* In view of later information referred to in the Preface, these references do not do justice to the work of these authors. Sellerio's first paper was in 1929, and Renaud has made further advances.

the tendency of physical systems to take up states of minimum potential energy. But this does not define these processes with sufficient precision, for there is no general rule covering the symmetry properties (in 3-D. space) of the states of minimum potential energy. The unitary principle transforms the problem by discarding the energy concept from fundamental theory, and relying on the observed spatio-temporal relationships; isolable physical systems tend toward states of higher spatial symmetry, i.e. states with a greater number of symmetry elements.

In fundamental systems minima (solutions of variational problems) are distinguished by unique symmetry properties, and the interpretation of states of minimal potential energy as possessing special symmetry properties therefore presents no difficulty. But this alone is inadequate. If a transformation of physical theory is to be possible, it is not only the stable states, but also the force-fields leading toward them, which must receive an interpretation in terms of symmetry character.

The clue to the answer lies in the fact that while physical systems possessing some stability, such as ultimate particles, atoms, crystals, etc., are characterized by their symmetry properties, physical forces and fields are distinguished by their characteristic asymmetry. When physical tests indicate the presence of an "electric" field, the objective content of the tests is the presence of a polar asymmetry in the causes of the phenomenon under examination. Theories of electrical "charges" etc., may contain arbitrary and mistaken properties; the only legitimate inference from an "electrical" observation is the presence of polar asymmetry with certain quantitative properties. Similarly, when physical tests indicate a "magnetic" field, the objective fact is the operation of causes displaying axial asymmetry or rotational distortion, and a similar reduction is possible for all kinds of physical forces. The reliable inference from a physical observation is the space-time relation-structure or symmetry character of the phenomenon. For example, the process of measurement consists in the determination of the presence or absence of a certain type of symmetry.

Fifty years ago Curie pointed out that "what is necessary [for the presence of a particular physical phenomenon] is that a certain element of symmetry should be absent. It is the asymmetry which creates the phenomenon." Apparently he did not take the further step and observe that just as the physical field represents a particular asymmetry, the process resulting from the field consists in the decrease of the asymmetry. The physical tension or force within any system can be regarded as a consequence of the tendency to establish its characteristic symmetry.

This analysis shows that the unitary method can in principle provide a reinterpretation both of stable physical systems and of the force-fields which lead toward them. But what of the wave-particle models and the tendency toward thermal disorder, if a formative process is universal?

On the unitary view the localized particles and extended wave-fields of physical theory are to be regarded as intellectual instruments of limited scope, each of which covers certain aspects only of the formative process constituting the actual phenomenon. This process consists in a specific decreasing asymmetry, i.e. in the development of extended spatial patterns of a specific character. The valid element in the particle concept is the co-existence within these patterns of spatially separated point-centers; the ultimate particles are reliable instruments in so far as they represent transient or permanent points of intersection within the pattern, but they neglect both the extended character of the patterns and their formative tendency.

On the other hand, the valid element in the wave-field concept is the extension of observable spatial relationships over finite regions and the discrimination of symmetrical solutions. But the concept leaves somewhat obscure the anchoring of the patterns to definite point-centers, and neglects their formative tendency.

Thus the unitary concept of process covers not only the valid aspects of these complementary models, but also the formative tendency which both neglect. The penalty for this neglect is the need to allow for a complex series of interactions, through which the one-way character of process can be introduced, as it were by a back door.

The unitary principle asserts a single universal formative tendency, but two major contrasted tendencies are evident in natural processes, toward local order and toward uniformity of general "disorder." The first is displayed in all processes where a region of order tends to differentiate itself from a less ordered environment. This is seen in crystallization, in chemical combination, and in most organic processes. The second tendency is displayed in the processes of radiation and diffusion, and leads toward a uniformity of thermal "disorder." The two tendencies normally work in opposed directions, the first producing regions of differentiated order and the second dispersing them. In any given situation either tendency may dominate according to circumstances. But it must be noted that what is misleadingly called the state of "maximum disorder" is in fact the state of maximum equipartition, or maximum uniformity of a certain kind.

These contrasted tendencies are both expressions of the unitary principle applied to a complex universe in a state of disturbance. For under that principle in so far as any system is isolable it will perfect its internal symmetry and thereby increase its differentiation from its disordered environment. But we have already seen that each system which is not isolable must be considered as a component of more extensive systems, and will therefore tend to reduce its asymmetry in relation to its neighbors, and to conform to their state of disorder and asymmetry. Thus in a disturbed universe isolable systems will tend to perfect their symmetry, and nonisolable systems to adjust their asymmetry to conform to the average level of asymmetry of their environment. The unitary principle applied to such a universe implies a tendency toward local symmetry and a tendency toward extended uniformity of asymmetry.

If the general "disorder" dominates, i.e. if the effective temperature is sufficiently high, local regions of order will be dispersed; while if the level of general "disorder" is low enough, the local development of symmetry will be completed, the asymmetry (absolute value of nonclassical "entropy") of perfect crystalline substances tending to zero at the absolute zero of temperature. At a later stage the mathematical development of unitary theory must define the exact conditions under which one tendency dominates the other. But on the surface of the earth these two aspects of the unitary process are often in fluctuating balance. In the argument which follows it will be assumed that the heat motions are not so great as to arrest the local formative processes.

The simplest example of the decrease of asymmetry is the separating out, and persistence or extension, of a single symmetrical structure, as in the formation of stable molecules and crystals. Every inorganic and organic molecule tends to perfect, and in some cases, as we shall see, to extend its own characteristic type of symmetry. When such systems have been brought sufficiently near to their characteristic symmetrical form they are stable, and display no inner tendency toward further change. In elementary systems of this kind the formative process reaches its terminus in a symmetrical structure which becomes static as the temperature approaches absolute zero.

(A similar process must be present in the formation of complex from simpler atoms, but the symmetry properties which determine the stability of atomic nuclei, if known, have not yet been published. Radioactivity, or the "spontaneous" disintegration of atoms, is also excluded from consideration here. But under the unitary principle, systems which possess a tendency to instability are not isolable. Thus radioactivity should probably be interpreted as a consequence of more extensive processes, and presents an interesting problem for subsequent treatment.)

The same tendency is at work in the formation of more complex symmetrical structures and states of regular molecular orientation, such as complex molecular aggregates, liquid crystals, crystallites, biochemical complexes, temporary molecular aggregates or ordered regions in liquids, paracrystalline systems, polarized regions in inorganic and organic systems, etc. Such structures and oriented states are stable, within broad or narrow limits, because a pattern possessing certain elements of symmetry has been established, and there is therefore no inner tendency toward further change (heat motion and radioactivity being neglected).

Under the unitary principle the process of the formation of a more complex stable structure from two (or more) simpler parts can be regarded as a single process of the decrease of asymmetry toward a more symmetrical end state. But viewed analytically in terms of three spatial co-ordinates this single process displays the interrelated aspect of *polarization, orientation, alignment, approach,* and *association.* For the two (or more) parts, being in each other's presence, will in general each possess some element of polar asymmetry (electrical polarization), and in the course of their combination these polarized parts are mutually oriented, aligned, brought closer, and finally associated as complementary components of one symmetrical stable structure. But these analytically separable processes are complementary aspects of one phenomenon, the decrease of asymmetry in the joint system.

This combination of parts to form a more complex stable structure can occur in two normally distinct manners. The first is the continuing, step by step, extension of an existing structure already possessing a characteristic (translational) symmetry, through the repeated association of a series of additional identical units. This process occurs in the growth of crystals and of molecular chains, fibers, rods, plates, and membranes, whether inorganic or organic.

The second consists in the union of two different but mutually complementary parts to form a symmetrical closed unit. This single step of the combination of complementary parts is probably present wherever there is the mutual compensation of inverse factors, e.g. in the neutralization of electric charges and of acids and bases, in the saturation of certain types of chemical valencies, in the covering of active and polarized surfaces by absorbed structures of inverse pattern, in the attraction of catalysts to their substrates, and in all cases of the selective interaction of two different entities.

Current physical theory does not provide an exact space-time description of the changing patterns involved in the combination of any two atoms or molecules to form a single stable unit. But it is likely that all such associating pairs have elements of mutually complementary asymmetry which under the given conditions can marry to form a more symmetrical pattern, though this relation of mutual complementarity may not be absolute. This inference is inescapable under the unitary principle, which implies that the series of electro-magnetic and quantum-mechanical fields involved in fundamental physical processes can only be fully understood as analytical components of the tendency for asymmetry to decrease.

If human vision were sharper, and all temperatures suddenly fell to absolute zero, the eye would see nothing but the mutual polarization, orientation, alignment, and approaches of structures, as they combined to form permanent symmetrical patterns. It would be an enlightening and yet deadly sight, revealing the inner formative tendency which has hitherto been neglected, and yet offering a vision of a spurious end of the world. For it could not happen. In this disturbed universe the inner formative tendency is arrested by the outer tendency to conformity, and thus distortion, movement, and life are maintained. For it will be seen later that life consists in the sustained alternation of inner and outer tendencies, in circumstances which prevent the attainment of static equilibrium, as long as life survives.

7. Physical Theories

In the previous section we considered, in a provisional manner, the relation of the unitary principle to physical force-fields and stable systems, particle-wave models, the tendency toward disorder, and the formation of complex systems. But the essence of physical theory lies in the conception of mathematical law, and the suggested interpretations lack coherence until the type of law used by each of the great theories of physics has been brought into relation to the new principle. We must therefore cover the ground again from a different point of view.

We may ask, for example: If the unitary view is correct and process can best be understood as the development of form in appropriately selected systems, then how is it that each of the branches of physical science, based on other principles, has proved so successful within its own field? What is the relation between the unitary principle and the axioms of each branch of physics?

These questions must receive an exact treatment at a later stage in the development of unitary theory. Here only a hint can be given of the direction in which the answer is to be sought as regards the six main branches of fundamental physical theory: Atomic Theory, Classical Dynamical Theory, Field Theory, Relativity Theory, early Quantum Theory, and Quantum Mechanical (Statistical) Theory. The purpose is briefly to indicate how *each of these theoretical methods may have owed both its success and its limitations to the fact that it took account of certain limited aspects of the unitary process.*

In order to represent process the intellect must assume some persisting property or type of continuity, so that earlier and later events may be correlated. The common characteristics of all physical theories have hitherto been determined by the assumption that this persisting factor, or invariant, is a quantity (or quantitative relationship) to be determined by measurement. On the other hand, the different branches of physical theory are distinguished from one another by the different kinds of quantitative invariant which each uses. Each main branch of physics covers a particular class of processes by assuming an appropriate type of quantitative invariant.

In *Atomic Theory* the invariant is the indestructible particle, and in the classical form of this theory the particles were assumed to possess persisting self-identity, unchanging properties, and simplicity. If this kind of atomic theory offered any promise of providing the basis of a universal science, there would be no need for the unitary principle. But this extreme type of mechanical atomicity is proving inadequate. It seems that the partial success of atomic theory does not imply that particle-permanence is the general form of invariant through which all fundamental processes can be understood.

The fact that physical theory is now using a considerable number of different kinds of fundamental particles, whose transformations and properties, within the nucleus and elsewhere, appear to be far from simple, suggests that the current methods may be open to improvement through a modification of the kind of invariant which they employ. It is possible that the success of atomic theory establishes no more than the fact that there exist definite centers of spatial pattern and influence, some of which may persist for considerable periods, and some possibly for ever. Thus it may be the extended pattern and its transformations, rather than the point-centered particle, on which the main emphasis should now be placed. The particle may be merely a component of an extended pattern.

In *Classical Dynamics* the main invariants were conserved dynamical quantities, i.e. quantitative parameters expressing conserved functions of the measurable aspects of motions in closed cycles. The principles of the conservation of mass, momentum, and energy are mathematical definitions of the invariants used in this theory, and as Planck * pointed out, the principle of the conservation of energy only possesses an unequivocal empirical content in relation to closed cycles. The fact that these definitions were so effective showed that many processes could be treated as lacking any one-way character. For a brief period toward the end of the nineteenth century it was thought that these dynamical invariants offered the final key to the understanding of nature.

But the concepts of mass and energy are limited in their theoretical and empirical scope, for they cannot alone cover such properties as scale, structure, orientation, and one-way succession. In classical dynamics conservation was

* *Das Prinzip der Erhaltung der Energie.* Fourth Edition, 1921, p. 111.

the main criterion of the isolability of any system, and there was no reason for any stable system to be of one size rather than another, or for any kind of ordered relationship to develop between one entity and another. Bodies were treated largely as points; their relations were supposed to depend only on their distance, structure and orientation being neglected; and the principles of dynamical conservation, in denying the existence of any one-way tendency in conservative systems, emphasized the possibility of cyclic and reversible states of motion.

The success of dynamical concepts proves that there is a widespread dynamical aspect to nature, that closed (or nearly closed) dynamical cycles do exist, and that for many purposes scale, pattern, and one-way succession may be neglected. But the physics of this century has been concerned with a wider field of phenomena for which the classical dynamical invariants are too narrow, and there is no need to argue their inadequacy as a basis for a comprehensive theory. From the standpoint of unitary thought, classical dynamics is applicable only where scale, orientation, and succession can legitimately be neglected.

Dynamics emphasized the separateness of material entities, and it could not easily account for certain types of interaction between distant entities. This led to the development of *Field Theory,* which used a new kind of invariant: an unchanging mathematical relationship (differential field equation) between changing quantities associated with every point of an extended region. The field equation possessed solutions representing the stable persistence, or propagation through space, of a wave or similar pattern of characteristic symmetry and finite scale.

This new invariant introduced a fundamental novelty into exact science: the correlation of spatially extended patterns with spatially localized entities. For example, solutions of the field equation possessed extended symmetry properties and yet they could be related to the position and movement of point-entities; wave patterns could be correlated with the periodic motions of particles. The pattern of the whole and the motions of the parts were thus for the first time brought into relationship. Clerk Maxwell knew that his theory of the electro-magnetic field constituted an advance toward a scientific theory of life because it imposed extended conditions on the relations of the atomic centers of force, thus "organizing" the point centers to conform to the extended patterns. But the weakness of classical field theory lay in its indefiniteness; unanchored waves or pulses might be doing almost anything anywhere at any time; the equations provided no measure of linear scale, no adequate criterion of orientation, and no satisfactory description of one-way processes.

These classical theories had taken for granted the universal availability of a unique co-ordinate-frame of space and time, but *Relativity Theory* showed that there were grounds for challenging this assumption. Nature offered no unique criterion of simultaneity, light was the swiftest signal, its velocity was an invariant, and the metrical aspects of space and time could be brought to a common basis. General Relativity Theory used two new invariants: the velocity of light, and a field equation determining the combined geometry of the space and time co-ordinates and therefore in certain respects confusing the spatial and the temporal aspects of process.

Relativity Theory represents a powerful synthesis of certain physical methods, yet it seems that it cannot provide a basis for further fundamental advice. Exact science requires an invariant which persists through time and can be used to correlate the earlier and later states of any system. The field equation of the General Theory is not an invariant in that sense, but an abstract formula which treats spatial and temporal relations as equivalent, neglects the relation of succession, and therefore cannot cover one-way processes. The symmetrical forms of relativistic mathematics, which extend the symmetry and metrical properties of space to measurements of time, cannot be generalized to include one-way processes without destroying the foundations of the theory.

A deeper revision of the classical theories began with *Quantum Theory,* which sought to come to grips with structure, i.e. with fundamental physical patterns of definite size and shape and their interactions and transformations. The new quantum constant served the purpose of introducing, in combination with other universal constants, an appropriate standard of linear scale into the theoretical equipment of fundamental physical theory, so that it could account for the fact that stable atoms and molecules and the stationary field patterns of electrons and light-quanta possessed definite sizes.

This was an important advance, as classical theory had neglected definiteness of scale, but early Quantum Theory introduced no new type of invariant, relying on the classical particles and waves, and using each when necessary. These so-called "models" represent invariant spatial forms to which the mind has grown accustomed and therefore conceives as possessing objective reality. Yet these classical invariants or models were not appropriate to the new processes being studied, and this fact was implicitly recognized in Heisenberg's principle of the indeterminacy of all spatial processes as regards their exact representation in a space-time frame of four metrical co-ordinates.

The difficulties arising from this use of inappropriate classical invariants (particle and wave models) were partly overcome in *Quantum Mechanical (Statistical) Theory,* the latest development in fundamental physical thought. Earlier statistical theory had shown that where classical invariants describing the motions of permanent bodies were inapplicable, e.g. in diffusion theory, owing to the myriads of molecules involved, a general tendency normally characteristic of the system could none the less be identified, whereby certain differences are evened out and the system moves toward "more probable" and more stable states. Classical statistical theory had here deserted the classical invariants because they were of no practical value, and had established instead an invariant one-way tendency (subject to fluctuations) toward a state of detailed and overall thermal balance. This one-way tendency was, however, regarded partly as an anomaly resulting from the fact that data on the movements of the individual molecules could be neither obtained experimentally nor treated mathematically other than by statistical methods. The one-way tendency was held to be only an average or normal property, the basic phenomenon consisted in the theoretically reversible dynamical motions of the individual molecules.

But the recent Quantum Mechanics goes further. In this theory all fundamental physical laws expressible in terms of four metrical co-ordinates are considered to be inherently statistical. The classical models are in effect eliminated from fundamental theory, and the only remaining invariant is an abstract field equation determining the probability of particular measurements being made in given circumstances. This theory is more comprehensive than its predecessors, the only systems which it cannot cover, at least in principle, being apparently those of high stability and symmetry, such as the nuclei of atoms and low temperature systems.

Statistical Quantum Mechanics displays an important characteristic which distinguishes it from all previous fundamental theories and may enable it to serve as a transition to unitary theory. The one-way character of process is for the first time implicit in fundamental physical law because the establishment of an interaction between two systems is a new irreducible event which increases the quantum entropy of each. For example, the process of measurement involves an interaction which changes the system measured in a quantitatively indeterminate manner. In Quantum Mechanics this change is left as partially indeterminate, while in unitary theory it expresses a tendency toward symmetry in the joint system (§ 13).

The advance of physical theory can thus be traced through the successive invariants which it has used: from the *particles* of Atomic Theory and the *conserved quantities* of Classical Dynamics, through the *extended patterns* of Field Theory and the *abstract pseudo-invariant* of Relativity Theory, to the *particle-wave models restricted by indeterminacy* of early Quantum Theory, and so finally to the *abstract probability fields* of Quantum Mechanics. In this latest theory properties of scale, shape, and orientation are included. Yet the theory lacks immediacy and simplicity, the mathematical methods are often intractable and sometimes lead to incorrect results, while many problems of great importance remain unsolved.

From the standpoint of unitary theory this must be so. Quantum Mechanics may include everything that is necessary, except one comprehensive simplifying principle; it certainly includes too much. For it still starts from the assumption of a universal four co-ordinate metrical frame, and in doing so postulates more than nature provides and demands from itself more than is necessary to cover the facts. The next advance in fundamental physical theory may therefore depend on the use of an invariant based on the conceptions of asymmetry and succession, which does not involve for its definition the device of a four co-ordinate metrical frame.

8. Physical Concepts

THE FOLLOWING TABLE sets out for convenient reference provisional unitary interpretations of some physical and chemical concepts. It is intended less for the general scientific reader seeking a first outline of the unitary method, than for the specialist interested in particular points bearing on the relation of the new method to that of quantitative physics.

No attempt is made in these interpretations to solve the critical problem of the relation of the unitary principle to the procedures and results of measurement. But they show the direction in which the solution must be sought, and thus define a program for theoretical research. This section offers *a challenge to the theoretical physicist* either to justify it by quantitative confirmation, or to show that it contradicts established facts.

More precisely, the interpretations seek to define the relationships of spatial asymmetry, symmetry, and temporal succession inherent in each concept. The aim is to formulate in the most general possible manner, by eliminating any unnecessary traditional or conventional elements, the actual space-time (nonmetrical) relation-structure of the phenomenon represented by each concept. If this has been done correctly the interpretations must be valid, and must be used, explicitly or implicitly, in any future physical synthesis employing the fundamental relations of space and time.

Two questions therefore arise in relation to this section: Does each interpretation represent a valid analysis of the causal or space-time relation-structure of the phenomenon? If so, can the unitary method be shown to lead to a quantitative derivation of fundamental physical theory? The first question is susceptible of direct analysis in terms of known methods, using Curie's principle (p. 21). The second requires the discovery of a fundamental correlation between the unitary process and the procedure of measurement. The two together constitute a challenge to the mathematical physicist, issued to further the development of a unified science.

Currents concepts	*Provisional unitary interpretation*
Natural Law.	A means of representing the actual course of a class of processes as uniquely distinguished by a certain symmetry character from all other hypothetically conceivable courses.
(Unitary Law. No equivalent principle in current theory.	The universal nonmetrical nondimensional principle of selection involving only asymmetrical relations: asymmetry decreases in isolable processes.)
A metrical co-ordinate system of one temporal and three spatial co-ordinates.	A method of representing metrical spatio-temporal relations (of excessive scope, expressing more metrical relations than are measurable).
Variational methods with derived expressions, based on a co-ordinate system.	Quantitative methods selecting the actual course of process as uniquely distinguished by constant symmetry properties from all other possible courses. This includes the form of

	stable systems as a limiting case of the course of process. Inapplicable to one-way processes with changing symmetry properties.
Physical law, in the form of a mathematical equation containing invariant parameters.	Mathematical representation, in terms of a co-ordinate system, of processes with invariant symmetry, permitting closed cycles and the application of conservation principles.
Conservation principle.	Formulation of an invariant quantity characterizing the four-co-ordinate description of processes which return identically to an earlier state (§ 7).
Energy function.	An invariant quantity uniquely characterizing any finite closed cycle of process.
Intensity, Quantity, and Capacity magnitudes in physical laws.	Parameters representing respectively the degree of asymmetry, the quantization of asymmetry, and the weighting of asymmetry, in unitary processes.
The tendency for Intensity magnitudes, or their differences, to decrease, i.e. the tendencies toward minimal potential energy, toward minimal available energy, and toward maximal entropy.	The tendency for asymmetry to decrease, including the tendency for differences of asymmetry to decrease.
The fine structure constant (x), correlating electron and light fields.	To be derived as the geometrical ratio of two stationary (and therefore measurable) components of the unitary process in certain fundamental structures.
Universal dimensional constants.	Characteristic parameters appearing in physical laws as a result of the application of four-co-ordinate description and conservation prin-

	ciples to the unitary process of fundamental systems.
Stable physical structure.	A spatial pattern characterized by specific elements of (latent) symmetry (e.g. group properties of Schrödinger function, in ordinary space).
Fundamental particle.	Unique point in an extended spatial pattern (§ 7).
Atom.	A stable pattern with one center of (latent) symmetry.
Molecule.	A stable pattern with two or more centers of local symmetry.
Chemical bond (between two neighboring atoms or molecules).	A local element of symmetry, stabilized by finite thresholds, in a system of two atoms or molecules; the terminus of a process in which a specific element of asymmetry decreases.
Catalysis.	The lowering of a particular threshold through the induction of asymmetry by a dominant (catalytic) structure (§ 16).
Physical field of force.	The representation, as a function of four co-ordinates, of a specific type of asymmetry in a system of two entities. (The asymmetry of a multi-term system is not expressible as a force of the classical type.) (§§ 6, 7, 12)
State of electrical polarization.	Polar asymmetry (§§ 3, 6, 12).
Process of electrical polarization or depolarization; displacement of electricity.	Increase or decrease in polar asymmetry.

Electronic current (at temperatures not close to absolute zero).	The continued induction, by a chemical source of polarization, of an extended state of polarization (in a conductor) which continually collapses into disordered molecular polarization (thermal motions; see below).
Electro-chemical system.	The dualism of "electrical" and "chemical" properties is eliminated by treating both as symmetry properties of structures; the "electrical" properties are related to the polar asymmetry of a structure, and the "chemical" properties are related to the combination of centrally symmetrical patterns to form extended patterns with new symmetry elements and corresponding stability.
State of magnetic polarization.	Axial asymmetry or rotational distortion (§§ 3, 6, 12).
Electro-magnetic process.	Process involving both polar and axial asymmetries; in general a chiral process. (§§ 3, 12, 43)
Decrease of Potential Energy, or of Structural Free Energy.	The decrease of asymmetry in an atomic, molecular, or mechanical system.
Increase of Structural Free Energy.	Increase of asymmetry, induced in the course of the decrease of asymmetry in a more extensive system.
Increase of Classical Entropy.	The decrease of asymmetry, in the special case of the decrease of the differences or gradient of a scalar parameter (temperature) defining the mean local asymmetry in a system near equilibrium (§§ 3, 6).
Temperature.	Scalar parameter representing the mean asymmetry in a small region of a disordered system near equilibrium.

Thermal motions.	Changes in the asymmetry of pairs and groups of atoms, molecules, etc.; normally described as changes in the relative positions, orientations, or internal structure of these entities.
Dynamical motion of two entities in each others' fields.	Changes in the internal and combined symmetry character of the two entities, degenerating to the limiting case of reversible or cyclic motions when the total decrease of asymmetry in the combined system is negligible.
The process of the mutual orientation, approach, and combination of two structures to form one.	The single process of the decrease of asymmetry in the combined system, the distorting effects of the environment (and of their separation) on each growing less as the two complementary structures marry to form a single more symmetrical and extensive structure (§ 6).
The attractive interaction of two or more entities.	The unitary process of the development of symmetry in the system composed of all the entities (§ 13).
The repulsive interaction of two entities.	The unitary process of the decrease of asymmetry in each of two mutually distorting entities (possessing no common latent symmetry).
Co-operative phenomena	The development of symmetry in a complex system which current theory treats as composed of otherwise independent entities.

9. Biological Processes

We have seen how it may be possible to identify a formative process of decreasing asymmetry in the field of physics, and the following chapters are concerned with this task in the realm of biology. But since many aspects of the unitary principle have long been recognized we can ask at once: have these already known aspects of the principle a clear application to biological processes? For if so it is probable that the unitary principle also applies to them. It will be recalled that these aspects are: the development of form; the movement from instability to stability; instability as due to differences; one-way causation; and the importance of asymmetrical relations.

There is no need to argue the relevance of the idea of the development of form to biological processes, for this idea first arose from the observation of organisms. Growth, differentiation, self-regulation, adaptive modification, and learning all display the progressive development of form, in the general sense of the appearance, restoration, and extension of characteristic spatial patterns of structure, inner process, and behavior. The formative aspect of biological processes is unmistakable.

The instability of protoplasm and its inner tendency to pass from unstable toward more stable states is equally clear. Every local region in an organism is normally in a state of labile equilibrium; if disturbed it changes into a less active state which must be recharged before the same response can be repeated. This movement from instability toward stability represents the inner tendency of every organic tissue and organ, and each tissue is only brought back to its original state through processes involving more extended regions of the organism.

This inner one-way tendency toward stability becomes more definite when we note that organic instability is often, if not always, due to differences between parts of the organism, between parts of its environment, or between organism and environment. Every special function is evoked by some difference which disturbs the organic balance: uncompensated differences of physico-chemical condition within the organism evoke internal processes, contrasts in the environment evoke behavior, and the difference between organism and environment maintains the driving potential of life. Moreover, the result of every cycle is toward the elimination of the difference which evoked it: internal processes tend to restore internal balance, and behavior tends not only to eliminate disturbing external stimuli, but to assimilate environment to organism and organism to environment.

Moreover, all these processes reveal a one-way causality in which the effect does not equal the cause. In every biological process a given pattern of causes produces a different pattern of effects, for some degree of transformation, whether of material structures or of energy configurations, always occurs. There is an element of one-way transformation in every organic process.

Finally, there can be no doubt regarding the importance of asymmetrical relations in biology. All the fundamental relations of the organic realm are asymmetrical; organism-environment, heredity, evolution, growth, differentiation, learning, assimilation, excretion, reproduction—all these and many other basic concepts contain reference either to the asymmetrical relation of temporal succession, or to that of the spatial contrast of internal and external factors. Only a science of asymmetrical relations can cover biological processes.

This brief analysis suggests that the unitary principle may be capable of throwing light on biological processes. The attempt to develop a unitary biology requires no further justification.

But this does not imply the reduction of biology to physics, as these sciences are now understood. Hitherto the problem of biological organization has been regarded as the elucidation of the relation of the properties of organisms to physical processes as interpreted by contemporary physical theory. This has proved a task of great difficulty, since physical theory has paid scant attention to asymmetrical relations.

Unitary theory adopts a different approach. It does not attempt to establish a direct relation between organic properties and current physical theory, but to go behind both to their common foundation in the unitary principle. The "problem of life" is divided into two parts each of which may be easier to solve: the relation of biological organization to the unitary principle, a provisional solution of which is given in this work, and the relation of physical processes as now interpreted to the unitary principle, which will be treated elsewhere along the lines already indicated.

Thus the question, What is life? is now supplemented by another, What are matter and energy? These are two of the three master problems of unitary theory: to represent physical, biological, and mental processes as special cases of the unitary process. The physical problem is technically the most difficult, and until it has been solved unitary theory has not mastered the classic problem of life. The biological problem is easier, and the general outlines of the solution put forward here may prove to be correct. If so, it must in turn throw light on the third master problem, What is mind? For under the unitary principle mental processes can only be understood by treating them as a special class of biological processes, as reinterpreted in unitary theory.

In unitary theory matter, energy, life, and mind are aspects of process which the human mind has wrongly hypostatized into entities, stuffs, or independent modes of existence.

10. Mental Processes

THE THEORY of mental processes lies outside the scope of this work, but if the new method is sufficiently comprehensive to provide the basis of a unified science it must be possible to recognize the formative tendency in mental processes. We can again apply the method used in the last section and consider how far the previously known aspects of the unitary principle are evident in mental processes.

The development of form is manifest in many processes of the conscious and unconscious mind, in the sense that patterns of relationships are clarified and their scope extended, though the relation of these mental patterns to the spatial patterns of unitary theory is uncertain. Moreover, the synthesis into a single response pattern of a stimulus pattern and a pattern preserved by memory, the combination of separate elements into a single result, the development of simple effects from more complex causes—these mental processes are essentially formative.

Next, the presence of differences as the source of instability, and the movement from instability toward stability, are also evident in mental processes. For mental processes are often evoked by some contrast or difference which becomes the focus of attention, and the result is frequently a process which tends either to eliminate an external contrast or to restore the balance of the mental process.

Again, mental processes display a one-way causation in which the effect does not equal the cause, for the results of a mental process are always characteristically different from their causes. For example, in many completed mental processes the cause is a complex nonintegrated group of factors arising from varied sources, while the result is a single idea or action. The one-way causation of mental processes often, and perhaps always in normal function, proceeds from more complex causes to simpler effects, though the precise meaning of these terms requires further examination.

Finally it is clear that asymmetrical relations play a determinant role in mental processes. The asymmetrical relation of temporal succession is inherent in the processes of memory, where the past influences the present, as also in the processes of anticipation and purposive action, where an image of the future guides present behavior so as to influence the future. Other asymmetrical relations present in mental processes are the internal-external relation involved in perception of, and action on, the environment, and the relations of the hierarchical organization of the person involved, for example, in the operation of conscious control.

This analysis suggests that the unitary principle may be applicable to mental processes, though probably in a specialized form, and that any theory of mental processes must emphasize the development, clarification, and extension of simple effects from more complex causes.

But this means that the causal law determining the course of mental processes cannot be expressed in terms of physical magnitudes subject to a quantitative invariant. If the present argument is valid, then the invariant characterizing mental processes is not a physical quantity, but some unknown law of the development and transformation of patterns. For example, in the stimulus-thought-response sequence the process often begins as a spatial stimulus pattern which is then transformed in thought into a spatial response pattern. Moreover, the fact that the causal law or invariant of mental processes is not expressible in terms of ordinary physical quantities is confirmed by the fact that we recognize a friend equally at one or at ten yards, and can form the concept of a tree without respect to its size or to the angle it subtends at the eye.

The main task of the theory of mental processes is to formulate the nonquantitative causal law characteristic of mental processes, and to define its relation to the quantitative causal laws of physical processes. When this is accomplished, the dichotomy of mind and matter, of conscious and physical processes, will disappear. The scientist may be a philosophical dualist or pluralist, but as scientist he must seek to discover the relation between these two modes of approach so as to establish a single order in knowledge. When the relation of mental to material causality is understood, he will no longer be confronted with the false choice of interpreting the totality as either mental or material. For on the unitary view there is one universal formative process; matter, energy, life, and mind, are names which man has given to different aspects of that universal process. There is process; but there is no essence, no substance, and no static existence.

The belief in the existence of two modes of reality has now exhausted its utility for science, and must be replaced by the recognition of one universal process. This emancipation from dualistic confusion will be possible when the causal laws of matter, of life, and of mind have all been interpreted as special cases of one general causal principle. In unitary theory this means that three conditions must be satisfied:

1. The quantitative properties of physical processes must be represented as components of a formative process.

2. The properties of organisms must be represented as components of a special type of formative process defined in a formula for organism.

3. The properties of (human) mental processes must be represented as components of the dominant formative process of the human individual interpreted as a special type of organism.

When these conditions are satisfied, psychology will coalesce with neural and endocrine physiology in a unitary theory of the dominant processes of the human individual.

The great circle of knowledge will then be closed, and the different sciences fused into a single unitary science. Specialized inferences of each branch of unitary science will constitute, together with the unitary principle, the axioms of its successor one-way round the circle. For example, starting at physics, we move by steps through chemistry and bio-chemistry to general biology, the biology of man (including human physiology and psychology), sociology, semantics, and mathematical logic, and so to physics again. But we can start anywhere; there are no absolute axioms, for every item of theoretical knowledge can be regarded both as an inference from prior principles, and as a premise for further inferences.

Thus the aim of unitary science is a logical circle representing man and his ideas as part of unitary nature, and unitary nature as a valid idea emerging to clarity in man. Man will then understand the laws of nature, and the laws of nature will interpret man to himself.

CHAPTER II

UNITARY CONCEPTS

11. Unitary Concepts

In chapter i it was suggested that the unitary principle represents the most general type of causality conceivable at the present stage. When this principle is applied to phenomena of different degrees of complexity various key situations, or patterns of changing relationships, are found to recur frequently as consequences of the principle. It is therefore convenient to name these key patterns, and so to develop a system of unitary concepts. The most important of these are treated in the present chapter.

These unitary concepts are not entirely new, but consist of terms in common use, the meaning of which is modified or clarified by relating each to one comprehensive principle. Like the principle from which they are derived, each concept represents the most general pattern of relationships having the essential properties of the phenomenon. Unitary concepts refer to particular patterns of relationships, and must apply wherever these patterns are present in the phenomenon.

A subtle change of meaning occurs in passing from the current usage of a term to the corresponding unitary concept. This is due to the transformation of a group of relatively disordered concepts, based on symmetrical relations and quantitative invariants, to an ordered system defined as aspects of one principle based on asymmetrical relations and on an invariant pattern of process.

The terms *unitary principle, asymmetry, symmetry, latent symmetry, tendency, character,* and *chirality,* have already been defined in § 3. In the present chapter the following further unitary concepts will be defined and illustrated: *polarization, relaxation, normalizing process, norm, resultant field, interaction, co-operative phenomena, threshold, terminus, transformation, modification, dominance, induction, facilitation,* and *ordered region.*

The explanation and illustration of these concepts, and of their relations under the unitary principle, provides a nonquantitative *theory of tendency* applicable to a wide class of one-way processes. It leads, for example, to a theory of organism using terms which are equally relevant to "physical" and "mental" processes, and do not imply any fundamental dualism. The theory is therefore unitary in this ultimate sense.

But unitary theory is not at this stage a complete deductive system based on a limited set of axioms. It is the result of a first application of the unitary principle to the facts and theories of contemporary science.

12. Polarization

In ordinary usage the terms *polar* and *polarization* refer to the presence of two contrasted aspects, and in physical theory a *polar vector* is a quantity possessing magnitude, direction, and sense (and distinguished from an axial vector by special transformation properties).

Unitary theory retains the term *polarization,* but provisionally discards the requirement that it must possess magnitude, since the conditions under which polarization is measurable have not been defined. A *polarized* system is one displaying an asymmetry which can be represented by a direction with sense. This asymmetry is recognized as a distortion from a particular type of symmetry which is latent in the system. Polarization is therefore a distortion from a latent characteristic symmetry. It will be convenient sometimes to refer to the process of the decrease of a distortion as the *relaxation* of a structure (toward symmetry).

For the present we shall neglect axial asymmetries, or distortions of orientation having the form of a twist, though it will be necessary to consider these later in relation to the process of synthesis in plants.

In electrical theories certain systems displaying polar asymmetry are regarded as being "electrically" polarized, and this interpreted as being due to "the separation of electrical charges." But this may not mean any more, as regards directly observable properties, than that a polar asymmetry with a given direction, sense, and magnitude, is present in the observed phenomenon. What are called "charges" may frequently be regarded as components of a polarized structure, as Maxwell showed. The unitary concept and the contemporary physical concept of polarization are equivalent in empirical content, except that in unitary theory the conditions under which polarization is measurable have not yet been determined.

For example, in physical theory the electrical potential energy of any system tends to decrease, and does in fact decrease to a minimum fixed by the structural conditions of the system and by any external influence which may arrest this one-way process. The mutual attraction and neutralization of electrical charges of opposite sign represent the decrease of electrical polarization and the decrease of electrical potential energy. In unitary theory such processes are interpreted as the decrease of a polar asymmetry toward a state in which the polarization disappears. Thus the tendencies of unitary theory here correspond to the tendencies of classical electrical physics, the quantitative aspect being provisionally neglected.

But unitary theory goes further. Consider the case of a system composed of two identical or similar molecules. The tendency for the asymmetry of the system to decrease will result either in both losing any polarization they may possess, or, if for any reason (e.g. owing to some external influence) that is not possible, in their taking up a state of parallel polarization. If the two molecules are identical and there is no reason for either to be distinguished from the other, this means that there will be a tendency toward a state of parallel and equal polarization; and if any such units are present, there will be a tendency toward uniformity of polarization. On the other hand, if different kinds of units are present, there will be a tendency to reduce any differences in polarization to the minimum permitted by the internal and external conditions of the system.

This tendency toward minimal differences of polarization is of great importance, particularly in organisms, and will be called the *normalizing process,* since it restores any system of polarized units to a normal state, or *norm,* after every sufficiently small disturbance. The *norm* is the state of minimal polarization differences subject to the conditions of the system. Where a large number of component parts are present the normalizing process can be regarded as everywhere reducing the system to a state of *minimal polarization gradients.*

A system of polarized parts, which tends to establish uniformity of polarization, is said to possess a characteristic resultant polarization field, or *resultant field.* Resultant fields tend toward uniformity, and the normal field is the most uniform field possible under the conditions determining the system.

The tendency of systems of identical units to establish a uniform resultant field, by the drawing parallel of polar vectors characterizing the units, is already recognized in physical theory in certain cases of the "coupling of vectors"; in "internal fields" in dielectrics, which operate so as to enhance the electrical asymmetry; in "conducting regions" or "conjugated bond fields" in molecules. These somewhat obscure phenomena possess a common characteristic: the tendency for uncompensated polar vectors to draw parallel.

Thus the unitary concept of polarization not only covers the tendency for electrical polarization to decrease, but also the induction of parallel polarization, i.e. the tendency for *differences* of polarization to decrease, between ultimate structural units. In unitary theory polarization tends to a minimum, and polarization differences in ultimate structures also tend toward a minimum.

The use of the term *polarization* in unitary theory is therefore justified. We must now consider the use of the term *field*.

In classical theory a *field* is a function of space and time co-ordinates, resulting from the presence of one entity and producing changes of momentum in another. This conception is particularly appropriate for describing the relative motions of pairs of entities which can be treated as points because they undergo no changes of internal structure. It is less suitable for treating processes in which there is a change of structure which cannot be reduced to interactions (forces) between pairs of entities. The failure of the classical field concept in molecular, atomic, and nuclear physics suggests that exact science has here entered a region where multi-term relations are involved and the classical force concept therefore breaks down.

What appears to be required is a mathematical representation, not of the stationary fields of single unchanging entities, but of the one-way development of a new type of structured field representing the history of a complex system. This new field would directly represent the process of the system, instead of the state of a medium linking the separate entities.

The unitary concept of the field meets this requirement. It refers to the presence of a system of polarized parts displaying a tendency toward parallel polarization, and, if the parts are identical, toward uniform polarization. The unitary field thus possesses a tendency toward uniformity, and this applies to all its parts; the process of the field therefore tends to bring each part into conformity with the resultant polarization of the system. This property of the unitary field is a direct consequence of the unitary principle.

While the classical field produces changes of momentum in inertial entities, the unitary field describes changes of shape, orientation, and position in polarizable structures.

In the ultimate analysis all unitary processes may be regarded as the normalization of some polarization field. But since we are not here concerned with nuclear and atomic fields, the fields under consideration will be mainly those representing the processes of systems of molecules, and the polarization vectors constituting the field will usually be the net polarization of individual molecules. For example, the normalizing of the field often consists in the induction of parallel molecular dipoles, after their disturbance and relaxation.

The unitary field does not express the state of any medium existing independently of the structures, for the phenomenon is nothing but the changing structures and their relationships. The tendency of the field to approach uniformity is a name for the transformation, transportation, and orientation of parts as components of the tendency toward symmetry of the system as a whole. More exactly, the process of the field consists in changes in the state of polarization and in the relative positions and orientations of the parts.

The unitary concept of the field is important because it refers to the complete pattern of polarization in any system excluding only unpolarized or symmetrical structures, and it is this polarization pattern which determines the processes of the system.

13. Parts and Wholes

THE ANALYTICAL METHOD seeks to describe the processes of complex systems by dividing them into parts which undergo less varied changes. In atomic and dynamical theories this general method is applied in a special manner, the changes of complex systems being treated as reducible to the relative motions of unchanging entities, such as massive objects, atoms, or particles. All processes are regarded as reducible, in the final analysis, to the relative motions of ultimate particles, and changes in these motions are ascribed to interactions or "forces" between pairs of particles. This dynamical type of analysis is distinguished by the assumption that the ultimate particles are permanent, undergo no internal changes, and interact in pairs, each member of an interacting pair being located at a geometrical point. Thus all process is reducible to the interactions of pairs of spatially infinitesimal, unchanging entities.

The unitary principle leads to a more general method of analysis, which in limiting cases becomes equivalent to the dynamical type of analysis. Under this principle the isolable phase of the process of a complex system consists in the decrease of some asymmetry characteristic of the system. But this system process cannot be fully defined unless the structure of the system is known, that is, until its fundamental component parts have been identified. However, these parts are neither unchanging nor infinitesimal, nor do they only interact in pairs. The unitary analysis of a complex system involves the identification within the whole, not of constant entities but of units of formative process, and even in the ultimate analysis these units of process have a finite extent both in space and in time.

Moreover, these ultimate structural units of process are formative groups which may consist of pairs, but may also be of any multiplicity, subject to one common unitary process. And these complex systems may again be grouped to form a higher system characterized by its own dominant unitary process, and so on, the ultimate units of certain types of systems being arranged in a hierarchy of subsystems within the complete system. In the unitary analysis a complex process is reduced, not to the interactions of pairs of constant point-entities, but to a hierarchy of groups, each with its tendency to symmetry. But in a logically degenerate limiting case the hierarchy may reduce to an assembly of interacting pairs, and the units of formative process may possess aspects which display the symmetry of point-entities or particles.

Just as the dynamical method of analysis led to the conception of ultimate structure as consisting in the spatial relations of independent point-centers with constant properties (particles), so the unitary method leads to a new view of changing structure as consisting in the interplay, under one overriding unitary tendency, of units of formative process extended over finite regions of space and time. The dynamical causation of permanence, conservation, and interaction between constant pairs, is generalized into the unitary causation of a system tendency affecting the mutual relations and progress of developing, formative groups. Instead of an interaction which affected only the relative motion of a pair of unchanging particles, there is an interplay, under a system tendency, which changes the actual course of the unit processes of which it is composed. The relation of static parts to one another is broadened into a relation of the process of the whole to the processes of the component units. The two-term relation of relative motion is subsumed within the wider multi-term relation of changing relative orientation under a developing system symmetry.

The clue to this transformation from dynamical to unitary analysis consists in the new interpretation given to the *interaction* of entities. In dynamical science, when a given system cannot be treated as being isolable, it is regarded as being "influenced by," or in "interaction with," some other system. But in unitary theory when a system is not isolable, it is conceived as forming a constituent of a wider system, the unitary process of which may involve changes not only in the spatial relations, but also in the internal processes of its constituent parts. If a system A is not isolable, that does not imply that it is in dynamical interaction with some other system B, but that the process of A is modified from its inner tendency because it is a constituent of the more extensive system (AB). The mutual action and reaction of A and B is replaced by the modification of the process A by the process (AB); the mutual interaction A⟷B disappears and its place is taken by (AB)→A and (AB)→B. The symmetry of the action and reaction of parts is (in general) replaced by the asymmetrical one-way action of the process of the system on the processes of its parts.

It will be convenient to continue to use the terms "interaction," "influence," etc., but they are to be understood as referring to *the effect of the unitary process of a complex system on its constituent processes*. If we speak of A and B being in interaction, this expresses the fact that there is a process (AB) which modifies the separate processes of A and B.

Moreover, this modification of the separate constituent processes is such as to develop the symmetry of the joint system (AB). This means that the interaction of A and B possesses a formative property which is neglected in dynamical analysis. In order to emphasize this important feature, the term *co-operative* will be used in unitary theory to describe the formative interactions of entities which classical dynamical theories have treated as "dynamically independent." Co-operative phenomena are those displaying the development of symmetry in a complex system which classical theory treats as composed of independent entities. Since all unitary processes display the development of symmetry, the use of the term would be redundant were it not necessary to emphasize a property which earlier theories have neglected. The relation of a whole to its parts in unitary theory differs from the corresponding relation in classical dynamical theory because the parts, being subject to the formative process of the whole, appear to "co-operate" so as to produce a single result: the development of the symmetry of the whole.

This general property may be clarified by noting three special cases:

1. *An already developed pattern modifies the processes of relatively small parts.*

This covers those phenomena in crystalline systems for which physical theory is now using the term *co-operative.* Certain atomic or molecular processes only occur because the parts are within an already established regular array. Here the parts tend to adjust themselves to conform to an existing symmetry.

The control which an organic system exercises on its parts provides a more complex example. Here, as we shall see, a cycle of changing resultant polarization modifies the processes of the parts so that they tend to conform to the cycle.

2. *An already developed pattern spreads externally.*

This process of the induction and spread of pattern will be discussed later (§§ 15, 16).

3. *No dominant pattern yet exists, and two changing parts are in continuous reciprocal interaction.*

This category lies outside the scope of this work. It covers the co-operative development of complementary forms and, as a limiting case, oscillatory processes in which there is alternation of dominance (see § 15).

The above discussion of the relation of a whole to its parts assumes the existence of a whole, i.e. of a common unitary tendency characteristic of the entire system under consideration. This excludes those complex processes in which there is no single tendency characteristic of the phenomenon. For example, two systems may separate out from each other, each developing its own symmetry as the two draw further apart. Such mutually repelling systems cannot be treated as together constituting one whole, for the complex process consists in the decrease in each system of the distortion due to the proximity of the other. They represent two systems marked by a common decreasing distortion, not a single system characterized by one developing symmetry.

14. Thresholds and Transformations

THE UNITARY PRINCIPLE defines a finite phase of process leading toward a symmetrical and stable end-state. But if that end-state is sufficiently distorted as part of a wider system it will change its character and display a new inner tendency toward another end-state characterized by a different symmetry. Once the *threshold* has been passed at which its character is transformed the system will, if left alone, follow its course toward the new type of symmetry. Thus *each finite phase of isolable process defined by the unitary principle begins at a threshold and ends at a terminus.* External influences must bring a previous system over a threshold so that a transformation takes place, but from the threshold to the terminus the new system can be treated in isolation. The threshold is the point of unstable equilibrium between two alternative tendencies, the terminus the state of stable equilibrium where a tendency culminates in symmetry.

No stability is absolute. With increasing distortion from any particular form of symmetry there always comes a point at which the system becomes unstable and a transformation occurs. Atoms are normally stable, but under a sufficient stress all complex atoms will disintegrate. Molecules are transformed if sufficiently distorted. Genes undergo mutation. More complex systems such as molecular aggregates, crystalline systems, or oriented regions in living protein, possess only limited stability and can be dispersed by an adequate disturbance. All stability is limited by thresholds.

The passing of a threshold is a definite event which marks the continuity of process, a new latent symmetry becoming effective in a new phase of isolable process. A threshold is a definite spatial pattern appearing at a particular moment in time; it is a crisis of transformation at which a new developing symmetry becomes isolable from the process of the environment. After the threshold a new pattern separates itself out.

It is only the existence of distinct states of stable equilibrium characterized by contrasted types of symmetry and separated by finite thresholds which makes possible the classification of systems into discrete categories. Without definite points marking transformations the intellect could get no grip on the continuity of process.

In physical theory thresholds are defined in terms of the energy absorbed in the process of distortion. This may be known as the excitation or ionization potential, the potential barrier, or the activation energy. For example, an atom can only undergo a particular transformation (e.g. disintegrate, emit light or electrons, or undergo chemical combination) if the necessary amount of energy is supplied to carry it over the corresponding threshold. A particular process will therefore be eased by any influence which distorts the system toward the corresponding threshold so that less additional distortion is necessary. Many catalysts operate in this manner by reducing specific thresholds.

Thresholds are defined by angular distortions from specific symmetrical patterns. But it is convenient sometimes to think of them as watersheds or cols separating the valleys which represent two alternative tendencies; once over the col the new way is clear, so long as nothing intervenes. The mountain climber may pause on a col, but physical systems cannot stay on a threshold, for there the equilibrium is unstable. The threshold is a transient pattern realized at one instant only, while the terminus is a limiting pattern which marks the end of an inner tendency.

Physical science has not yet identified the types of latent symmetry which characterize all the different classes of stable systems. For example, the different chemical atoms must represent variants of some general type of symmetry, probably with respect to one point, the center of the atom. But this is not yet sufficiently understood, at least by free scientists, to permit a simple comprehensive theory of nuclear properties.

Similarly, the types of symmetry characteristic of different classes of chemical molecules are not yet fully known, and it may be that the concept of a molecule is not absolute, since there may not exist any criterion by which "a molecule" can always be identified within the complex molecular aggregates of inorganic and organic systems. Nevertheless, for the purposes of this work, it will be assumed that the term "molecule" has an adequately definite meaning to permit a distinction to be drawn between individual molecules and associations of molecules.

We have used the term *transformation* for the change in the character of any system on the passing of a threshold. But it will be convenient in future to use *transformation* to refer to intramolecular changes, i.e. to an alteration of the character of individual molecules, and *modification* for changes in intermolecular relations of distance and orientation. The distinction is not absolute, since the two types of change are interrelated and no definition has been given of a molecule, but it will serve to clarify the present argument.

The transformation of any molecule involves a change in the atomic pattern (e.g. motion of protons) accompanied by changes in its polar asymmetry, or polarization, with respect to some axis through the molecule. Complex molecules often possess two different characteristic states, consisting of a more symmetrical, less polarized, stable state, and of a less symmetrical, more polarized, metastable state. The metastable state may require only a small distortion to change it into the stable state, which can then be converted back into the original metastable state, provided that external influences distort it sufficiently. Thus a complex molecule may be capable of undergoing cycles of minor transformations while retaining its characteristic pattern intact, the pattern having relatively high thresholds for fracture, and relatively low thresholds for minor, easily reversible, internal transformations. These cycles consist (in general) in alternating transformations of the three-dimensional pattern of the molecule, but they are often characterized by cycles of polarization along a single axis.

For example, chain molecules, such as those of protein in certain states, may undergo various types of easily reversible transformation, involving folding, coiling, sinuous movement, etc. The changing three-dimensional pattern of such chains or molecules may be extremely complex, but the resultant cycles of the total polarization of the molecule along a unique axis may be simple. Such characteristic cyclic transformations constitute the specific activities, "modes of action," or "functions" of cyclic systems, such as enzymes, membranes, and tissues.

Cycles of molecular transformation normally consist of an "upward" phase of distortion under external influence, i.e. as part of a wider system, followed by a "downward" spontaneous phase of relaxation toward the state of highest symmetry. The upward phase is not an exact reversal of the downward, for it occurs under external influence, but the two together complete the cycle of the molecule. As we shall see later, such local closed cycles can only occur as components of a more extensive one-way process which exerts the distorting influence necessary to produce the upward phase of the cycle.

On the other hand, the modification of a system of similar molecules involves changes in the distances, orientation, and polarization of the individual molecules. The unitary process of such a system results in general in a tendency for the individual molecules to be adjusted, in relative distance and degree and direction of polarization, toward uniformity of polarization, subject to the conditions set by the environment of the system. In isolation such a system will tend toward a uniform depolarization, but as part of a polarized environment it will tend to establish or restore a uniform polarization.

Thus a system whose state of polarization is stabilized by its environment may tend to control the processes of its constituent molecules, i.e. it may tend to restore a normal state after any local disturbance. The resultant field of the whole system represents the polarization of the individual molecules, but these are subject to the unitary tendency of the system, as stabilized by the polarization of its environment. The individual molecules, and the system itself, will relax toward a depolarized symmetry whenever the state of polarization of its environment fails to sustain it.

The physical science of structure has hitherto been mainly concerned with the measurable properties of thresholds and termini. The unitary method draws attention to the one-way character or temporal sequence of the processes which occur between these limiting states. The isolable (relaxative) process moves from threshold toward terminus; the inverse (upward) process is not an exact reversal of this and only occurs as a component of a more extensive process moving from its threshold toward its terminus.

15. Dominance

Nature does not look with equal favor on the stable and the unstable; the rule is "to him that hath, shall be given." The stable pattern enjoys ascendancy over the less stable, and its own stability tends to be reinforced. *The more* *stable pattern tends to dominate, and to extend itself at the expense of the less stable.*

It is easy to see how this may be so under the unitary principle. Suppose that two systems, A and B, have come into proximity, and that A is more stable than B, i.e. has the higher threshold for a particular transformation. For example, A may be a new face on a growing crystal nucleus and B the neighboring solution, or A may be a catalyst and B the substrate on which it is acting. In the course of the unitary process of the joint system (AB), the asymmetry of (AB) will be decreased by distortions of both A and B (from their separate equilibrium states) so that the pattern of each conforms more closely to that of the other. But since A is the more stable, equal distortions of A and B may result in B being transformed while A is not. The result will be that A does not undergo any change of character, while B is transformed into a new pattern conforming in some respect more closely to the pattern of A. To this extent the pattern of A spreads at the expense of B, and A may be regarded as dominant to B. The threshold of B for the particular transformation is reduced by the presence of A.

This situation is present wherever a pattern of a given character tends to multiply or extend itself, and it will be defined thus: a system A will be said to be *dominant* to a neighboring system B when, in the course of the unitary process of (AB), A remains unchanged and B is transformed to conform more closely to the character of A. This implies that A is in a particular respect more stable than B, and that they have certain features in common. The relation of dominance is asymmetrical (A→B) and implies the one-way *induction* of a transformation heightening the symmetry of the joint system (AB). Thus dominance is a one-way spatial relationship evidenced in a one-way process of induction, and this induction of pattern may be simple, or it may express the steric action of many co-operating factors.

The relation of dominance is illustrated by the extensive class of processes in which a polarized but stable structure induces parallel polarization in a less stable neighbor. This includes all induction of electrical polarization in microstructures, and all catalytic rearrangement of polarized atoms or groups of atoms, in fact all cases where the unitary process in the combined system expresses a tendency toward the establishment of equal and parallel polarization in the two components. It may prove that all cases of the spread of specific pattern depend fundamentally on the induction of polarization.

The growing crystal nucleus is dominant to the neighboring solution. Genes, enzymes, and catalysts in general, when inducing in neighboring molecules features of their own structural pattern, are dominant to those molecules. An oxygen atom, or any other oxidizing agent, is dominant to the fuel or other molecule which it distorts or fractures in the course of oxidation. A great hierarchy of relations of dominance guides the differentiation of the developing embryo, highly specific and stable structures acting on less specific and less stable materials, the stationary genes producing the wandering catalysts and enzymes that control the differential synthesis throughout the system.

These examples of dominance all refer to the spread of the specific pattern of a unit structure. But the term will also be used to cover the case where the dominant system, A, is not a single molecular unit, but an extended pattern, such as a crystal or an ordered region in cytoplasm, and B is a part of that pattern which does not yet conform to it. Thus we shall extend the definition and regard a system (AB) as *dominant* to a part B, when in the course of the unitary process of (AB) the pattern of B is transformed to conform to that of A.

This asymmetrical relation between more stable and less stable parts, or between a stable system and a less stable part, holds the clue to all one-way influences and is the fundamental factor underlying all development and maintenance of pattern, and therefore all biological organization. The stabilization and maintenance of organization require a controlling relation either between one part and another, or between the whole and the part. This relation must be asymmetrical, for control implies a one-way causal influence, and this causal influence must be exerted by the more on the less stable. Dominance is thus the relation characterizing all causal influences underlying the maintenance or development of patterns, whether in the inorganic or the organic realm.

16. Facilitation

Many inorganic, organic, and mental processes are autocatalytic, that is they produce a stable result which furthers the repetition of the process. These autocatalytic processes fall into two classes. In the first class the stable result is a localized unit of specific structure which furthers its own reproduction in part or whole, while in the second the result is an extended modification of an existing system, which furthers the repetition of the process which produced the modification.

The crystal nucleus promotes its own further growth. Many solid chemical products catalyze their continued production. Certain types of protein units, such as genes and auto-synthetic enzymes, act as catalysts of their reproduction within the organism. In all these cases a one-way process leads to the formation of a new unit of structure, which may either remain independent or contribute to the growth of an existing structure, but in either case persists as a nucleus for the further reproduction of its specific pattern. This class covers all cases of the extension of specific structural pattern.

The second class is less well understood but equally important, and covers all cases of the increase of order in an already existing extended system. Elementary examples are the improvement in the state of order of a disordered solid or liquid crystal. Any increase in the state of order of such systems, for example in the state of orientation of a system of static polarized molecules, tends to promote a further raising of the state of order. A more complex example is the case where the state of order of a system of cyclically polarizable molecules is improved by a double pulse of depolarization and repolarization passing through the system, so that the modified system reinforces and stabilizes the repetition of the pulse under similar circumstances.

This second class of autocatalytic processes includes, as examples of cyclic processes of this type, all cases both of functions producing structures which stabilize the function, and of adaptive modification and learning. The essence of the development of functional structures (as well as of adaptive modification) is that a cyclic process modifies an extended system so as to reinforce its own repetition under similar circumstances. In such cases the modification consists in the establishment or improvement of an orientation pattern in a system of cyclically polarizable molecules. The extended pattern may be complex, as in the higher nervous centers, but its local component is always a simple state of polarization.

There are therefore two particularly important classes of autocatalytic process: the one-way production of units of local specific structure, and the improvement and operation of extended patterns of cyclically transformable structures. The first process underlies all cases of the reproduction of specific structural patterns, and the second all cases of the reproduction of extended patterns of cyclic process.

Neither the identical multiplication of unit structures nor the adaptive modification of extended systems can be adequately covered by existing theories, for these theories all lack a fundamental principle of the development of pattern. The unitary principle transforms the two problems simultaneously by emphasizing the common factor underlying both identical multiplication and adaptive modification: the property of certain types of process whereby they promote their own repetition.

This property is of fundamental importance in relation to the development of order, and will be called *facilitation*. A process will be said to *facilitate* its reproduction when it leads to a stable result which tends to bring about a repetition of the process. In unitary theory a wide class of processes possesses this self-facilitating property.

Every unitary process culminates in a stable pattern of characteristic symmetry, but its influence does not end there, for no isolation is absolute. If the environment is appropriate, the asymmetry between the stable pattern and its environment will tend to grow less and the pattern will spread, if this is possible, by inducing the repetition of processes which contribute to its own formation. Under the unitary principle all processes are self-facilitating which lead to a structure possessing a symmetry character which can be extended by spatial repetition (translational symmetry). Thus all unitary processes that lead to a pattern of symmetry and asymmetry which can be repeated by induction, are self-facilitating.

Every process which satisfies this condition tends to develop a structure facilitating the repetition of the process, and every such structure facilitates the process which produced it. This general property may be lost under certain conditions, but it is a normal characteristic of this class of unitary processes. Thus unitary processes not only lead toward stability, but may have a further self-stabilizing and self-developing character as a consequence of the fact that the unitary tendency of any system may operate externally as well as internally.

In the previous section we saw that a dominant structure, as there defined, induces elements of its own pattern in some neighboring system. Dominance is thus an asymmetrical relation between one system and another, while facilitation is the asymmetrical relation between the corresponding processes, that is, between an earlier and a later process.

The property of facilitation underlies all development and extension of form. Crystal growth, organic growth, identical multiplication, and adaptive modification, are four interrelated examples of the extension of form. By providing a direct interpretation of the property of facilitation the unitary principle throws light on all four processes and on their relations.

The unitary principle does no more and no less than to express the fundamental space-time relations, or causal relation-structure, common to all processes in which form is developed. All formative processes involve the decrease of some asymmetry, and those which tend to establish a structure possessing translational symmetry necessarily facilitate their repetition.

17. Ordered Regions

WITHIN this disturbed universe every system tends to separate itself out and to perfect its own symmetry. Wherever conditions favor this tendency a stable nucleus pattern is formed which may facilitate its own growth until an island of order is established, distinguished by its characteristic pattern from the relative disorder around.

Such *ordered regions* are characterized by the stabilized relations of their constituent units, i.e. by the relative distances and orientations of the atoms or molecules, stabilized by finite thresholds. The appearance and development of ordered regions is furthered by an adequately low temperature, by the presence of a latent or stabilized nucleus pattern, and by the presence of an appropriate medium.

Examples of ordered regions in the inorganic realm are solid and liquid crystals, and various paracrystalline systems, such as regions of close-range order in liquids, adsorbed layers on surfaces, etc. On the other hand, all the directly functional parts of organisms are built up of ordered regions where the protein and other large molecules are oriented in a characteristic manner. Even in relatively fluid cytoplasm the protein molecules probably tend to take up a definite functional orientation when undisturbed. Thus an organism may be regarded as a non-uniform, or differentiated, ordered region within a relatively disordered environment.

Here we are mainly concerned with uniform ordered regions, i.e. those in which the relations of a set of identical molecules are stabilized in a manner characteristic of the region as a whole. The properties of a uniform region therefore in certain respects reflect the properties of its constituent units, and the common orientation of the units may result in the region having different properties in different directions (anisotropy shown by optical or other properties). For example if each molecule is polarized, the region will possess a resultant field parallel to the polarization of the oriented molecules, and if any molecules are disturbed they will, under the unitary principle, tend to be reoriented so as to conform to the resultant field.

An important example is the case already mentioned of a system of identical molecules, each of which can undergo a cycle of polarization and depolarization. If the environment of such a system is maintained in a state of adequate polarization, the normal state of the system will be that in which all the molecules are polarized in parallel. But if a sufficient number of molecules are disturbed they will tend to relax to their less polarized state, and this depolarization process may render other neighboring molecules unstable and result in their depolarization, so that a pulse of depolarization may pass along a channel of associated molecules. When the disturbing stimulus has passed, the normalizing effect of the resultant field of the neighboring parts will tend to restore the polarization of the relaxed molecules, and so a pulse of repolarization will, under suitable conditions, follow the pulse of depolarization.

Thus a double one-way pulse evokes the polarization cycle of each molecule, the depolarization phase being due to the spontaneous relaxation of each molecule, and the repolarization phase to the inductive influence of the resultant field of neighboring molecules and of the environment. The molecules form a working association with a characteristic cycle.

We have already defined the normalizing of the field of a uniform region as the unitary process whereby disturbed or relatively depolarized units are brought into a state conforming more closely to the resultant field. Normalization is a process which tends to establish uniformity of polarization in any uniform region set within a polarized environment. Thus the term includes as special cases the tendency toward uniformity of polarization, not only of cyclically transformable protein or other molecules, but also of inorganic dielectrics.

Normalizing processes are intrinsically self-facilitating.

If a normalizing pulse passes through any partly disordered system of polarizable molecules the effect of the pulse is not merely to repolarize certain molecules, but also to adjust their positions and orientations so that they are more symmetrically and regularly arranged. This ordering tendency of the pulse may be arrested or reversed by thermal or mechanical factors, but where that does not occur, the net internal result of the cycles of depolarization and repolarization will be to work the molecules, or any other polarizable structures, toward the most regular possible arrangement expressing the character of the region. Thus the drawing together of similar polarizable structures, as in chromosome pairing, may be due, not to specific long-range "forces," but to the resultant effect of polarization pulses passing through the highly polarizable medium between pulsating structures. (See § 37.)

Inorganic and organic ordered regions share the normalizing tendency toward uniformity of polarization. But it is only in organic ordered regions that cyclically polarizable molecules undergo repeated one-way pulses of depolarization and repolarization as components of a more extensive and complex one-way process characteristic of the whole system as a unit.

CHAPTER III

THE PHYSICAL BASIS OF LIFE

18. The Physical Basis of Life

The problem of biological organization can be divided into two parts. We can first examine the various properties of differentiated systems of living protein, and then we can consider how these systems are combined in the complete organism so that life is maintained. In discussing the first aspect we assume the existence of the organism and consider its component processes, while in treating the second we assume the existence of the component processes and consider how they co-operate to form the comprehensive process which is the living organism. In this chapter we are concerned with the first part.

But does not the term *physical basis* beg the question? In what sense does the basis remain physical when it is a functioning part of an organism? What is the relation of the ordinary properties of the physical and chemical constituents of organisms to their properties when they form parts of a living system? This fundamental issue must be clarified before we can consider the various physical constituents of the organism.

The study of groups of men and women in isolation from one another would not reveal the possibility of the human family, for the sexes are radically modified when they live together in mutual orientation and working association. No more can the study of the individual chemical constituents in a pure state reveal their properties when each is modified by the presence of a pattern of neighbors, many of which may be chemically different from itself. A protein molecule, for example, may have hundreds of smaller molecules of more than ten different kinds taking up specially oriented positions in its neighborhood, and in these oriented associations special directional properties are of importance which do not come into play when similar protein molecules are examined outside the organism. Moreover, these directional properties are not static, but are directly involved in the processes of the organism.

Thus the difference between the properties of any constituent *in vitro* and *in vivo* is twofold: (1) since many molecules *in vivo* are surrounded by a pattern of different neighbors, directional properties acquire a new significance; and (2) these oriented groups are working associations, i.e. the molecules maintain each other in states permitting cyclic co-operative transformations. Living material consists of oriented working associations of molecules which lose their mutual orientation and their capacity for cyclic transformation when excessively disturbed or removed from the organism. Consequently no theory based solely on ordinary chemical analysis, and no physico-chemical model based on classical physical conceptions, can exhaustively cover its properties.

This does not mean that it is impossible for an analytical method of approach to lead to a correct theory of organism, but only that a dynamical analysis based on structural units without directional properties cannot do so. A unitary analysis does not neglect the organizing relations of the living system, because these are automatically allowed for by the unitary interpretation of the relation between wholes and parts.

As we have already seen this relation is determined by two tendencies which normally alternate in dominance: (1) toward highest symmetry and lowest polarization of the parts; and (2) toward uniformity of their resultant polarization. The second of these tendencies is characteristic of the system as a whole and it is this aspect which is neglected in ordinary dynamical or chemical analysis. We can therefore proceed to an examination of the physical basis of life without risk of neglecting its living properties, so long as we bear in mind that as part of an organism the physical structures are perpetually being repolarized to conform to resultant fields which would not be stable outside the organism.

The following analysis also assumes that enough is already known of the properties of the physical constituents, e.g. of protein, to provide a reliable basis for the argument. If the interpretation proves inadequate this need not be the fault of the unitary method, but may be due to limitations of the present exposition.

With this preface we can now examine the role of some of the more important constituents of organisms. We shall consider only those properties which are directly involved in biological organization. Moreover, for reasons which will become clear later, the argument will at first be restricted to animal organisms, green plants and more primitive organisms being discussed toward the end of Chapter IV.

Under the unitary principle each of the chemical atoms is characterized by a specific type of latent symmetry and of residual asymmetry, with corresponding thresholds and modes of polarization. These are not yet understood, but the following suggestions may be made regarding the most important properties of hydrogen, carbon, and oxygen atoms in the free state. The residual or uncompensated asymmetry of any will be referred to as its residual vector or vectors.

The *hydrogen* atom displays in many situations the properties of a fundamental unit of asymmetry or polarization, and can then be represented by a fundamental unit vector. This unit vector tends to complete the symmetry of more complex patterns, either by combining with another atom, or by acting as a link between two atoms in such a manner as to extend and enhance their common polarization or to permit a fluctuating polarization.

The *carbon* atom has four residual vectors normally forming a centrally symmetrical (tetrahedral) pattern, but capable of building up linear and planar structures, e.g. when combined with other carbon and hydrogen atoms into chain or ring molecules. Such molecules may have a high degree of symmetry and stability. The linear and planar form of many organic carbon compounds makes them specially suitable as fuels for oxidation.

The *oxygen* atom has two residual vectors at an oblique angle to one another, which cannot easily be brought into a more symmetrical state. Therefore, in tending to complement these residual vectors and to complete its central symmetry, the oxygen atom distorts and often destroys other linear or planar structures whose components it can seize. In tending to compensate their own polarity the two oblique vectors of the oxygen atom grip, distort, and fracture the symmetrical but less stable patterns of fuel molecules.

These two vectors induce asymmetry in ("transfer free energy to") the linear or planar fuel molecule and frequently also in other neighboring molecules which are not fractured in the process. In the course of the oxidation process the tendency of the oxygen atom to complete its own central symmetry is dominant, and induces a polar asymmetry in neighboring molecules possessing linear or planar symmetry.

A respiratory system, whether it consists of a simple fuel molecule or of a complex series of oriented molecules, is thus a structure which extends and renders more effective and efficient the polarizing influence (i.e. "the free energy") of a free oxygen atom or its equivalent. Within an organism oxidation normally means the induction of polarization in a linear structure, and reduction normally involves the restoration of linear symmetry.

Water pervades all tissues, and serves as dispersion medium, lubricant, propagator of polarization, and above all, at normal temperatures, as stimulant of change. Water molecules are highly asymmetrical, flexible structures (high polarization, specific heat, dielectric constant, etc.), and they tend to associate with and modify other materials (by solution, ionization, activation, etc.), thus furthering chemical changes in general. No other material has in the same degree as water this general property of promoting movement and change. The asymmetry of the isolated oxygen atom is so powerful that it tends to destroy nearly all molecular patterns not already oxidized; when combined with hydrogen this power remains, but in reduced intensity. Water is the supreme *nonspecific* facilitator of chemical change.

Groups of water molecules continually bring their polar vectors into mutual orientation, and thus form tiny oriented aggregates like liquid crystals, though these have low thresholds and at normal temperatures are perpetually dispersed by heat motions. Moreover, water molecules tend to take up and extend through the medium the static or cyclic polarization fields of protein structures, though at greater distances this tendency is rendered ineffective by heat motion. The ceaseless alternation of more and less oriented states and the gradation of polarization patterns becoming less specific and stable at greater distances constitute prototypes of the cyclic changes of polarization and the gradation of fields which characterize many protein processes.

All the other nonprotein constituents serve some special role in relation to the protein processes which determine the general properties of animal organisms. The *fats* act as reserves, and the *sugars* as immediate sources of free energy, if oxygen is available. They provide linearly symmetrical structures which, in the course of respiration (fermentation or oxidation), become distorted and by induction carry neighboring structures over thresholds so that synthesis or the performance of work is accomplished. *Salts* modify the properties of protein molecules by adsorption on special parts of their surfaces. The *enzymes, hormones, vitamins,* etc. (some of which are proteins) are structures with specific polarization patterns which, either in tending to extend their own pattern or in some other manner, act as catalysts and regulators of other transformations: they lower particular thresholds, and so act as the facilitators of *specific* chemical changes. The *polysaccharides* (in plants) and the *nucleic acids* serve as accessories which are indispensable for the stabilization of certain processes of living protein.

19. Living Protein

Protein forms the functional pattern of animal organisms. All the properties which mark animal organisms as organized units result from their protein constitution. We shall see that these properties of organization are necessary consequences of the unitary principle under particular conditions, and it is only in protein systems that these conditions are realized. In this work we are only concerned with the properties of *living protein,* i.e. with the special properties displayed by protein when it is a component of living cells.

The spatial aspect of the functional pattern of an organism consists in the appropriate relative orientation of all its constituents. Protein constitutes the basis of this functional pattern (in animals), because it is mainly the protein framework which determines the normal state of polarization in any region and therefore the normal orientation of all polarized constituents. Directed processes in organisms, that is, all those processes which occur not only at particular times and places but in particular orientations, are largely determined by their relation to the protein framework.

Organisms combine in a unique manner the properties of stability and instability. In animals the stability of all functional tissues in relation to certain types of disturbance is due to the general stability of the protein structure, while their instability in relation to the stimuli which evoke their functions is due to the capacity of the protein structure to undergo characteristic transformations without passing high thresholds.

This remarkable combination of properties receives an immediate interpretation in unitary theory, since all stability is due to symmetry, and asymmetry is the source of change. On the one hand, the tendency to stability in protein systems expresses the capacity to form linearly symmetrical chains which can be folded into a variety of other symmetrical structures. On the other hand, the tendency to undergo characteristic changes following a slight stimulus arises from the asymmetrical (polar or polarizable) side and end-groups which can be strung on these chains, the interaction of these polar groups with their changing environment determining the manifold transformations of the protein molecules. Thus the protein chain serves as a relatively stable carrier of specific polar (or polarizable) groups whose processes determine the changes which the chain itself undergoes.

But living protein displays a further all-important property. The polar or polarizable side groups are arranged regularly, and establish a continuous resultant field throughout each functional region (and throughout much of the animal organism) so that one normalizing process dominates the region, and alternating pulses of depolarization and polarization are propagated without interruption along channels of identical or co-operative molecules. We shall see later that this property provides the clue to the co-ordination of local processes as components of one extended normalizing process. It is the continuity of induction of polarization throughout the functional regions of the organism, so that one normalizing process composed of a pattern of local normalizing processes controls the whole system, which underlies the developmental and functional stability of the organism.

Thus the combination of *stability* in a symmetrical polypeptide chain, with *instability* of asymmetrical (polar) side-groups, so arranged as to produce a *characteristic resultant field* capable of normalizing all the molecules in a given region, fits protein for its unique role in organisms. We will now consider these three characteristics more closely.

The stability of all protein, i.e. the persistence of certain geometrical patterns of definite size, is fundamentally due to three stages of synthesis:

1. The basic synthesis of the peptide link, which provides a stable unit of *linear structure* of definite size ($3.6.10^{-8}$ cm. in fully extended, planar form). This link determines the linear scale of all protein structures along one axis. (In all naturally occurring proteins the carbon

atom linked with four different groups is "left-handed." This important fact will be referred to later [§ 43].)

2. The condensation of a finite number, say some hundreds, of these links into a stable but flexible polypeptide chain (or narrow, flat or twisted strip about 10^{-7} cm. wide and half as thick), capable of folding or combining into loops and sheets, and so forming a stable *two-dimensional structure* of protein monolayer, or reticular structure of protein strips of almost any size. Some protein molecules appear to consist of a set of identical self-reproducing platelets with a specific pattern of side-chains.

3. The third stage is less understood, but may consist of the arrangement of such chains and sheets to form a cubic lattice or closed quasi-spherical surface, which, with its contents, constitutes a stabilized unit of *three-dimensional structure*. Some globular protein units have a diameter of about 10^{-6} cm., equivalent to thirty peptide links. Genes (defined as the nuclear structural units stabilizing genetic properties) may be stabilized, yet pulsating, three-dimensional structures composed of a pile of self-reproducing monolayers of identical pattern.

Finally in living protein, these molecules, with associated water molecules, are arranged in a stable or elastic, two- or three-dimensional lattice possessing a characteristic resultant field.

The various nonspecific properties of protein express different aspects of this triple geometrical basis: the basic linear unit of stable structure; the capacity of chains of such units to form stable open sheets and networks; and the folding of these sheets into stable closed surfaces. In other words, the nonspecific properties of all kinds of protein must be interpreted as the result of increasingly complex combinations of the basic peptide unit.

The stability of protein structures, however, is due not only to this tendency to form symmetrical patterns from a basic main chain, but also to a further property of active self-stabilization. Any complex molecular framework, such as probably exists in many types of protein, tends to increase its stability by attracting into position structures, such as hydrogen or other links, which can further complete its symmetry. Any internal asymmetry, present in such a framework when it is first formed, will attract complementary structures into position, and the symmetry and stability of the complex molecule or association will thus tend to be raised. In fact, any structural network containing an internal residual asymmetry will tend to stabilize itself further through the complementing of that asymmetry. It is thus reasonable to expect in certain types of protein a tendency to form stable patterns which are self-stabilizing, i.e. which tend to increase their own stability.

In all such systems it is only the general structural pattern which displays stability within certain limits; the individual atoms, and even the individual molecular groups, are continually exchanged for other chemically identical units. But this flow of individual atoms or radicals usually leaves the characteristic pattern of any given type of protein unchanged.

Parallel with this tendency to stability in the symmetrical patterns of the chain, protein molecules display instability owing to the tendency for changes to occur in the general arrangement of the chain as a result of the polar asymmetry of the side and end-groups. The interaction of these groups with their environments determines most processes occurring in protein, the flexible skeleton serving to hold these polarized patterns in position and to carry them about under the influence of their interactions. This tendency of the polar groups to initiate changes would lead to confusion if it were not for the tendency to stability of the main chains.

But just as complex symmetrical structures, if left undisturbed, tend to stabilize themselves, so any cycle of transformations occurring in the internal structure of a protein molecule tends also to become stabilized, in the sense that the thresholds involved in the cycle tend to diminish, so that the cycle is more easily performed. For it is a general property of such linked structures subject to restraints that they tend to rearrange themselves in such a manner as to offer the minimum resistance to any imposed movements.

A system of this kind which is repeatedly worked in a definite manner, for example folded and unfolded, will tend to adjust its structure so as to offer the least resistance to the enforced cycle of changes. Adjustments occur which facilitate the changes imposed on the system. Thus while structures which remain unchanged tend to grow more stable, cyclic changes which recur tend to be facilitated. In this sense *protein structures and cyclic protein processes are both self-stabilizing.*

These protein structures are not, however, isolated, but are set in and pervaded by an aqueous medium at a certain temperature. At every point the stabilized pattern of the protein structures and their spatially directed processes not only influence the aqueous medium, but are themselves influenced by the disordered heat motions of the water and other small molecules. The normal orientations of protein structures and processes are perpetually disturbed by the heat motions of the medium; the directed character of protein processes is challenged by the thermal disorder.

Up to a point the influence of the medium will aid the protein processes by supporting the molecules against gravity and by lubricating them; beyond that point it will tend to disturb them. But the tendency of protein structures and their cyclic transformations to become stabilized means that, if the temperature is not too high, there is a bias on the side of the directed as against the disordered processes: polarized regions tend to grow: long-range interactions become possible: the role of directed influences relatively to that of thermal disorder tends to increase: there is a tendency toward increasing biological efficiency (economy of free energy). This tendency for living systems to develop more efficient methods does not imply the presence of any teleological factor operating independently of structure, but is a direct consequence of the self-facilitating property of unitary processes, as realized in protein systems. Order, once established, tends to stabilize itself and to extend its scope.

It is, however, the third characteristic, the property of maintaining and restoring a characteristic cyclic resultant field in each functional region, which distinguishes living protein from denatured protein and from all other physico-chemical systems. In functional protein the molecules possess two characteristic states separated by a relatively low threshold, and are normally held in the higher, meta-stable state by the resultant field of the region in its undisturbed state. The normalizing tendency of this resultant field holds polarized groups, such as free radicals, in definite orientations and so prevents them from combining with one another. But if the molecule is disturbed by any external influence it will tend to pass into the more symmetrical depolarized state, though the cycle will later be completed by the restoration of the resultant field of the system as a whole. Thus living protein is continually pulsating.

The normal condition of functional protein is thus one of high polarization sustained by a resultant field characteristic of the region; the molecules are highly polarized and regularly oriented patterns which tend to collapse if the balance of the system is excessively disturbed. The maintenance of this condition of cyclic transformability requires:

1. Large molecules or extended networks, so that thermal motions do not unduly disturb their regular arrangement and rhythmic pulsation.
2. High uniform polarization fields relative to the size of the molecules, i.e. high molecular polarizability, or regular and sufficiently close repetition of polarizable groups or H-bonds. (These protein fields dominate normal thermal motions and are comparable to the intermolecular effects determining the cohesive strength of solids and liquids.)
3. A medium which allows adequate scope for intra- and inter-molecular changes, and helps to maintain the polar groups in a state of polarization.

These conditions can only be satisfied in a system of molecules composed of chains with regularly repeated polar side-groups, assembled into regions with a characteristic resultant field which tends to sustain the molecules in their regularly arranged polarized condition. The protein of a functional region in an organism is precisely such a self-sustaining arrangement of polarizable units. The units are metastable and are transformed by any stimulus, but the system as a whole is stable and tends to restore its normal state, unless the disturbance has been too great.

The denaturing of protein consists in the loss of this characteristic arrangement which permits cyclic transformations, owing to an excessive disturbance of the resultant field in any region. The protein chains collapse from the functional state in which they are held apart in regular positions, into a relatively static and irregular aggregation.

20. *Multiplication*

In unitary theory all stability of specific pattern is due to single units possessing a characteristic type of symmetry. The physical stability of organic structure in the individual adult animal expresses the structural stability of existing protein molecules. On the other hand, the general stability of organic form, both in the species and in the development of the individual, depends on the capacity of certain types of protein molecules to multiply by facilitating the synthesis of new identical molecules, possibly through the intermediary of a molecule of complementary form. This process of the synthetic *multiplication* of prototype molecules is a fundamental component in all organic synthesis, antibody, gene, and virus activity, chromosome multiplication, cell division, growth, differentiation, and repair of tissues. It is, as we shall see, one of two fundamental organic processes.

Many aspects of organic synthesis are still obscure, and in no case is the exact space-time pattern of a synthetic process yet known. Nevertheless, it is scarcely open to doubt that regular organic synthesis of specific units depends on the extension or duplication of the pattern of an already existing prototype. More precisely, a fundamental chemical step involved in the synthesis of a complex organic structure can only occur regularly in the neighborhood of a similar, i.e. identical or complementary, structure in which that step has already been completed, such as a pulsating protein platelet.

A new structure may be established through the convergence of a number of factors, brought about either by "chance," as in the first origin or origins of life, or by human intention, as in laboratory synthesis. But the first process is rare, and the second irrelevant to organic synthesis in a living cell. Moreover, the extraordinary stability of species characters throughout the generations, and of tissue character in the growth of the individual, suggests that the multiplication of stable unit prototypes underlies normal organic synthesis.

This conclusion, however inescapable it may be, has a somewhat anomalous character within the context of contemporary physical and chemical theories, which contain no *explicit* recognition of a formative tendency such as might cover the multiplication of units of pattern. But regular organic synthesis, regarded as the induction of pattern in less stable materials by a more stable prototype, presents no problem for unitary theory, since it is an expression of the unitary principle. (See §§ 15, 16.) The biochemical problem of organic synthesis is transformed into a special case of the unitary process.

The multiplication of a protein molecule is a complex process achieved in a series of synthetic steps, which may be grouped as follows: the basic synthesis of peptide links; the condensation of these into protein chains; the folding of these chains into loops, strips, or sheets; and, at some stage or stages in this process, the specific synthesis, or establishment of a characteristic pattern of side-groups and conjugated groups. Every living cell, it seems, can perform all of these processes, with the important exception that animal cells, and some others, cannot achieve basic synthesis. It is probable that only the final steps of specific synthesis or folding are performed by direct induction from the prototype molecule which represents the end result of the series. For example, this may consist in the multiplication of the protein monolayer platelets of which genes and other self-reproducing protein units are probably composed.

Thus the multiplication of a highly specific protein molecule is not a sudden complete synthesis of an identical complex structure, but a step-by-step process, occurring probably at a series of different sites in the cell, which may be interrupted by the diversion of intermediary products. A chain of successive processes operates so as to multiply, perhaps simultaneously, all the structures involved in the chain. Protein synthesis is a multiple autocatalytic process, leading one way along the main path, but capable of branching to supply less specific products.

This process of the progressive synthesis of protein is (in one sense) prior in time to all other organic processes (except the absorption and digestion of foodstuffs, which must precede it), and yet (in another sense) represents the cumulative internal result of all other processes. For protein molecules must be synthesized before they can be associated in tissues, perform their functions, or disintegrate, and no life exists without protein. Moreover, we shall see later that all the processes of differentiation, self-regulation, and adaptive modification are so arranged as to facilitate the dominant process of protein multiplication. This is the fundamental internal process in all organisms.

The result of any process of protein synthesis is a step of growth, that is, an increase in the number of molecules of some characteristic protein. Biological organization is such as to insure that this process of synthesis follows an optimum, or most direct, path from one cell division to the next, and from one fertilized ovum to the reproduction of the next generation. This most direct path represents the most highly facilitated process, so that all orientations are most closely controlled and least left to chance, subject to the existing conditions. In every cell actively performing synthesis there is a flow of influence, or one-way induction of specific pattern, outwards from the hereditary or already synthesized specific structures on the simpler materials passing inwards through the external membrane, and there is a flow of materials passing inwards and undergoing a succession of synthetic steps according to its path in the cell. A hierarchy of dominant prototypes, itself the product of earlier multiplication, exerts its formative influence outwards, inducing its own multiplication.

But this process of the catalytic multiplication of specific chemical units does not occur in isolation. A specific type of synthesis only occurs when it is evoked in a certain manner by the rest of the system, and when it has occurred the product influences the rest of the system in various ways. Even this dual expression of the relation of a local process of synthesis to the rest of the system is inadequate, for every process of specific synthesis occurs as a component of a normalizing process extended over wider regions of the organism. The causes producing synthesis, the local synthetic process itself, and the effects which it produces, are all components of one comprehensive normalizing process.

The significance of this relation of local specific processes to the comprehensive normalizing process of the organism will become clearer as the argument proceeds. The specific units of hereditary origin constitute the dominant structures in the organism, and their continuing reproduction is the dominant internal process. But the process of synthesis continues because it is a component of the more comprehensive self-maintaining process which is the organism in its environment.

21. Modification

THE SECOND FUNDAMENTAL PROCESS in organisms is protein *modification,* or the establishment of ordered relationships between the units produced by multiplication. The latter process normally leads to the formation of a single unit of structure, while modification produces stable or metastable relations of position, orientation, and polarization, within extended groups of such units. Moreover, the process of protein modification, like that of protein multiplication, leads to a result which facilitates its repetition. (It will be convenient to use the term *modification* to cover both the process and the resulting modified state.)

Multiplication produces no new pattern; it merely preserves and extends structural patterns derived from the past. But modification results in local novelty, for it represents a residual effect produced by contemporary influences derived ultimately from the environment. While multiplication is the reproduction of hereditary units of stable symmetry, modification consists in the common polarization of such units under normalizing fields which express the fact that the hereditary units are not isolated, but are set in a contrasted environment. The former represents the inner or local, and the latter the outer or extended unitary process. The outer process evokes the latent potentialities of the hereditary units by establishing states of common polarization and working association.

All organic modification leads to the establishment, or improved arrangement, of an ordered region of polarized units, that is, a region in which the polarization tends either to become uniform, or to establish the minimal gradient compatible with the boundary conditions of the region. The simplest class of modifications is that in which a large number of identical units are present, tending to establish a common orientation and polarization.

These relatively uniform modifications range in size from intracellular parts, such as membranes and cytoplasmic gels, to the extensive tissues of the largest organisms. They are characterized by the regular orientation of polarized protein and other molecules, and consequent anisotropy of the region. Thus optical and other tests have established the presence of regular states of orientation in chromosome spindles and asters, ectoplasm, pseudopodia, muscle fibers, nerve sheaths, cilia, virus concentrations, etc.

The unitary theory of organism suggests that all protein organization (in animals) depends on the orientation of polarized parts, and that all protein modifications are characterized by a tendency toward minimal (or zero) gradients of polarization. This applies to all cyclically functioning tissues, and excludes only those structures which are temporarily out of function, such as aqueous vacuoles, circulating fluids, reserves, etc.

On this view the initial response of all protoplasm to an exciting stimulus consists in a disturbance of the normal field of a protein modification. The normal state is one of metastable polarization, sustained by the normalizing tendency of the region of which the molecule is a component; the stimulus consists of some environmental change which disturbs this state and sets free the inner tendency, thus producing a local depolarization; this disturbance upsets the balance of a more extensive region so that a pulse of depolarization occurs; but when the stimulus has passed, the normal state is restored by the normalizing tendency of the whole region. This cycle probably underlies all rapid propagation of cyclic transformations, as in the gel-sol-gel changes in cytoplasm and the functioning of neuromuscular tissues.

22. *Functional Systems*

THE RELATION of any organic system to its component parts is determined by the states of polarization of the system and of the parts. The parts, if disturbed, tend to depolarize, but the system, if not excessively disturbed, tends to normalize itself, and to restore the polarization of any depolarized parts. Thus cycles of depolarization and repolarization will be repeated provided that appropriate disturbing stimuli occur, and that the normal polarization of the system is in turn sustained by the polarization of some wider system of which it is itself a component. So long as these conditions are satisfied the alternation of the inner tendency to structural symmetry, and the outer tendency toward extended uniformity of polarization, will maintain the operation of any cyclically transformable systems in the organism. We now have to consider in greater detail the properties of such functional systems.

For the purpose of the present argument a functional system may be regarded as a finite region within an organism, in which the spatial relations of the protein molecules are sufficiently stabilized in a pattern which facilitates a particular cycle of changes of polarization. It is thus a local modification facilitating a particular cycle. Every functional region is in continuous relationship with one or more other neighboring regions of different character, and the net result of a cycle in one region always influences another region. Thus the cycle of one region is causally linked with the cycle of the next, and the normalizing process of any region is, in the ultimate analysis, to be regarded as a component of one comprehensive normalizing process: the developing and functioning organism in its environment.

We shall return later to the consideration of the organism as a whole. For the moment we have to consider the individual functional systems separately.

Functional systems may be either uniform or nonuniform, that is, they may be composed either of a system of identical protein molecules or of ordered sequences of nonidentical molecules or other units. The first category covers all uniform membranes and conductive and contractile tissues, the second all sequences of nonidentical molecules which co-operate to facilitate a specific polarization cycle, such as synthetic enzyme-systems, and possibly also ordered sequences of genes (if such sequences exist) in chromosomes. In the first class, the properties of the region depend on the resultant effect of a succession of processes in identical structures; in the second, on the resultant of a succession of complementary and cumulative steps of processes in an ordered series of different structures.

Nonuniform functional regions are mainly concerned with the transformation of chemical units, for example with the synthesis (or lysis) of characteristic protein, etc., and these will be treated in greater detail later in relation to synthesis (§ 32). In this section and the next the argument will be restricted to the uniform functional systems concerned with either the selective transmission of materials (semipermeable membranes), or the propagation of changes of asymmetry, i.e. of shape and polarization (contractile and conductive tissues).

If it is true that all cyclic function consists in a cycle of changes of polarization under the unitary principle, an important consequence follows for the theory, both of the function of differentiated parts, and of the general organization of the system. For this means that the general principles of biological theory can be formulated in terms of inner and outer tendencies, and of part and system polarization, without specifying the exact three-dimensional structure or atomic arrangement of any particular kind of protein. If all cyclic function represents the alternation of processes of relaxation and normalization, then ignorance of the detailed structure of any particular protein does not prejudice the establishment of a general theory, provided that the fundamental principles of the theory are valid, and that the properties common to all living protein have been correctly identified. A general theory of biological organization can precede complete physical and biochemical knowledge even of any one kind of protein. This fact is of importance, and alone justifies the development of the unitary theory of organism at the present time.

A basic principle in the theory of crystals (Neumann's principle) states that the symmetry type of the most complex macroscopic form of a crystal provides an adequate foundation for a theory of the symmetry character of its physical properties. The unitary interpretation of organic function suggests that a comparable principle applies in the theory of cyclically transformable systems of identical protein molecules: there is complete correspondence between the directional properties of the polarization cycle of the region as a whole and that of the individual molecules. It follows that a general theory of uniform functional systems can be based on the general characteristics of their cycles, without a detailed analysis of the structure of their component units. In other words, the general theory of uniform functional systems is nondimensional in character, like the general theory of crystals, and applies to systems of all sizes and of any atomic and molecular structures, provided that certain symmetry conditions are satisfied. Thus it is indifferent to the following discussion whether a uniform region consists of a few molecules about 10^{-6} cm. in diameter, or of an extensive volume of differentiated tissue composed of myriads of such molecules.

23. *Uniform Systems*

If all function consists in cycles of changing structural asymmetry, the net result of the cycle of a uniform region may be:

1. *The maintenance of high asymmetry.* This extreme case may be exemplified in the electric organ of the Ray Torpedo.
2. *The propagation of pulses of increasing and decreasing asymmetry.* This wide category covers:
   (*a*) gel-sol-gel and other cycles involving propagation of changes of both shape and polarization in relatively undifferentiated cytoplasm;
   (*b*) propagation of changes of shape and polarization in nervous tissue; and
   (*c*) propagation of change of shape and polarization in contractile (e.g. muscular) tissue.
3. *The restoration of normal local symmetry and asymmetry after local disturbance.* This covers semipermeable membranes, which tend to return to a normal state of symmetry and continuity along a surface, and a normal state of polarization perpendicular to it.
4. *The maintenance of symmetry.* In this second extreme (and logically degenerate) case cyclic function reduces to the purely mechanical function of elastic connective, or rigid supporting tissues.

The two extreme cases will here be neglected, and we shall consider only semipermeable membranes and conductive and contractile tissues. The argument will suggest that in each of these three types of tissue the influence of a more extended system tends to establish the normal polarization of the region and to restore it after disturbance, thus producing a cycle with a characteristic net result. Moreover, each phase of the local cycle has a one-way directed character, so that, though certain aspects of each phase complement each other and form a closed cycle, the net result of the functional cycle of the region is a one-way process forming a component of the comprehensive one-way process of the system, organism in environment.

Semipermeable membranes. Every cell is separated from its environment by a continuous surface forming the common boundary of two different media, the internal plasm and external fluid. The chemical difference between these media establishes a state of polarization across the boundary, which is the ultimate source of polarization stabilizing all the polarized regions, either within the cell or within a multicellular organism. All the normalizing processes of the organism originate from, and are stabilized by, the normal polarization of the external membrane, which is spontaneously restored after every disturbance.

The polarization of the external membrane is not a consequence of its internal structure. On the contrary, the polarized structure of the membrane, expressing probably the regular orientation of molecular dipoles, is a consequence of the asymmetry between the internal and external media inducing an asymmetry in the protein and other molecules at the interface.

After every disturbance which has not unduly interrupted the regularity of the boundary, the membrane is automatically restored, as a consequence of the interaction of the contrasted media. The membrane normally consists of a few layers of oriented and associated protein and other molecules drawn into position by the polarized interface and forming an extensible and moderately stable self-repairing sheet with a characteristic normal polarization (resting potential). In unitary terms: the local normalizing tendency orients and arranges the molecules of the membrane to conform to the dominant polarization resulting from the contiguity of the two contrasted media.

This state of polarization along an axis perpendicular to the membrane tends normally to spread into the neighboring cytoplasm, orienting the protein molecules and tending to set up the gel state. If the membrane is disturbed, or its polarization otherwise reduced, the gel tends, because of thermal disturbances, to revert to sol. Any factor tending to raise the membrane polarization tends also to increase the degree of orientation and rigidity of a gel, and vice versa.

Thus cyclic changes in the state of an external membrane and of the neighboring plasm form components of one-way pulses which pass inwards from the external boundary. The disturbing stimulus acts from outside, a depolarizing pulse passes inwards, and the normalizing process which restores the polarization also starts from the outer boundary and works inwards.

But in the case of semipermeable membranes every disturbance not only upsets the local polarization perpendicular to the membrane, it also destroys the continuity along the membrane, sending concertina-like shivers in all directions. This shivering of the membrane facilitates the movement through it of chemical structures of appropriate symmetry type in a direction determined by the polarization of the membrane. Parts of the membrane may form special channels facilitating the passage of particular molecules, and such directed transport may be accompanied by simultaneous chemical transformations, if appropriate enzyme-systems are sited on the membrane.

These considerations also apply, with appropriate modifications, to internal semipermeable membranes.

Conductive tissues. All protein systems tend to establish, by propagation or otherwise, a uniform resultant field, but in undifferentiated protoplasm this property is often masked by thermal and mechanical disturbances. Fine protein fibrillae may convey states of polarization from the outer membrane toward the interior of the cell, and gelled states may acquire some stability. But it is in the further differentiation of a protein modification similar to the membrane, i.e. the stabilization in conductive tissue of certain properties of the membrane, that the tendency to uniformity of resultant polarization, and the consequent propagation of a state of polarization, finds its fullest expression.

Here the same basic factors recur, but in a more stabilized form. The chemical difference between the media exterior and interior to the surface of the nerve axon provides (when reinforced by a respiratory system) the extended normalizing field necessary to restore the normal polarization of the molecules of the conducting membrane. It is important to notice that, in unitary theory, the polarization and depolarization of the membrane do not necessarily imply a transport of electricity, in the sense of a spatial displacement of ions requiring a change in the permeability of the membrane. The depolarization may consist simply in a relaxation of the molecular structure from a more to a less asymmetrical state, when the sustaining influence of the extended system has been reduced through the depolarization of a neighbor.

The individual protein and other co-operating molecules go through closed transformation cycles, but these cycles are induced by, and produce, one-way pulses of polarization and depolarization along the membrane. The local cycle is a component of a more extensive rhythm of relaxation and normalization.

Contractile tissues. Transformations of a protein molecule in general involve both a change of shape and a change of net polarization. In nerve fiber sheaths and in semipermeable membranes the molecules are so associated that their individual changes of shape do not accumulate to produce a resultant macroscopic change in the shape of the tissue as a whole. On the other hand, in certain regions of some cells, and in muscular tissues, the microscopic changes of shape do produce large-scale effects. For example in the ectoplasm of amoeba a pulse of polarization passing through the medium by induction from molecule to molecule produces a macroscopic contraction along a particular axis, resulting in cyclosis. This property is further developed in muscular tissues where the protein molecules are so associated into (myosin) fibers that a pulse of polarization results in a propagated and co-ordinated change of shape, molecular folding leading to macroscopic contraction, even against high resistance. (This is one case in animal organisms where the chiral character of protein may play a direct functional role.)

In these three cases a differentiated local cycle of molecular transformation constitutes a component of an extended one-way process. The cycles of disturbance and re-formation of a semi-permeable membrane are merely the local component of the inward moving pulses of polarization and depolarization, of which the directed transport of materials across the membrane may form another component. Again, the cycles of the nerve protein molecules are the local component of one-way pulses of polarization and depolarization passing from sensory toward motor organs. Finally, the cycles of contraction and elongation are one component of a pulse of polarization and depolarization transformed into macroscopic one-way changes in the spatial relations of the organism to its environment. These cases illustrate a general principle in unitary theory: the functional cycles of differentiated regions can only continue as components of alternating one-way processes of relaxation and normalization passing through the organism.

24. *The Formation of Functional Systems*

We are now in a position to consider the general principles determining the formation, structure, and operation of functional systems, i.e. of all regions in an organism possessing a characteristic cycle of resultant polarization. This resultant may be that of a system of identical molecules or of a graded series of different molecules or other units, the essential condition being that the resultant field is sufficiently continuous to be self-stabilizing. In this section we are still mainly concerned with the individual functional system, rather than with the co-ordination of such systems in a complete organism.

The process of formation, the stabilized structure, and the mode of functioning of these systems are three inseparable aspects of one process, and there is therefore a close correlation between them. For example, the last stage of the process of formation is identical with the normalizing phase of the cycle of function, as we shall see later. Further, the stabilized structure is no more than the terminus of the formative process, and the function of the structures is to facilitate the repetition of the process by which they are formed. A complete description of any one of these three aspects must contain a description of the others, and understanding of any one implies that of all three, for they are components of a single comprehensive process in terms of which they must be understood. Yet these aspects have been separated in recent theories, and the transition to the unitary view is aided by their separate consideration.

Formation. The formation of functional systems, whether in the developing animal organism or in a single cell which has been mechanically disturbed, may be regarded as due to the interplay of two factors: an inherent tendency for such systems to be formed under suitable conditions, and the presence at a particular site of the hereditary and environmental conditions which enable that tendency to be realized. The second factor, which determines the formation of a functional system at a particular site in the cell or in the differentiating embryo, will be treated under the problem of differentiation (in § 33). Here we shall consider the first factor. It is necessary to show that unitary processes will in suitable circumstances lead to the formation of complex systems with a characteristic cycle of resultant polarization.

We have already seen that, with certain exceptions not relevant to the present argument, every unitary process leads toward the establishment of a structure facilitating the repetition of the process, and that protein structures in particular tend to stabilize themselves and to extend their pattern in facilitating the formation of further similar structures. This fact may be expressed in terms of fields: every resultant field in protein tends to become more uniform, and to complete or extend itself by a process of induction. Or in terms of molecules: a stabilized pattern of oriented polarized molecules tends to draw appropriate molecules into regular positions and orientations, and in doing so if necessary even to transform them, so that they conform to, and either complete or extend, the pattern. Structures with either identical or co-ordinated polarization, i.e. structures which when suitably oriented can together produce a more uniform resultant field (subject to any boundary condition), tend to be drawn into those sites and orientations which result in maximum uniformity of the field.

The formation of cyclic systems represents a special case of this general principle, where each molecule individually, and therefore also the field as a whole, possesses two states, a metastable and a stable, of greater and less polarization, separated by low thresholds. Here the process of the formation of the functional system consists in a pulse of normalization arising from outside which, in passing through the site marked by certain stable hereditary units, draws all the molecules toward those positions and orientations that enable them to co-operate in the cycle. Moreover, the functional working of the system, which may equally be described as the one-way pulsation of the field or as the successive cyclic transformation of a sequence of molecules, facilitates the further development of the system.

Certain attractive and orienting forces between mutually polarizing molecules have already been recognized in quantum theory. It will later be the task of rigorous unitary theory to show that the unitary process in a protein system of specified structure is equivalent to the operation of a complex series of forces such as would lead to the formation of the corresponding specific functional system.

25. *Structure and Operation*

Structure. The exact molecular structure of the protein of functional systems is not yet known, but unitary theory suggests that all such systems must possess:

1. *A primary vector axis* in each small region of the tissue. This vector axis lies parallel to the linear structure of the protein chains and the direction of maximum struc-

tural stability, and is identical with the direction of the extended process constituting the net result of the cycles, i.e. with the direction of transport of materials or of propagation of polarization. (In special cases the vector axis may reduce to a direction without sense, as in nerve fibers capable of two-way conduction.) The importance of the primary vector axis lies in the fact that it determines the relationship of the local cycles of the functional system to the one-way normalizing processes of the organism as a whole.

2. *A secondary vector axis,* at each point in certain synthetic systems, and in small regions in other systems. This secondary axis represents the resultant field of the molecules in the normal state. In uniform tissues, where there is no macroscopic curvature of the tissue, this vector axis is identical throughout. But in nonuniform systems the secondary polarization axis of the molecules (or polarized groups) may vary, both as between neighbors, and in course of function. The cycle then consists of a pulse of changing orientation passing along a sequence of co-ordinated vectors.

In the nonuniform synthetic systems (of animal organisms) there is probably one dominant secondary axis fixing a plane of polarization characteristic of the system. (See § 43 on Plants.)

The significance of the secondary vector axis arises from the fact that it determines the local cycle of the molecule or system.

3. *A residual axis* which, at least in animal protein other than that of muscle fibers, is probably not directly involved in the operation of the system, and is therefore available for the stabilization of protein chains into extended sheets, etc.

The various types of functional systems differ in respect of the relative orientation of the primary and secondary axes. In conductive tissues they may be perpendicular; in contractile, oblique; and in synthetic, variable.

In any functional system the individual molecules, if separable, must be sufficiently close and stable in their siting on the primary axis to insure continuity of induction of polarization, so that relaxative and normalizing pulses are regularly propagated along the axis. The axis may possess a macroscopic curvature, but there must be a stable skeleton of protein chains parallel to it.

The spatial relations of the individual molecules will only be adequately stable if there are a sufficient number of molecules to form a group of adequate size to resist thermal and minor mechanical disturbances. Typical protein molecules of roughly spherical form have a diameter of the order of 10^{-6} cm. The following stable structures have one or more dimensions at least of the order of 10^{-5} cm.: membrane thickness, mitochondria, golgi apparatus, flagella diameter, and small virus. This suggests that differentiated intracellular structures only possess adequate stability to perform cyclic functions if they have one, or two, dimensions at least of this size. If these systems are composed of roughly spherical protein molecules (which may not be the case) this means that a line equivalent to some 5–20 such molecules may be sufficient to stabilize one dimension. A chain of, say, ten protein molecules along the primary axis would, however, have little stability, unless associated with other similar molecules into a small sheet, or network, equivalent to at least some hundred molecules.

Operation. The general mode of operation of functional systems has already been described above, but it will be convenient to restate it from a different point of view.

We have seen that an ordered region of cyclically polarizable protein molecules tends to facilitate a particular cycle of local processes and a particular extended one-way process. This means that while high thresholds protect the molecules in many respects, the normal polarized state is only stabilized by a low threshold, so that a small stimulus may release the relaxation phase of the cycle. The exciting stimulus may be either a chance variation of local factors, or a spatially directed influence resulting from the functional activity of a neighboring system or an internal self-exciting circuit.

For example, a small local change due to thermal, chemical, or mechanical factors may be sufficient to initiate the function of the tissue. If this occurs frequently it is known as internal or autonomous activity, overproduction of movements, etc. A spontaneous tendency to activity in any tissue or organ implies that internal factors, which may be statistical, mechanical, or functional (in the case of closed circuits of tissues), are sufficient to initiate function repeatedly, by raising the molecule or tissue over its functional threshold. Such autonomous activity may underlie the inherent rhythms of self-excitation which characterize many tissues and organisms, e.g. in primitive slime, in the movements of amoeba, and in self-exciting nervous circuits. Functional systems may thus operate as closed circuits, the result of function serving to initiate a repetition of function. This is a logically degenerate (less complex) case in which the one-way character of normalizing processes is temporarily lost, and a self-exciting spatial circuit takes its place.

Function is normally evoked by the one-way propagation of polarization or transport of chemicals from a neighboring system, and the result of the function may be propagation or transport into another neighboring system. The external stimulus, the local cycle, and the external result, are all components of one extended one-way process. But this extended one-way process can only be repeated provided that a normalizing pulse restores the normal resultant field of the system. In general this only occurs if there is a respiratory system, or local source of polarization, whose co-operation in inducing polarization is evoked by the normalizing pulse. To this we shall return (§ 33).

Thus the one-way process displays two phases which, as we have already seen, are not the exact inverse of each other. The depolarization or relaxation pulse is a wave of disturbance releasing the inner tendencies of molecules held in a polarized state by a narrow threshold, and requiring no major additional source of polarization. In contrast to this the normalizing pulse is a wave of repolarization caused by the resultant field of the system and acting against the inner tendencies of the molecules. The normalizing pulse can therefore only act regularly and sufficiently if the propagated induction along the channel of the tissue is reinforced by sources of induction lying beside the tissue, which are also evoked into activity by the trigger action of the pulse.

This leads to a broader view of the functional cycle, not as a narrow cycle of transformations confined to one specific tissue, but as a one-way process the normalizing phase of which may possess components extending into neighboring tissues. Cyclic function and respiration are to be understood as two local components of this more extensive process.

26. Protein Properties

THE GENERAL PROPERTIES of animal protein have now been brought into relation to the unitary principle. It will, however, be convenient to summarize them in anticipation of their application to the theory of organism in the next chapter.

The following properties are consequences of the unitary principle in any system with the fundamental property which is characteristic of living (animal) protein:

Unitary characterization of living (animal) protein: A linear structure with side groups providing an adequately stabilized and extensive continuity of cyclically variable resultant field so that extended normalizing processes are propagated along appropriate channels.

Stabilization of structures and processes. Protein structures which remain unchanged tend, if their structure permits, to be further stabilized. Structures which undergo cycles of transformation tend to be altered so that the cycles are facilitated. Structural thresholds which are not passed tend to increase; those which are passed tend to decrease.

Facilitation. Every local process tends to produce either a unit structure, or a modification of existing structures, facilitating the repetition of the process. Units of structure facilitate their own reproduction, and modifications facilitate their own growth and/or cyclic function.

Two-phase cycles. Every cycle of a local tissue consists in a relaxative phase, followed by a repolarizing phase induced by the normalizing tendency of a more extended system. All living protein is continually pulsating.

One-way process. The local cycles normally occur as components of extended one-way pulses passing inwards (in some cases followed by one-way pulses passing outwards).

Vector axes. A primary vector axis determines the orientation of each functional system in the organism, the normalizing pulse consisting in the successive drawing equal and/or parallel of vectors, of molecular or atomic origin, lying oblique or perpendicular to this axis.

Extended process. Functional systems are anisotropic, and the operation of a system normally involves the co-operation of various neighboring systems. Thus every local cycle is a component of a more extended process which possesses other components extending outwards in various directions. All these component processes are subject to continuity conditions, both in space and in time, which express the dominance of one comprehensive unitary process ultimately involving every part of the organism.

Steps of process. All process is reducible to steps, which either do occur, or do not occur, at any particular time. Thus every extended process either evokes, or does not evoke, each particular local cycle, and consists therefore of a selected array of co-operative but discrete unit processes.

This summary suggests that all processes in living protein represent the alternating relaxation and normalizing of a resultant field, and that this conception holds the clue to a simple formula for organism.

27. Transitional Systems

THE GENERAL THEORY of organism can be approached most directly through the study of animals because only in animals are certain primary properties of living protein unmistakably differentiated in spatially distinct tissues. The multiplication of specific protein molecules occurs in synthetic enzyme systems which are found in all forms of life. But the modification of such units into extended systems displaying the normalizing process on a macroscopic scale can best be studied in the neuromuscular tissues of animals. This clue to the secret of biological organization is accessible to direct inspection only in animals, and elsewhere lies subtly concealed in a more complex pattern of relationships.

This contrast between animals and plants or lower organisms is not merely one of scale. Nerves and muscles are suitable tissues for unitary interpretation, not because they are large, but because they are clearly differentiated from each other and from other tissues. Moreover, this functional and anatomical differentiation expresses an important theoretical and logical differentiation: certain formal properties of the unitary process which are concealed in undifferentiated protein become manifest as spatially separated, independent components in conductive and contractile tissues. It is not possible to recognize immediately the subtle pattern of co-ordinated changing relationships which constitutes the total unitary process of any organism. This understanding can only be attained by stages, and the study of animals is the appropriate first stage.

The argument therefore passes from the examination of the properties of living protein to the co-ordination of these properties in the animal organism. This is the appropriate method for an introduction to the unitary theory of organism. But it is neither the logical sequence which must be followed in a definitive unitary science, nor can it have been the historical sequence of the evolution of species. Prior to the divergence of animal and plant forms there certainly existed more primitive cellular organisms, and probably before these yet simpler noncellular forms, and earlier still there was a time in the history of this planet when no living organisms can possibly have existed.

A complete science must eventually trace the story of the origin of life, as far as inference from the available data permits. In doing so it will probably also reveal the logical sequence appropriate to a definitive theory of organism.

But it is not yet clear whether that complete science will require to include a precise definition of life. There are indications that there may not exist any single group of properties which can suitably be selected as providing a scientific definition of a living system. It may be necessary to pass from clearly inanimate systems to cellular organisms by several steps, none of which may correspond to the transition from "inert" to "living" systems, in the ordinary meaning of these terms. After the liquid crystals and complex molecules of organic chemistry, there may exist several stages of increasing complexity before the simplest virus or the simplest living cell is reached, and there may be no need to say where "life" begins.

In order not to prejudge this question we shall speak of the transitional systems between clearly inanimate and clearly animate systems, without seeking to define any point at which "life" enters. Indeed it may prove that the important issue is not whether a given system is alive, but in what respects it is alive, which of the normal properties of cellular organisms does it possess?

Unitary theory cannot at this stage make any predictions with regard to the transitional systems, but the following suggestions are relevant:

1. The effect of recent research has been greatly to reduce the gap between inert chemical molecules and protein systems which are capable of self-reproduction in suitable environments, such as genes, viruses, etc.

2. The remaining gap may disappear when the correct theoretical approach is used.

3. On the other hand, an important distinction may exist between those systems which do and those which do not contain living protein (i.e. a system maintaining and propagating cyclic changes of polarization). It seems that only living protein can regularly synthesize living protein.

4. It may indeed be impossible for protein to be synthesized except as living protein; it may be impossible for inanimate protein to be synthesized without living protein being formed first. In fact the first step toward the more stabilized forms of life may have consisted in the synthesis

of a small region of (living) protein, as a consequence of exceptional local conditions.

5. If this supposition is correct, then the first origin of an unstabilized region of living protein must have been due to the interplay of exceptional factors which evoked the formative properties possessed by all processes and structures, but in a novel combination. The convergence of these factors was due to chance (in the sense of factors not causally related to any prior organized system), but these conditions realized a tendency inherent in all unitary systems: the tendency to form self-stabilizing and self-developing systems. All the general properties of organisms are implicit in the unitary principle, but exceptional conditions are necessary to render them explicit in actual processes. There is a bias toward order in the unitary principle; in certain circumstances this leads to crystalline symmetry, in others to biological organization.

6. On this view there is no fundamental principle operative in the organic realm which is not also evident in the inorganic. Both realms illustrate the properties of one universal formative process, but in systems of different orders of complexity. The more complex systems grow spontaneously out of the less complex when the necessary conditions are satisfied. The origin of life no longer represents an anomaly, but is merely a rare type of unitary process.

CHAPTER IV

THEORY OF ORGANISM

28. *The Complexity of the Organic Realm*

A THEORY of organism must cover a realm of stupendous complexity, including an apparently inexhaustible variety of organic systems and processes. How can a comprehensive simplification of this vast realm be possible?

The complexity of the organic realm is of several kinds. There is first the enormous number of individual atoms, molecules, or cells in any one organism; this is the numerical complexity. Then there is the inconceivably extensive field of differences between individual organisms, such as differences of species, sex, age, and of individual variation; this may be called the intercomplexity of the organic realm. Finally, there is the great number of physical, chemical, physiological, and biological principles at present necessary to describe the processes of the molecules, micells, cells, tissues, and organs of any higher organism, and even the processes of a single cell; this is the functional complexity.

A simple theory of organism must show that this uniquely complex field of knowledge, with its interrelated numerical, inter-, and functional complexities, can be covered by a few general principles. Such a task is intimidating—until it is solved. Then the complexity is seen to arise from multiple variations on one theme, and to be less than had appeared.

For the total complexity of the organic realm is subject to striking limitations. Firstly, the number of different types of atoms, molecules, micells, cells, and tissues is relatively low. The processes of a great part of the realm could be covered by ten types of each, and of the entire realm by less than a hundred, suitably chosen. The numerical complexity, in this sense, is not merely finite, but easily within the range of a trained intellect.

It is clear that the dynamical description of the space-time paths of all the individual atoms in a cell would require a monstrous formula. But this is unnecessary; indeed the organism is designed in such a way as to make this the most clumsy way of inventing a needless complexity. For the atoms and molecules in an organism are not dynamically independent. The number of degrees of freedom, or parameters necessary to describe the relative changes of position, orientation, and polarization of the functional parts of organisms is exceedingly low. Biological organization consists precisely in the existence of extensive co-ordination between the positions and orientations of functional parts, and this organization maintains itself in spite of a ceaseless interchange of individual atoms and molecules.

The intercomplexity of the organic realm falls into three parts: interspecies variety, normal changes in the life-history of the individual organism, and individual variation from the norm of the species. The first is already partly covered by the principle of the selective evolution of species, though this principle still awaits clarification in various respects. Individual variation from the norm is a secondary problem to be considered after that of normal development, which is the subject of this chapter.

Finally there is the functional complexity of current theories. This is partly due to the use of concepts which introduce a spurious multiplicity. For example the triad: structure-field-function ceases to burden the mind when seen as triple aspects of a single formative process. Moreover, countless thousands of "different" chemical and biochemical processes consist of varied combinations of a few fundamental chemical steps. And these steps often fall into simple sequences, each characterized by one co-ordinating principle. The functional complexity is greatly reduced when the process of the organism and its component processes are all seen as alternations of inner and outer formative tendencies.

Thus the apparently unlimited and intimidating complexity of the organic realm resolves into a number of problems of strictly limited complexity.

In a nut-shell the unitary principle leads to a simple theory of biological organization because it

- clarifies the relation of wholes to their parts;
- unifies structure, field, and function in one concept of a formative process;
- reveals a common tendency, or one-way space-time pattern, which may underlie all quantum-mechanical, chemo-dynamic, and thermo-dynamic processes;
- reduces the processes of corresponding molecules, cells, and tissues to a common basis independent of scale; and
- presents all the constituent processes of the organism as co-ordinated components of one comprehensive one-way process.

29. *The Unity of the Organism*

"The organism is a unity." This phrase calls attention to an important fact, and yet leaves it vague and elusive. "Unity" is a term which has rightly been treated with suspicion by exact scientists, but it refers to a fact which demands interpretation.

This paradox is resolved when it is seen that the equivocal character of the term "unity" arises from the implication that unity is an absolute property not subject to specific limitations. To conceive unity as absolute is to pass beyond the realm of science.

On the other hand, when unity is conceived as a property subject to specific conditions, the vagueness disappears and the property is open to scientific analysis.

The legitimate scientific content of the phrase "the unity of the organism" consists in its reference to the fact that *certain properties, within finite limits and for finite periods, characterize organisms as single entities.* The organism may be regarded as a unity, in respect of these properties, within defined limits, for a given period of time.

For example, every healthy organism is a single self-stabilizing entity within strict limits of time and of environmental variation, and within these limits may be said to be a unity in respect of the property of self-stabilization. But a member of a sexually differentiated species cannot reproduce itself without a sexual partner, and is incomplete in this respect. The unit in relation to reproduction is here the mated pair, and not the single organism.

The task of a complete theory of organic species is twofold: to account for the properties which characterize organisms as entities, and to specify the exact limits beyond which those properties are lost in the case of any species or individual organism. The present general theory is restricted to the first problem.

30. A Formula for Organism

A COMPREHENSIVE THEORY of organism faces three main problems: How did organisms first arise? How have they since evolved? How does the individual organism develop from the fertilized ovum so that its constituent processes combine to display all the properties characteristic of organisms? The question, How? means: What is the structure of these processes, and what is their relation either to physical processes or to the unitary principle which may underlie physical processes?

Here we are not concerned with the origin and evolution of organisms. These two problems are not susceptible of fundamental analysis until an adequate theory has been established of what an organism is. Until biological organization is understood one cannot properly consider how it first came into existence, nor how it may change under the complex conditions of selective evolution. The problem of the nature of self-regulating, adaptive, and self-reproducing organization, and of its development in the growing organism, underlies all the other problems of life.

What is required is a *structural formula for organism* condensing all the relevant facts in a simple conception of biological organization. The formula must indicate the organizing relations of the system, and so provide a working conception of organisms. It must reduce the developmental, self-regulatory, and adaptive processes of organisms to one underlying type of causal process. We shall assume that the formula must, at this stage, be verbal, and descriptive of tendencies, rather than algebraic or quantitative. But as a scientific formula it must ultimately lead to conclusions capable of experimental test.

More precisely, a formula based on the unitary principle must identify a special class of unitary processes as constituting organisms. The correctness of the formula must be judged by two criteria:

1. The deduction, as consequences of the formula, of all the general properties of organisms as tendencies possessed by that class of systems, which will be realized under appropriate conditions.

2. The successful application of the formula to clarify the distinguishing characteristics of special groups of organisms, such as primitive organisms, plants, and animals, and of special types of organs and tissues.

The formula put forward here for the comment of specialists is based on the unitary principle of Chapter I, the unitary concepts of Chapter II, and the unitary interpretation of living protein of Chapter III.

31. Formula for Animal Organism

An animal organism is a continuous normalizing process stabilized by hereditary units and an outer boundary.

The constant, cyclic, self-stabilizing, and developmental properties of organisms are all aspects of this normalizing process imposed on the relaxative tendencies of local structures.

The terms used in the formula require amplification.

A *continuous* process is a process extended over a finite region of space, reproducing itself in time, and subject to boundary and continuity conditions determining the changes in the spatial relations of its components.

A *normalizing* process is a process in which polarization differences decrease (in animals restoring the normal resultant field after the relaxative process caused by any disturbance, and so maintaining the operation of cyclic components). The continuity conditions are given by the tendency toward minimal polarization differences and gradients.

Hereditary units are dominant microstructures, derived from the multiplication of hereditary prototypes, which determine the stable continuity of all specific patterns. They provide the unchanging inner boundary conditions stabilizing one pole, and sequences of steps, of the normalizing process.

The *outer boundary* is the external limit of the continuous normalizing process, through which the environment and the system mutually influence one another. The boundary provides the variable outer boundary condition, both stabilizing and varying the other pole of the normalizing process. The normalizing process comes to an end if the outer boundary condition is either too constant or too variable.

The normalizing process has two aspects, an extended and a local. The extended aspect is the normalizing of the gradient of the field stabilized by two boundary conditions, the hereditary units and the external membrane. So long as the environment remains normal this gradient is never exhausted, and the normalizing process continues (until death). The local aspect is the transformation of structures leading to the multiplication of the hereditary units. Synthesis of characteristic protein, duplication of chromosomes, and multiplication of reproductive cells constitute the net result of the process.

The formula does not specify the required degree of stability either of the hereditary units or of the boundary. This means that such matters as the theory of mutations and the line between inanimate and animate systems lie beyond its scope. For example a virus, and even a gene, displays a continuous normalizing process and so falls within the formula, but only in the highly stabilized environment of living cells.

Apart from this appropriate limitation, which will require further consideration in relation to plants and primitive organisms, the formula provides the necessary and sufficient characterization of an organism. Subject to this explicit restriction the formula covers all organisms, and nothing but organisms. There is no organism which is not a continuous normalizing process in a system stabilized (in some degree) by hereditary units, and there is no such normalizing system which is not an organism.

Moreover, the formula is sufficient in the further sense that all the general properties of organisms follow as necessary consequences within the context of unitary theory. These properties can be shown to represent tendencies which must be displayed by all unitary systems covered by the formula. The main properties with which we are concerned are the tendency for synthesis, differentiation, self-regulation, and adaptive modification and response, to occur in a co-ordinated manner as components of one comprehensive normalizing process.

This result will first be established in a condensed argument using the most general unitary principles. The argument will then be developed in greater detail in the subsequent sections, each property being treated separately and related to the structure of the corresponding process. This deductive procedure, passing by stages from the most general unifying formula toward the detailed discussion of special processes, is appropriate to a theory of organism. For the different properties of organisms are strictly inseparable, and can only be understood in the light of the unifying principle to which they remain subject, in spite of fargoing apparent differentiation.

The most general classification of the properties of organisms expresses an analysis into three components: the constant aspects, the self-stabilizing tendencies restoring the norm, and the progressive development and modification of the norm. Each of these three components expresses one aspect of the unitary formula. The constant properties are all consequences of the structural stability of the hereditary units, even the alternating phases of the normalizing process often leaving their structure unchanged. The self-stabilizing tendencies express the fact that the normalizing process tends to restore a normal resultant field. Finally, the progressive properties represent the normalizing of the highly heterogeneous field of the fertilized ovum or seed, through the multiplication of units, their association into functional regions, and the modification of junctions in the course of response to environmental disturbances.

This formal analysis into constant, restorative, and progressive components does not, however, reveal either the temporal pattern of the normalizing process of the organism or the genesis of the different properties. For this a deeper developmental analysis is necessary.

The animal organism is a complex continuous normalizing process beginning at fertilization (or division). In the course of this comprehensive process there is developed a differentiated system with the properties of biological organization, the chief of which are self-regulation and adaptive modification and response. We have to show that the process of normalization which begins at fertilization results in a process of co-ordinated differential synthesis and movement leading to the establishment of an organized system with the properties of self-regulation and adaptive response. The supreme problem for the theory of the animal organism is how differential synthesis leads to self-regulation and adaptive response, and the condensed argument of the solution runs as follows:

Synthesis. The synthesis of each specific protein is evoked as a component of the normalizing of a field of corresponding specific pattern, and results in a structure which facilitates the repetition of the process by which it was formed, either by extending its specific pattern or by undergoing cycles of polarization and depolarization.

Differentiation. The normalizing of the polarization field (first two-dimensional at the surface of the fertilized ovum, and becoming three-dimensional in the developing embryo) evokes at each point the synthesis of a specific protein corresponding to the character of the local field. This differential evocation of synthesis occurs in a spatially continuous and progressive manner, subject to the steps of molecular transformation fixed by the hereditary units, with the result that the resulting tissues form co-operative components of a continuously organized system with the property of facilitating its own normalization. The increase in visible complexity in course of differentiative development does not conflict with, and is in fact a consequence of, the tendency to symmetry in ultimate structure, which results in the multiplication of the hereditary units and renders visible the heterogeneity originally latent in the chromosomes.

Self-regulation. Every tissue and organ system so developed possesses a characteristic cycle which is evoked by, and facilitates, the same specific normalizing process as evoked its original formation. Each tissue and organ operates at such times and in such manner as to normalize the field, i.e. to eliminate a specific type of deviation from the norm.

Adaptive modification and response. The normalizing process takes time, and a component process which is evoked too frequently, because it fails to eliminate the evoking stimulus, becomes exhausted and some other process is evoked in its place. Tissues which are restored relatively slowly after function will therefore control responses in an adaptive manner, unsuccessful responses being replaced by others.

Thus all these properties of animal organisms represent components of the normalizing process in a system appropriately stabilized, internally by hereditary units which have proved effective in the course of evolution, and externally by a sufficiently favorable environment. The co-ordination of these properties as components of one comprehensive process being established, we can now turn to consider each separately in greater detail.

32. *Synthesis*

Chemical synthesis is the combination of two or more chemical components (or of parts of such components) to form a single system with some degree of stability. Here we are only concerned with a special type of chemical synthesis, the formation of organic molecules composed of chains and/or rings from simpler components ultimately derived from inorganic materials. It has already been suggested that organic synthesis occurring regularly in an organism is always due to induction by a prototype, either identical with, or similar to, the molecule being synthesized. The present argument is based on this assumption.

This implies that all regular synthesis is the result of a spatially directed process of induction which reduces the asymmetry of prototype and substrate and tends to normalize the local field. All synthesis is a local normalizing process which can only be repeated as a component of a more extended normalizing process.

The process of synthesis underlies all assimilation, growth, and repair of tissues, as well as the normal function of synthetic and reproductive tissues. All other organic processes reduce to local cycles which leave no cumulative chemical result within the organism. But a part of the products of synthesis accumulates within the system, providing the basis of growth and reproduction. The products of synthesis represent the net chemical result of the normalizing process. The hereditary units are dominant structures, and their multiplication represents the dominant inner process of the organism.

We have seen that synthesis of proteins must occur in a sequence of fundamental steps, and we must now consider these steps in greater detail.

Basic synthesis, or the combination of carbon and nitrogen atoms from inorganic components into the molecular chains and rings characteristic of all organic compounds. This first step of organic synthesis probably only occurs in plants and in more primitive organisms, such as bacteria, etc.

The essential feature of basic synthesis is the combination of point-centered tetrahedral carbon and nitrogen atoms to form the linear patterns of organic molecules. In the course of basic synthesis atoms or inorganic molecules, which have a unique center but no axis of linear symmetry, are transformed into a complex structure with translational symmetry along a unique axis. Basic synthesis is the transformation of separate systems, the stability of which depends on point symmetry, into one system whose stability expresses a translational symmetry. Just as oxidation involves the *distortion* of linear or cyclic symmetrical structures, so the reduction of inorganic carbon and nitrogen in the course of synthesis normally involves the *establishment* of a linear structure, with absorption of energy.

Basic synthesis is thus the induction of a unique primary axis, by a system already possessing such an axis, in atoms previously possessing point symmetry. In this process existing linear structures (e.g. of pulsating protein) normalize the residual polarization of tetrahedral atoms to conform to their own field.

The fact that all naturally occurring amino-acids possess a "left-handed" configuration shows that basic synthesis depends on the induction of *parallel* polarization by the dominant prototype, and not of antiparallel or inverse polarization. The induction of inverse polarization would result in the production of mirror images of the prototype, and it seems that this does not occur.

Condensation, or the association of linear molecules into extended linear structures. This association often occurs through the elimination of hydrogen and oxygen atoms from neighboring free ends of linear molecules, i.e. by the mutual neutralization of ends inversely polarized along the chain axis. Condensation underlies all growth of homogeneous tissues.

Specific synthesis, or the establishment of a specific arrangement of side groups on the chain or ring, either before or after condensation, by induction from a dominant prototype. In so far as the side groups are polarized this process consists in the normalizing of fields whose polarization lies oblique or perpendicular to the primary axis. This can occur either during the prefunctional differentiation of a tissue, or during its functional cycles when it may result in the growth of the tissue.

The synthesis of specific protein appears to depend on the presence of nucleic acids, but their role is not yet understood.

Complementary to specific synthesis is the further process of the folding of chains to form closed rings and platelets, such as those of the globular proteins.

The exact structure of synthetic systems has not yet been established, but the unitary interpretation suggests the following conception of their mode of operation:

Every fundamental step of binary synthesis requires the following factors:

1. *A primary vector axis,* defined by the stable structure of the synthetic system, which determines the direction of the normalizing pulses and hence also the path toward the system of the two units being synthesized, and their orientation during the process of synthesis.

2. *A specific resultant field* undergoing local cycles as a complex one-way pulse passes through the system. This pulsing field normalizes two polarized atoms or groups to conform to itself, draws them over a particular threshold as the two units reach a unique point in the system, and may later carry the synthesized unit out of the system. A synthetic system is thus a structure of pulsating protein, one phase of whose polarization cycle is identical with the progress of its own formation and therefore induces identical synthesis in appropriate free components.

3. *A less specific respiratory system,* or source of polarization, which stabilizes and restores the normal state of the field. While the prototype units determine the specific structural pattern of the system and its process, and the extended normalizing process initiates its operation, the respiratory system drives it.

In normal chemo-synthesis the respiratory system is a chemical process evoked by the extended normalizing pulse, but in the special case of photosynthesis in green plants solar radiation probably combines the roles of evoking stimulus and source of polarization.

4. The simultaneous operation, or co-operation, of these processes of transformation, transport, and respiration to form one comprehensive pulse of the field.

This co-ordination is established, and when deficient improved, because the processes of orientation, transformation, respiration, and transport are components of one comprehensive normalizing process, whose operation tends to bring all its component processes into that state of mutual adjustment in which the field gradients are minimal. Each synthetic system is formed and adjusted, and its subsequent function is evoked, by one specific type of normalizing process. Thus the same type of field process evokes a specific type of synthesis, whether during differentiative growth or during subsequent normal function of a synthetic system.

33. Respiration

EVERY COMPLEX SYSTEM would sooner or later reach a static condition with all its parts stabilized by thresholds if no polarizing factor were present. Such polarizing agencies fall into two classes, in which the induced polarization respectively is, and is not, oriented in relation to the structure of the system. For example, thermal influences induce random states of polarization, while respiration induces a directed polarization, i.e. an asymmetry along a unique axis of the structure.

The term *respiration* will here be used to cover all processes involving the directed induction of polarization in parts of an organism by a system which derives its own polarization from chemical sources, such as fermentation or oxidation. The essential feature in respiratory processes, on this view, is the directed induction of asymmetry (directed transfer of free energy), so that an organic structure is raised into a more asymmetrical, polarized state.

The induction of asymmetry in organic structures (supply of free energy) is an essential component in many different types of organic process. It is necessary, for example, in synthesis or lysis, to raise the structures over certain thresholds; in the restoration of cyclic tissues, such as nerves and muscles, to their normal polarized state; and in the maintenance both of the directed fields responsible for cyclosis and transport, and of the level of thermal or undirected molecular polarization.

All these processes require the presence of a source of polarization which can be drawn on whenever this is necessary for function. Thus interlaced with the main functional pattern of the organism, there is a complementary pattern of respiratory systems available to induce polarization whenever their operation is evoked by the passage of the appropriate pulse. The respiratory processes are essential to the restoration phase of every organic cycle, and therefore also to the continued operation of every cyclic structure, but they may be regarded as secondary to the main functional system because they leave no permanent mark, their material products being ultimately eliminated.

Within the comprehensive one-way process of the organism which leads ultimately to the synthesis and multiplication of hereditary units, there is this secondary one-way process of respiration which keeps the main process going, but itself leads to nothing but the fracture and dispersal of fuel molecules taken in from the environment. The space-time patterns of the two processes fit together like hand and glove, the respiratory system covering the functional systems and being excited into co-operation as a complementary component of the one-way pulse of function.

The typical respiratory system consists of oxygen atoms, or an equivalent; linear fuel molecules; and linear functional molecules. Oxygen atoms, in an activated or free state, possess two uncompensated polar vectors at the tetrahedral angle. These tend to draw hydrogen bonds, or their equivalent, from their parallel orientations in the fuel molecules into the oblique orientations necessary to complement the free vectors of the oxygen atom. During this process the fuel molecule as a whole is distorted or polarized, and it in turn polarizes the neighboring functional molecule. The functional molecule passes over a threshold and slips into its metastable polarized state, the fuel molecule is ultimately fractured and dispersed as carbon dioxide, and the remaining oxygen atoms are saturated as water molecules.

In this process the operative factors are the powerful, because stable, tetrahedral angle of the oxygen valencies, and the relatively low thresholds of the linear fuel molecule and of the linear functional molecule. The oxygen atom is dominant in relation to the fuel molecules which it distorts and destroys. The fuel and functional molecules fit closely for one phase of function, after which the fuel molecule is dispersed and another slips into place.

But a simple system of this kind cannot fit together very closely, for the oxygen atom exerts too concentrated and violent an influence, and the fuel molecule is linearly extended and weak. The result is that the system as a whole fits poorly, and a large part of the directed induction gets lost as disordered molecular polarization (heat). The biological efficiency, or the proportion of the induced polarization which is employed in closely-fitting oriented processes as against that degraded into disordered processes, is necessarily low in simple respiratory processes.

Complex respiratory systems, composed of oxidases, carriers, deyhdrogenases, etc., may be co-operative systems in which the intense local induction of polarization by an oxygen atom (or its equivalent) is converted by a series of steps into a more extended and gradual process, so that the induction is carried out by small stages. The inductive influence of the oxygen atom is harnessed by building up around it closely-fitting shells which mediate between it and the functional molecule or tissue. In the course of operation of a complex respiratory system a pulse of polarization first passes outward from the oxygen atom toward the tissue, and then the whole system relaxes and contracts, allowing room for a fresh fuel molecule to slip into place. The respiratory system pumps polarization into the functional tissues so that they are normalized.

In the simplest case the oxygen atom is a node or center of radial polarization, and the respiratory system may be a fan-shaped field which converts this central polarization into the polarization of a linear structure. The tendency of the oxygen atom to complete its central symmetry induces asymmetry in a linear structure; central symmetry is here dominant to translational symmetry. This is the inverse of the process of organic synthesis in which translational symmetry is dominant and extends itself at the cost of central symmetry. Basic synthesis and respiration are thus complementary processes; the reproduction of linear protein molecules is achieved at the cost of the fracturing of linear fuel molecules.

The formation of respiratory systems in appropriate sites is a result of the same general tendency as leads to the formation of all functional systems. Every field tends to become more uniform, and either to complete or to extend itself. This means that an already established field fixed by certain boundary conditions (e.g. oxygen atom and functional tissue) tends to draw into position molecules which render the field more uniform, i.e. reduce its gradient. Polarizable molecules will thus be polarized by the field and worked by it into those sites where they conform most closely to the field, and reduce its gradient. The normalizing tendency is thus responsible for the formation of co-operative systems, and for their increasingly close fit (increasing efficiency) where conditions permit. Cyclic structures are drawn into those positions where they facilitate the pulsing of the fields which work them.

The siting of the respiratory systems is determined by the process of differentiative development which shapes the functional pattern of the organism, and each functional system tends to develop the appropriate respiratory system besides itself, because the two form co-operative components of one normalizing process. Moreover, the combined system, composed of functional tissue and respiratory system, operates whenever the field gradient is such as to carry all the components of this combined system over their thresholds, either simultaneously or successively, so that an oxygen atom is saturated, a fuel molecule fractured, and a tissue repolarized.

34. The Cell

WHAT LIGHT does the unitary formula for organism throw on the nature of the living cell and its significance as a biological unit?

Cells are normally characterized by a threefold differentiation of structure: a nucleus or equivalent (containing linearly arranged multiple sets of stable hereditary units); a quasi-fluid cytoplasm enclosing the nucleus; and an external semipermeable membrane. Moreover, every cell can perform the following functions: synthesize its own specific tissue proteins, induce the necessary polarization (supply free energy) from its own respiratory system, and duplicate itself by duplicating all its parts and dividing (though differentiated cells often lose this capacity).

The unitary analysis of any system involves the identification of the formative process which produced it. To discover the unique significance of the cell we have therefore to consider the process of its formation at the division of the parent cell. This process is not yet fully understood and the following speculative description covers only some of its main features.

The processes of the parent cell culminate in the duplication of all its components, including the multiple set of hereditary units. At this point the hereditary units, which constitute the inner boundary conditions of the parent cell, no longer adequately stabilize the system. Some factor, as yet unidentified, upsets the stability of the system, which disintegrates into an interspersed assemblage of the components necessary for two cells (though division may be delayed for a considerable period after the duplication of the chromosomes).

But this duplicated assemblage of components is not in a state of confusion. First, the separation of the duplicated chromosomes into two independent structures takes place in advance of any general instability, so that two organized centers are present from which the process of the reorganization of the two new cells can spread. And second, the systems are subject to both local and extended normalizing processes which everywhere tend to establish organized components of the two new systems.

Before any duplicated components of the parent cell have separated, no components of the functional organization of the new cells exist. Yet once the division is completed, the new organization of each of the two cells is ready for normal operation. Cellular organization has thus the property of organizing itself, under certain initial conditions. The significance of the cell as a biological unit lies in the fact that it is the entity capable of reproducing its own organization by duplicating components which, even when initially unorganized, tend to establish organization.

The parent cell provides the chemical constituents of the three components: nucleus, cytoplasm, and membrane, and these constituents are capable of organizing themselves into a new functioning cell. Moreover, they are not merely capable of doing so; under normal conditions they always do so, the development of organization being then a necessary consequence of the unitary process. The hereditary units group themselves to form new chromosomes and nucleus, and so provide the unchanging inner boundary condition if the new cell, and after division the membrane provides the variable outer boundary condition. The normalizing of the field determined by these two boundary conditions establishes the organization of the cell, that is, it arranges components already formed by local normalizing processes.

The cell is thus the only unit of biological organization which can multiply itself. No smaller unit can do so without the aid of a cell, and no more complex multicellular systems can do so, other than through single cells specially adapted to this function. No simpler and no more complex form of organization can multiply itself, because only the constituents of a single cell can spontaneously organize themselves; only an inner and an outer boundary condition can define a normalizing process.

This principle is crucial to the understanding both of the individual cell and of cellular differentiation. The entire organization of any cell is the result of one self-normalizing process stabilized by two boundary conditions, but initiated at the moment of the first separation of duplicated components in the parent cell. If alien viruses or other systems capable of intracellular multiplication are neglected, there is no organized system in any cell, more complex than the individual hereditary units, that was not formed by the normalizing process which began after the completion of the duplication process in the parent cell. Moreover, in any cell still capable of division, differentiated structures are only stable as components of this normalizing process, and they tend to disperse when the normalizing process ceases at the commencement of division.

The argument can be carried a step further. Not only is every organized system in a given cell the result of the normalizing process which shaped the cell after the parental duplication, but so also is the intra- and intercellular organization of all its descendant cells. Each cell forms itself from constituents provided by the parent, but the cell so organized remains subject to the more extensive normalizing processes of any wider system within which division may be taking place. To this we shall return when considering differentiation; we must now examine the structural components of the cell more closely, with respect to their role in multicellular organisms. (In the following analysis we shall neglect the processes of cytoplasmic heredity, which are at present insufficiently understood, and assume that all multiplication is controlled by hereditary units in the nucleus.)

The *nucleus* is an inner region normally containing a complete, linearly or spirally arranged, multiple set of hereditary unit structures of specific pattern, which are capable of (1) complete identical multiplication; (2) reproduction of individual mobile units selectively evoked by specific normalizing fields; (3) attraction of corresponding paternal and maternal units, in sexually differentiated species; (4) linear rearrangements; and (5) mutation, or changes in their number or structure (and possibly arrangement), under external influences.

Chromosome duplication, following the duplication of other cell constituents and leading subsequently to cell division, is the terminus of a balanced, or nonselective, one-way process of the progressive synthesis of all the specific proteins in the cell. But this balanced, nonselective, or undifferentiated terminus of the process is only reached if the process is not sidetracked into a specialized function. This may occur through the influence of an extended normalizing process passing into the cell from outside and leading to a result passing out of the cell, either as a special synthetic product or as propagated polarization.

Thus, at any one time, the one-way process of the cell can be *either* balanced and internal, leading to complete duplication and division of the cell; *or* differentiated as a component of an extended one-way process passing through a multicellular organism of which the cell is a part. In the latter case the extended process may be: (1) the transport and synthesis of special chemical products either forming differentiated tissue or passing out of the cell; or (2) the propagation of pulses of polarization into and out of the cell; or (3) a combination of chemical transportation and propagation of polarization. But it is not possible for a cell to be a differentiated component of an extended normalizing process and simultaneously to be performing the nonselective synthesis which leads to cell duplication. At any moment it is either on its own main line, or on a differentiated path; it cannot be on both at once, because one normalizing process controls the whole cell. A cell can either divide, or perform a differentiated function; it cannot do both simultaneously. (The processes of the nucleus are probably only involved in the balanced main line process, and may be unaffected by differentiated processes.)

The cytoplasm contains all the factors necessary for assimilation, respiration, and the synthesis of the functional tissues of the cell. At any one time the cytoplasm of any cell is controlled by a characteristic normalizing process involving *either* a single hierarchy of hereditary units culminating in one dominant hereditary unit that determines the differentiated function which the cell is performing, *or* a complex hierarchy culminating in the complete set in the nucleus. (In the former case the normalizing process probably does not penetrate the nucleus, while in the latter it does.)

The *external membrane* contains areas differentiated for some or all the following processes: directed transport of chemicals, induction of polarization, reception of chemical or inductive (electrical) stimuli, and rigid or elastic support. Multicellular organization consists in the differentiation of intercellular relations, so that contiguous areas of neighboring cells, which are in functional relationship, have the same differentiated function. Each cell needs from outside nutrition, inductive stimulation, and support, yet these must normally be separated, for they would mutually interfere. Transport of complex nutrients would interfere with induction of simple polarization pulses; receptive surfaces must be protected from irrelevant disturbances; mechanical support presupposes the absence of excessive molecular processes which would disturb stability; and so on. The surface of the cell and the areas of functional contiguity with other cells are the regions where the different components of the normalizing process are separated. These components here cease to be combined in the one co-ordinated normalizing process of the cell, and constitute differentiated links with the processes of other cells.

In the differentiated cells of a multicellular organism the nucleus is thus the region of undifferentiated multiplication characteristic only of the species, the membrane is the differentiated boundary linking the cell with other differentiated cells and with the environment, and the cytoplasm the field of interplay of hereditary and environmental factors.

35. *Differentiation*

The adult multicellular animal has certain properties because it has developed in a certain manner; in unitary theory we can only understand those properties by understanding how they have been established. In the course of differentiative growth a pattern of varied tissues is formed which becomes capable of self-regulation and adaptive response. The process of the development of organization must hold the clue to the nature of organization.

We shall simplify the problem by dealing here only with the crucial phase of embryological development, after any rearrangement of existing chemical units in the fertilized ovum, and before cyclic function begins. The most important established principles regarding this prefunctional phase of development may be summarized thus:

The differentiation of the embryo displays the progressive development of a complex system of (ultimately cyclic) processes from relatively static and uniform foodstuffs. This process of differentiation is determined by the interplay of two internal factors: (1) a linearly arranged set of dominant self-reproducing hereditary units; and (2) the location of each region within the extended field, first of the surface and later of the body of the embryo, which selectively evokes this multiplicative tendency in specific hereditary units. The development of organization is a one-way stepped process, passing from simpler to more complex patterns, both in the synthesis of units and in the field as a whole, and progressively determining the specialized character of all the local regions of the system. The problem is to see how this process leads to an adult system with the properties of self-regulation and adaptive response. It will be convenient to treat different aspects of this problem in turn.

The morphogenetic field. This is the unitary resultant field arising from the polarization vectors of the individual protein molecules, and all changes in the field (i.e. in the polarization of the molecules) are due to its own self-normalizing tendency. The normalizing process of the field is a spatially directed one-way process composed of individual pulses. The original source of the field is to be found in the intrinsic polarization of the external membrane of the ovum and in external factors acting on the ovum prior to and at fertilization. But in embryonic development the morphogenetic field probably first acquires its property of anisotropic evocation of synthesis in one dominant formative region (possibly at the dorsal lip of the blastopore).

Selective evocation of differential synthesis. The normalizing of the field has at any one time a different character in different regions in course of differentiation, and in each region selectively evokes the multiplicative synthesis of the corresponding hereditary unit. A specific mode of synthesis is evoked wherever it renders the resultant field more uniform.

Since the exact structure of functional protein is not yet known it is not possible to give a representative example of the manner in which a specific normalizing field evokes a corresponding mode of synthesis. Yet a specially simple case may be cited. A line of persisting or static tension involves the polarization of structures and therefore a resultant field along it, and this leads to the condensation of fibers composed of protein chains (or the precipitation of relatively inelastic structures) along the same line. In this special case a static field evokes the formation of a static structure parallel to it.

Increasing complexity. As differentiation proceeds, the field becomes more complex, and evokes progressively more complex successive stages of synthesis. At first the field is relatively simple, having the form of a closed polarized surface rendered unstable by the additional local polarization caused by fertilization, and containing the latent animal-vegetable vector axis of asymmetrically distributed materials in the volume of the egg. The progressive development of complexity in the field is thus the result of the normalizing tendency in a system displaying originally three contrasted types of polarization: a uniform surface polarization, a unique point of polarization, and a volume polarization, the interplay of which evokes new and more complex patterns of polarization. The tendency of the field toward uniformity establishes locally uniform linear structures, and the development of these within an originally spherical system results in a complex sequence of movements and involutions.

There is a superficial paradox in the fact that a unitary process in which each component process tends toward symmetry can, in the special case of differentiative development, result in an apparent increase in complexity. But this increase is only in the visible complexity, for the entire complexity of the adult organism must be contained in the hereditary units in the nucleus and cytoplasm of the fertilized ovum, which units, being dominant structures (in the special sense used here), have merely extended their patterns in the course of development and so made visible a part of their own complexity.

Unitary theory must later provide a precise description of the development of structural complexity as the tendency toward uniformity of the field stabilized by given boundary conditions (hereditary units and outer boundary). The hereditary units determine the number and character of the fundamental steps of synthesis, but the extended pattern of the normalizing field determines the time, place, and extent of each specific synthetic process.

Development of functional organization. As we have already seen in considering synthesis (§ 32), the normalizing process which evokes a particular synthesis is of the same character as the normalizing process which represents one phase of the subsequent function of the particular tissue. The particular difference or gradient of polarization which is normalized by the synthesis of a given tissue is of the same character as the difference which evokes the function of the tissue.

Thus synthesis anticipates and mimics function. Tissues function under a normalizing pulse of the same kind as that which produced them. The synthetic enzymes perform in miniature the transformations which later characterize the corresponding differentiated cell.

Moreover, since the process of differential synthesis occurs as one comprehensive spatially continuous normalizing process, the resulting differentiated structures also display a co-operative spatial continuity. In other words, the local structures are linked into co-operative tissues and channels or organ systems (e.g. receptor-neural-muscular, circulatory, etc.) corresponding to the paths of the original normalizing pulses which produced them. Thus not only does each localized specific synthesis mimic the subsequent function of the specific tissue, but the last stages of the three-dimensional extended pattern of differential synthesis mimics the subsequent total functioning of the adult organism.

Stability of development. The process of growth and differentiation occurs in a medium subject to thermal and mechanical disturbances, and involves the co-operation of extremely complex and sensitive structures. Development could not proceed successfully if it represented the action of some arbitrary external principle imposed on an otherwise chaotic collection of units. In the unitary theory of organism the reverse is the case. Every process which occurs, whether local or extended, moves from asymmetry toward either symmetry of structure or uniformity of polarization, and results in an increase of the stability either of a local symmetrical structure or of an extended polarized field. Every molecule in the directly functional parts of an organism is held in position, oriented, and transported in accordance with the local and extended fields. Each unit tends to find its place, and each co-operative group of units to stabilize and extend itself. The entire organism, in all its parts, is a process of the development of order.

This tendency toward stability and order is subject to one exception: the influence of thermal and mechanical disturbances, i.e. of factors not oriented in relation to the pattern of the organism. But thermal and mechanical disturbances below certain thresholds are essential to life, for they provide the stimulation without which the system would immediately seize up.

36. Self-Regulation

Organisms display stability; the original state tends to be restored after a limited disturbance. Yet this stability is not static, except in extreme cases such as that of the resting spore. Nor is it even the expression of a simple process equilibrium like that of a river flowing down a valley. The stability of the complex process of the animal organism is of a dual nature: local structures tend to relax to their stable symmetrical form, while the extended field tends to restore a normal state of polarization stable within its environment. This normal state, or norm, is, as we saw in § 12, the state of minimal polarization differences subject to the conditions of the system. At every level, in every smaller and larger component system and also in the organism as a whole, there is perpetual oscillation from a more stable to a less stable state and back. The organism is not like a pendulum oscillating by its own impetus about a stable position, but resembles a metronome knocked one way by a disturbing stimulus, and brought back by the normalizing field.

But this analogy is soon exhausted, for the regulating metronome of the organism is biased; the inner processes relax toward greater stability, while the field processes restore local structures toward a sensitive metastable state. Moreover, the rhythm of the organic metronome is irregular; no cycles, except possibly the oscillations of an enzyme system, recur with clockwork precision. Finally the completion of a cycle does not in general bring the system back to the same state; the effect of synthesis, differentiation, and modification, is perpetually to carry the system further along its one-way path.

Thus the irregular oscillation of the organism from metastable to stable states and back, if it rarely brings the system back to an identical state, does carry the system along a stable developmental path. The normalizing process always tends to establish the state of minimal polarization differences subject to the conditions of the particular stage of development, i.e. to sustain the normal course of development. This normal course leads toward the adult norm, which again is not a static condition, but a pattern of processes each with its normal rhythm in accordance with the environmental situation, i.e. the season, the hour, and the current activity. Differentiative development leads along a normal course toward the adult norm, and the organism displays the self-regulating property of tending to restore the normal course after every disturbance that is not excessive.

For the present we may neglect growth, differentiation, modification, wear and tear and repair, and all the aspects of the overriding one-way process, and consider only true physiological self-regulation (homeostasis). This is the property of returning to the norm after every disturbance exceeding a lower limit, the threshold of function, and below an upper limit, the limit of tissue stability. The task is to show that differentiative development leads to an organized system with this property of physiological self-regulation.

But this conclusion is now self-evident, for the norm is nothing but the state of the organism in which all polarization differences are minimized, and we have seen that the process of differentiation tends to develop an organized system facilitating its self-normalization, i.e. the restoration of the norm after disturbance.

For convenience the argument may be restated. All field processes consist of the normalizing of fields; all such processes lead either to static or cyclic structures facilitating their repetition; the normalizing process therefore leads to structures facilitating normalization; in particular, differentiation evokes the synthesis of a pattern of structures facilitating the normalizing of the pattern of the field. Every deviation from the norm evokes the function which eliminates that deviation. Differential synthesis leads to self-regulation because both processes are evoked by the same normalizing of deviations.

This argument establishes a developmental tendency toward self-regulating organization; the realization of that tendency depends on the appropriateness of the hereditary units, and, if they have survived the evolutionary process as the basis of viable self-reproducing organisms, this appropriateness has already been proved.

At a later stage a precise theory of differentiation and self-regulation must relate the specific structure of the hereditary units to the general form of the adult organism and determine the quantitative limits of self-regulation.

37. Transport

Little is yet understood of the means by which chemical units, such as atoms, ions, and molecules, are conveyed from one site to another, either within the cell, through membranes, or from one cell to another. The mass flow of a liquid medium may be produced by contractile pulses of a muscular tissue, but this process cannot cover the displacement of individual chemical units without circulation of a medium.

The problem is to account for *directed transport,* which may be defined as the noninertial movement of chemical units in a direction related to the organization of the system, i.e. from one functional site to the next, or from one functional process to the next process in which the unit plays a part. Here the term *noninertial* means that the movement cannot be interpreted as diffusion down a concentration gradient.

Directed transport is a process which occurs at such times and in such directions as to co-operate with the preceding and subsequent functional processes. It must therefore be interpreted in unitary theory as a component of the one-way normalizing pulse which passes through the organic system from one functional region to the next.

Pure transport, i.e. transport of unchanged units, is a degenerate case of the more general process in which the unit is transformed as it moves through a field of changing character.

It will be noted that a pulse of polarization passing along a functional channel is a one-way process which is continually repeated, normally without the occurrence of any process in the reverse direction. The local cycles are closed by depolarization phases, but the extended pulses (in general) all move one way.

Since the individual pulses all move one way, any polarized or polarizable mobile unit will tend to be drawn in the direction of the pulses. For example, if the mobile unit is intrinsically polarized it will be gripped by the pulse (i.e. adjusted to conform to the local field), and tend to move forward as a component of the propagated field. Just as a polarized molecule tends to move into a field which it normalizes or extends, so it will tend to move with any field to which it conforms, as though under long-range specific forces. In the language of quantitative physics, there is a component of force acting on the unit in the direction of propagation of the pulse.

On this view all directed transport constitutes a component of extended one-way pulses. The alternative case where the field is static, and the unit moves down a potential gradient or toward that region of the field to which it conforms best, is unlikely to play an extensive role in organisms, since all function involves both local cycles and one-way pulses of polarization.

The one-way pulses may produce rhythmic contractions in structural channels, as in animal intestines, etc., and possibly in the protein linings of plant tubes, or they may act directly on polarized chemical units. Indeed in the ultimate analysis these two cases reduce to one, for every pulse must produce some degree of contraction.

38. Adaptive Modification and Response

An organic modification is a residual change in a tissue produced by a process occurring in it and persisting after the process has come to an end. In the cases with which we are here concerned the residual change consists in a stabilized alteration in intermolecular relations of distance and orientation, and the use of the term *modification* is consistent with the general definition given in § 21. An *adaptive modification* is one which tends to facilitate the normalizing process of the organism within its environment, and an *adaptive response* is the resulting change in the relations of the organism to its environment, i.e. a response which facilitates the normalizing process of organism in environment.

The unitary theory of organism has to show that the organization produced by the normalizing process of differentiative development is such as to lead to adaptive responses being repeated, and nonadaptive responses being eliminated. This conclusion will be established here on general unitary principles, and developed in more detail in the next section in relation to the organization of the nervous system.

1. Every propagated pulse of polarization occurring in protein tends to leave a result which facilitates its repetition. The internal state and the behavior patterns of any organism tend to remain unchanged in any environment which sustains the state of the organism. The continuance (or repetition) of responses which sustain the state of an organism is automatic and involves no process of control; the favorable is taken for granted.

2. On the other hand, environmental conditions which cause a change in the state of an organism give rise to processes tending to eliminate the disturbance. All cyclic functions tend to eliminate disturbances or deviations from the norm, and to restore the norm. So long as they achieve this result they are repeated automatically, and may be called reflexes, in a generalized sense. (They are not, however, mere mechanical reactions to stimuli, since they express the inner tendencies of the organism.)

3. Every complete one-way process from stimulus to response involves both highly differentiated tissues, which possess respiratory systems restoring them rapidly to their normal state, and less differentiated tissues, which are re-

stored at a slower rate dependent on the general condition of the organism.

4. Any response which does not lead to the adequate elimination of a disturbing stimulus, and is therefore too frequently repeated, exhausts the less differentiated tissue and is stopped. Thus reflex responses which are unsuccessful tend to be inhibited, and cease to occur automatically on the presence of the stimulus.

5. In these circumstances the inherent tendency to activity results in another, more general, response being evoked by the same stimulus in place of the specialized response which has proved ineffective.

6. Since every protein process leads to a result facilitating its repetition, the process of the substitution of the new response for the unsuccessful one itself leaves an adaptive modification which tends to facilitate the repetition of the new response in similar circumstances, provided that it in turn is not evoked too frequently.

These general principles are illustrated by the behavior of certain primitive organisms, such as Amoeba. If the surface of an amoeba is lightly disturbed characteristic responses follow, and if the disturbing stimulus is repeated at sufficiently long intervals, the same kind of response will be repeated indefinitely. But if the stimulus is repeated too quickly, the original response ceases and a more extensive response takes its place. The disturbance has penetrated beyond the regions which are quickly restored, the original state can no longer be restored in the time available, the organism has suffered a temporary residual modification, and the identical stimulus now evokes a different response.

The essential factor in this selective control of responses through the elimination of those which fail adequately to eliminate disturbing stimuli, lies in the *time-integrating* property of slowly restored tissues. The local cycle of function of a fully differentiated tissue is closed immediately after depolarization by the automatic repolarizing effect of the respiratory process. There is no opportunity here for residual effects to accumulate, because the normalizing pulse restores the depolarized tissue and closes the cycle.

But when the normalizing pulse reaches a tissue which is less differentiated and does not possess its own automatically operating respiratory system, the normalization of this tissue has to wait for the slower diffusion processes of a more extensive part of the organism. Each cycle of a depolarizing and repolarizing pulse leaves this tissue changed, probably by the gradual exhaustion of its reserves of the constituents required for the respiratory process, and these residual changes are accumulated and balanced against the slow restoring processes. Thus the total residual (exhaustive) effect of a number of repeated responses is accumulated and balanced against the total effect of the restorative processes in the same period. If the former exceeds the latter, i.e. if the response has insufficiently eliminated the exciting stimulus, then the response is brought to an end.

This time-integrating, or rate-measuring, property of slower as against quicker cycles is the basis of the unitary interpretation of all adaptive modification and response. The adaptive character of responses depends on the combination of the positive self-facilitating property of protein processes in general, with the negative property of the exhaustion of less rapidly restored tissues.

39. The Nervous System: Time-Integration

THE PHYLOGENETIC DEVELOPMENT of the nervous system may be traced from the spread of volume excitation in the undifferentiated cytoplasm of primitive cells, through the reversible circuits of nonsynaptic nerve-nets, e.g. of jellyfish, and the hierarchy of paths subordinated to one center of the synaptic cephalized systems of fishes and amphibia, to the establishment of a dominant surface in the superficial cortex of reptiles and mammals.

In unitary theory these four types of the propagation of polarization: volume excitation, reversible linear paths, one-way paths, and sheet excitation, all represent a normalizing process, but in tissues of different structure. We shall here neglect the more primitive forms and deal only with certain aspects of the mammalian nervous system.

Adaptive responses involving synaptic and hierarchically arranged nervous systems have two aspects:

1. The apparently independent processes of conduction along single, anatomically separate, nerve fibers.

2. The organization of these independent processes, i.e. their temporal and spatial integration into adaptive stimulus-response patterns.

The first aspect has been extensively studied. The process of conduction along the cylindrical surface of a single nerve axon consists, at least in the simplest cases, in the propagated induction of an all-or-none depolarization process, the depolarization of one element disturbing the equilibrium of the next, and so on. This depolarization pulse is then followed by a similar pulse restoring the normal state.

It is not yet clear whether the depolarization and repolarization of an element of surface involves the transport of electrically charged ions and depends essentially on changes in membrane permeability. As we have already seen, unitary theory suggests a simpler explanation, since the cycle may represent, not the spatial displacement of electrically charged particles, but changes in the degree of asymmetry of the molecular structures. Any free movement of ions may be secondary to cyclic changes of polarization in fixed molecules.

Relatively little has yet been definitely established about the organization of the processes of the individual nerve fibers into spatially and temporally extended action patterns. Various theories have been advanced of the mutual inhibition, summation, and reinforcement of the processes of the individual nerve fibers, but no definitive conclusions have been reached. This is not surprising, as there is still uncertainty as to the precise nature of the simpler conduction process along single nerve axons.

The processes of the nerve fiber are in some degree isolated from those of the rest of the organism; therein lies their efficiency in linking spatially separated regions. Yet the pulses of polarization are not restricted to the surface of the fiber, but are merely concentrated, stabilized, and guided along it, their effects extending some depth into neighboring tissues and sometimes even inducing synchronous pulses in parallel fibers.

But it is at the nerve-cell endings and particularly at the synaptic, nerve-gland, and nerve-muscle junctions that the induction process is least isolated from the rest of the system and also least stabilized along one structurally defined path. It is therefore mainly at the nerve endings that a principle of spatio-temporal organization can control the further propagation of the pulses.

Along the length of the nerve fiber the pulse of depolarization is automatically followed by a pulse of normalization. The respiratory systems which sustain the normalizing pulse lie within the surface and operate spontaneously as components of a continuous normalizing pulse which succeeds the other after a brief interval. These respiratory systems possess their own reserves of fuel, and can sustain a considerable rate of operation without exhaustion. But at or near junctions the induction field passes across less stabilized tissues which are unlikely to possess stabilized respiratory systems with adequate reserves to maintain the same rate of operation. Here the restoration of the normal state appears to depend more directly on the general chemical condition of the organism. In this way the general level of activity of certain parts of the nervous system can be affected by the chemical state of the circulating fluids.

The residual effect of the propagation process in such junction regions will therefore be twofold. A protein modification will be produced (or improved) tending to facilitate the repetition of the same junction process. This modification consists of an improved orientation and arrangement of polarizable molecules. But this modification will not facilitate indefinite repetition of the same process unless sufficient time is allowed for the restoration of the junction tissue.

The nerve conduction processes thus tend to produce junction modifications which facilitate the not-too-frequent repetition of the junction processes. If a response does not adequately eliminate a disturbing stimulus, the pulse of depolarization gradually spreads into other regions and initiates a new response. The final result is the adaptive selection of responses in accordance with their results as measured by the elimination of disturbing stimuli.

The time-integrating aspect of the organization of the nervous system thus depends on the negative or inhibitory property of less-differentiated and exhaustible junction regions with longer refractory periods.

(The role of shock, and of the conduction of pain signals, in the organization of behavior is excluded from the present treatment.)

This interpretation of the manner in which the later conduction of excitation is modified, in accordance with the results of earlier conduction processes, rests on a definite assumption regarding the nature of the residual effects left by any conduction process when it passes beyond fully differentiated tissues. The necessity for assuming some residual modification as the basis of all learning has long been evident, and it has been given many names, such as trace, engram, neurogram, neural disposition, physiological schema, etc.

The assumption made here is that the residual modification consists in an improved orientation of depolarized protein molecules, which only results in facilitated repetition (lowered threshold) of the same process, provided that it is not repeated too frequently to permit the restoration of the polarization of the molecules under the given chemical state of the circulating fluids of the organism. This assumption is not a necessary consequence of general unitary principles, but is an application of these principles in a form which meets many of the known facts regarding synaptic transmission. Since the modification must affect transmission from one fiber to another, and also be more sensitive to the general state of the system than is the surface of the nerve fiber, it is probable that the modification occurs at or near junctions, or on the surface of special junction cells, rather than in the body of ordinary nerve cells. Whenever such a modification is produced and affects subsequent transmission, the response ceases to have the character of an automatic reflex, since its rate of repetition is controlled by processes dependent on the general state of the organism.

On this view the mode of response of a junction will depend on the frequency of its recent operation in various manners; on the rate of its restoration by chemical secretions, such as hormones, reaching it from circulating fluids; and finally on the inductive influence of neighboring polarization pulses. This brings the argument to the problem of spatial integration.

40. The Nervous System: Space-Integration

While the time-integrative aspect of nervous function is concerned with the adaptive selection of responses in accordance with their results, the space-integrative aspect involves the formation of extended patterns of activity from the individual pulses of anatomically separated fibers. In each case an extended process with adaptive value results from the combination of individual elements. We have seen that the adaptive selection of responses is achieved by balancing their frequency against the rate of an internal restorative process. But the space-integrative aspect appears more subtle, both because it has been less studied, and because it runs counter to the misleading analogy of the conduction of electricity in linear circuits.

The problem is, how are the inductive pulses of individual fibers organized at junctions or elsewhere into extended spatial patterns of activity displaying, as patterns, the characteristics of memory and of mutual reinforcement and inhibition, so that co-ordinated adaptive behavior results?

Here the term pattern is used for an extended space-time distribution of nervous activity and inactivity which can be treated as a unit because it leads to co-ordinated behavior and often to one definite result, the adaptive success or failure of the response. There is no doubt that at some stage in the stimulus-response processes of cephalized nervous systems the further spread of excitation is determined by the properties of patterns of nervous activity rather than by the linear continuity of individual fibers. At some stage the pattern of activity, rather than the induction along linear fibers, plays the causal role, as may be seen from the following facts:

1. Stimulus patterns evoke characteristic response patterns.

2. The nondimensional spatial proportions of the stimulus pattern determine the responses, and not the particular set of afferent fibers excited by the stimulus (just as the temporal rhythm and not the exact tempo of an auditory stimulus is decisive).

3. The patterns are self-stabilizing, and operate as units leaving a residual modification which can facilitate the response pattern even if a part only of the original stimulus is present (conditioned reflexes; acceptance of part as equivalent to the whole; operation of symbols; etc.).

4. Dominant patterns tend to simplify themselves by eliminating discordant elements (Gestalt character of perception; inhibition of incompatible patterns; formative properties of cerebral processes; tendency to smoothness of posture and response; etc.).

5. The sensory pattern can be displaced from a given set of afferent fibers, and the motor pattern displaced to other sets of efferent fibers.

These properties of sensori-motor processes in animals with cephalized nervous systems suggest the following conclusion: *In certain regions the causal law characterizing the induction of excitation determines the development and transformation of patterns as units and not as arrangements of independent processes each following a structurally determined linear path.* If this is correct, we have to discover a causal law of pattern which reveals in what sense the individual nerve processes cease to be independent when they reach integrating regions.

In a fundamental unitary analysis the characteristic feature in nerve conduction is that the path of propagation is determined by the one-dimensional form of the fiber, each protein molecule inducing polarization mainly in one neighbor lying next to it along a line parallel to the fiber. This *one-one*, one-dimensional induction plays a decisive role in the propagation of the pulse. The anatomical structure of the tissue determines the path of propagation.

These conditions do not necessarily hold throughout the nervous system. For example, at or near junctions, or on the surface of cell bodies, a depolarized protein molecule may induce depolarization in more than one neighboring molecule, and more than one of these inductive processes may play a role in the further propagation of the excitation. Effective induction may here be *one-many* and many-one, instead of being one-one. It may, for example, in certain regions be from one molecule to all its neighbors in a sheet, so that a complex field of superimposed inductive processes is set going from a limited number of points of entry. The question is, What will happen in such a field?

Assume the simplest case: a plane monolayer of identical polarizable protein molecules each of which tends to induce its own state in n closest neighbors, where n is greater than one. Let a definite selection of these molecules be repeatedly excited by induction from outside the sheet. Every pair of nearest neighbors will tend to reduce its polarization difference to the minimum. The resulting propagation of excitation in the sheet will tend to set up a field of minimal gradients subject to the boundary condition fixed by the repeated excitation of the selected set. The contrast of the excited set and the nonexcited background will be strengthened, all outstandingly sharp gradients being eliminated, and any regular pattern inherent in the selected set being clarified and stabilized by the uniformizing process of one-many and many-one induction.

The mathematical expression for this process in the limiting case of infinitesimal molecules with continuously variable polarization, each inducing in all its immediate neighbors, is the differential equation for diffusion in a conducting sheet. The solutions of this equation representing steady states have the form of regular patterns with characteristic symmetry properties, similar in some respects to those of a vibrating plate struck at selected points. Thus a protein sheet of this type may act as a harmonic analyzer biased in favor of simple patterns.

The normalizing property of protein fields, in the case of a two-dimensional region with one-many induction and a rough pattern of excitation induced in it from outside, may therefore account for the self-clarifying and self-stabilizing property of excitation patterns. Moreover, such patterns, once established, will tend to leave modifications facilitating their repetition as units even when only part of the original stimulus is present. Though further research is necessary, it is probable that one-many induction of this general type is responsible for the pattern characteristics of nervous processes, and therefore of all sensori-motor processes in animals. The displacement of patterns between different sensory and motor channels, and their causal independence of spatial magnitude and of tempo, are problems requiring further experimental and theoretical research.

The above general interpretation of the self-clarifying and self-stabilizing properties of patterns of nervous activity can be applied in many different ways. If the protein molecules possess only two alternative states the normalizing tendency would stabilize *a regular pattern of sharp contrasts* rather than one of continuous gradation. Moreover, the one-way induction may be (1) from molecule to neighboring molecules, e.g. on the surface of a cell body; or (2) from one fiber to neighboring parallel fibers; (3) in a more complex manner, from one point to many distant points by conduction along many radiating fibers; or (4) through a combination of these methods. Only experimental research can decide between these, the essential factor in the unitary theory of all types of pattern causation in neural processes being one-many induction in a two-dimensional region, the third dimension being required for afferent and efferent tracts.

The task for neural physiology is to use this concept of one-many induction to account for all the pattern properties of central nervous activity, for example in the cortex and possibly also in the retina. These include, as well as the self-clarifying and stabilizing character, the following special properties: the displacement of patterns; the reduction of patterns of different spatial extent to a common basis before recording in a stable modification; the abstraction of common formal properties; the recording of patterns by the production of facilitative modifications, possibly in specialized cerebral regions; and the corresponding temporal properties, such as the reduction of patterns of different tempo to a common basis, the recording of temporal sequences, etc.

Moreover, the resulting theory of neural patterns must cover the phenomena of summation, reinforcement, and inhibition. For example, identical or similar stimulus patterns will tend to intensify and stabilize each others' effects in the one-many inductive sheet. On the other hand complementary or incompatible patterns of excitation and nonexcitation will tend mutually to neutralize each others' influence, and so to display antagonistic properties. A powerful complementary stimulus pattern will eliminate the effects of a less intense stimulus pattern, and so inhibit its normal effect.

So far we have considered the time- and space-integrative properties separately. But these are merely aspects of one comprehensive process in which an extended stimulus pattern is transformed into an extended motor pattern. This transformation process follows a course determined by the facilitating modifications left by previous processes, provided that these are not exhausted by too frequent, ineffective use. The entire process from stimulus to response involves selective reception, afferent conduction, recording, space- and time-integration, discrimination in accordance with the dominant internal tendencies, and the distribution of the efferent conductive processes.

All induction of polarization in neural tissues has a fundamental all-or-none character, since each molecule either does, or does not, pass its depolarizing and repolarizing thresholds. It follows that all neural action patterns consist of a changing three-dimensional matrix of two-valued parameters, which is shaped into regular patterns at unique integrating sheets, and adaptively controlled in accordance with the results of past action patterns and the momentary internal condition of the system.

41. The Endocrine Glands

THE ENDOCRINE GLANDS are pockets of specialized cells absorbing materials from the blood and returning to it synthetic products, or hormones, many of which act as regulators of the rates of different groups of processes throughout the system. Such hormones are not specific to any one species, and most of them control the rates of extensive groups of processes over wide groups of species. The structure and mode of operation of the individual glands and their co-operation as a self-balancing system are not yet understood. Nevertheless, the unitary theory of the animal organism leads to a suggestion which may be of value for research.

Three factors are involved in the functional cycle of any differentiated cell:

1. The characteristic system of molecules, derived from hereditary prototypes, whose cycle determines the function of the cell, whether synthetic, conductive, contractile, etc. This highly specific factor determines the *specific character* of the cycle.

2. The stimulus to function, which is either a pulse of depolarization or a chemical change, e.g. the arrival of materials for synthesis. This determines the *timing* of each cycle.

3. The respiratory system, which reinforces the normalizing pulse, and determines the *maximum rate of repetition* of the cycles.

Of these three factors, the respiratory system is the only one which is relatively nonspecific, is concerned with the regulation of the rate of repetition of cycles, and is directly influenced by the circulating fluids. It is therefore probable that some, at least, of the rate-controlling hormones are chemical units which are indispensable to the operation of the respiratory system, possibly acting as links between it and the more specific functional system.

In the present state of knowledge no detailed classification of the glands and their varied secretions is possible in terms of unitary theory.

42. Co-ordination

EACH DIFFERENTIATED TISSUE and organ system in an animal organism operates in such a manner as to eliminate deviations from the norm of a specific type, and the processes of such differentiated systems are co-ordinated as components of the comprehensive normalizing process of the organism in its environment.

The application of this general principle to a detailed theory of the general co-ordination of the animal organism must await further knowledge of the endocrine system, and of its relation to the nervous system. But this principle leads immediately to certain general conclusions regarding the relationship of these two differentiated systems as components of the central co-ordination.

It is clear that, if every differentiated organ system eliminates deviations of a specific type only, no one such system can exercise absolute control over any other, or over the organism as a whole. Though the two systems influence each other, the nervous system does not control the endocrine, nor does the endocrine system control the nervous. The comprehensive normalizing process of a healthy organism holds all the differentiated systems in co-operating balance, each differentiated process representing one component of the total process.

The central nervous system eliminates deviations from the norm mainly arising in the relation of the organism to the environment, and may therefore be said to control the external balance. On the other hand the endocrine system, together with associated parts of the nervous system, controls the internal balance, eliminating internal deviations from the norm, by controlling the relative and absolute rates of different groups of internal processes. But the two systems are in intimate interaction, and their balanced coordination is sustained by the comprehensive normalizing process of which they are components.

In the normal internal history of the individual animal the process of the synthetic reproduction of characteristic protein overrides all others, for that is the net result which all other processes are adapted to facilitate. The pituitary and reproductive glands have a unique status, for they appear to control the tempo of this central process, which expresses the dominant internal tendency of the individual and species.

But the organism is set in its environment, and at each stage and level the internal tendencies alternate with the external tendencies of the wider system constituted by the organism-in-environment. The tendency toward external balance culminates in the dominant processes of the cerebral cortex, in which the formative character of all natural process finds its supreme expression.

Yet this duality of internal tendency and gland, contrasted with external tendency and central nervous system, does not express a dichotomy prejudicial to the balance of the organism, but a rhythmic alternation which is the essence of animal life.

43. Green Plants

We now have to consider how far the formula covers other groups, such as *green plants* (used here in the restricted sense of plants rooted in soil and growing vertically), and more primitive organisms.

Typical green plants differ from animals in the following respects:

1. *Basic Synthesis*. Special regions in green plants possess the capacity to combine the point-centered tetrahedral patterns of inorganic carbon and nitrogen compounds to form the linear patterns of carbohydrate and protein chains.

A consideration of the symmetry character of this operation shows that chiral factors are involved, and the "left-handed" configuration of amino acids in natural proteins suggests that only one of the two possible chiral processes is regularly used in protein synthesis.

2. *Fluid protein and extended carbohydrate tissues.* Plant protein is relatively fluid; there are no stable extended protein structures (such as the animal protein fibers or structures capable of undergoing propagated cycles of polarization and/or contraction) and therefore no centrally controlled locomotion; the stable extended structures in plants consist of relatively static polysaccharide, e.g. of spirally constructed cellulose tubes; and protein constitutes a smaller proportion of the plant cell.

These properties suggest that there may be no stabilization of uniform fields in plant protein, and therefore no extended normalizing process of a uniform character.

3. *Growth* continues throughout the life cycle in undifferentiated growing regions, and displays rhythms determined by external factors, whereas in animals growth is spread more uniformly throughout the system and is completed at maturity. The growth of stable plant tissues depends on the condensation into stationary extended (cellulose or lignin) structures of units synthesized elsewhere. New plants can be grown by vegetative reproduction from any parts containing adequate synthetic regions and growing points.

These facts indicate that the structural aspect of plant growth consists in the stabilization in stationary, extended polysaccharide tissues of a relatively static (often helical) pattern determined by the hereditary units; and not, as in animals, mainly in the multiplication of hereditary units to build up a differentiated pattern of tissues capable of undergoing specific functional cycles under an extended normalizing process.

4. *Differentiation* is determined partly by the continuing influence of external factors (such as the air/soil contrast, sunlight, gravitation, etc.), and not, as in animal embryos, by factors originally of external origin which have been stabilized internally. The orientation of all stabilized plant

structures is fixed in relation to the external organization of the organism, and plant differentiation therefore does not involve the complex internal transformations of embryological development.

In both groups the hereditary units determine the character of the elements composing the adult pattern. The orientation of these elements is fixed in plants in relation to a single external axis, and in animals in relation to a primary axis and a normalizing field which are both internal.

5. *Modification.* There is little, if any, residual modification of plant protein as the result of processes occurring in it, and no adaptive learning by experience comparable to that in animal protein and animal behavior.

This suggests that there is relatively low stabilization of the intermolecular relations of orientation in the more fluid plant protein.

If basic synthesis is set on one side, all these properties of green plants may be viewed as expressions of one general characteristic: in plant protein there is relatively little direct stabilization of the interrelations, in regard to position and orientation, of neighboring protein molecules. If this is a general property of plant protein molecules it can account for the following special properties: the fluidity of plant protein; the absence of highly stabilized protein fibers and membranes; the absence of extended protein structures undergoing local cycles and propagated pulses of polarization; the dependence on relatively rigid polysaccharide structures; the orientation of these structures in relation to an external axis; and the almost complete absence of adaptive modification (of the animal kind) in plants. All these properties involve extended relationships (or their absence), and they can all be related to the absence of directly stabilized molecular interrelationships in plant protein. Where a polysaccharide structure is present a relatively stable protein film may be formed on its surface, but it appears that plant protein molecules do not in general directly associate to form stable extended structures.

In unitary theory the process of condensation, for example in polysaccharides or in animal protein, involves the mutual compensation or neutralization of oppositely polarized groups at the ends of linear molecules. The inference is therefore that plant protein molecules may not, at least in their normal state, possess a dominant *vector* axis (or dominant polarization along the primary axis). They must possess a unique axis, but not a vector axis, since if they did they would tend to condense or associate to form chains or fibers.

We must now leave the extended molecular interrelationships, and consider the highly localized and possibly even intramolecular process of basic protein synthesis. In this chiral process point-centered and planar inorganic atoms or molecules are converted into organic molecules of a chiral character. This is clearly seen in the synthesis of natural proteins, which do not merely possess a chiral configuration, but are all of one kind (left-handed). The protein molecules guiding the process of basic synthesis must therefore possess a unique primary axis (probably not vector in character) and a characteristic univocal spiral process about that axis. Whatever the actual pattern of atoms may be in any molecule acting as the catalyst of basic synthesis, that molecule must possess a cylindrical character with a unique, say left-handed, spiral process. For example the cylinder might undergo cycles of changes of shape, growing first longer and thinner as its spirally arranged components draw more nearly parallel to the axis, and then shorter and fatter as they return to their normal state. This process may be carried over its threshold by the chiral influence of sunlight. Moreover such spirally operating molecules would be less likely to form membranes, or any other form of stabilized intermolecular relationships (except possibly when packed in spiral arrangements).

We are thus led to the following *working hypothesis* which invites experimental test:

All functional protein has a chiral character; in animal protein this is normally less marked and the "molecules," being nearly planar, can be associated into extended pulsating structures with a nonchiral propagated polarization *cycle; while in plant protein the chiral character is generally more marked (helical angle greater) and the pulsation of each molecule involves a chiral, nonpropagated polarization cycle and cyclic changes of shape, which prevent stable association into extended structures, but provide the necessary conditions for basic synthesis.*

On this view the formula for a green plant becomes: *a normalizing process of local chiral fields stabilized by hereditary units and supported by stationary structures conforming to an external axis.* The following interpretations result from this formula:

Basic synthesis is the normalizing process of a local chiral field, the stable hereditary unit inducing its own chiral pattern as it brings the components together. Sunlight or chemical processes of a special character (e.g. oxidization of sulphur) provide the chiral polarization necessary to carry the system over the specific threshold, though this may be assisted by special respiratory processes. Each synthetic region makes all the basic units necessary for the whole plant.

Condensation is the progressive precipitation of a static component of this local field. The single plant protein molecules adhere to the polysaccharide scaffolding and, as a by-product of their own spiral process of protein synthesis, deposit new links of polysaccharide into position, step by step. Each growing region contains potentially the whole pattern of the plant.

Differentiation is determined, not by extended pulses, but by the response of the relatively undifferentiated protein molecules to external influences, within the setting of already formed polysaccharide structures. Static seeds can retain the power to grow, because in plants the property of synthesis is inherent in individual protein molecules, and is not dependent on an extended and already established normalizing process.

Transport (e.g. ascent of water) may be the net result of the pumping effect of the cyclic changes of shape of all the protein molecules throughout the plant on a fluid whose direction of flow is stabilized by root pressure and leaf transpiration.

Finally, the total process of the plant is a normalizing process *stabilized at one boundary only,* the inner boundary condition determined by the hereditary units. For the external boundary in plants is open and unstable, the growing points being always ready to extend the outer boundary of the plant when conditions are favorable.

The absence of any stabilized outer boundary corresponds to the fact that there are no inward moving normalizing pulses as in the animal, no restorative phase bringing functional structures back to a normal polarized condition. Indeed there are no true functional cycles in the plant, no individual structures which pass through a cycle of transformations and return to their original state, other than the individual protein molecules controlling synthesis. The rhythms of the plant consist mainly of externally initiated steps of multiplicative synthesis or of condensation, and of the periodic formation and dispersal of new tissues.

The comprehensive process of the plant is thus a one-way process without the local structural cycles of the animal organism. The differentiated structures of the plant are stationary; they can be distended, dispersed, and made anew, but otherwise they merely support the fluid protein which controls the rhythmic one-way process of chiral synthesis.

44. Primitive Organisms

When we pass from the relatively large and differentiated animals and green plants to the most primitive single-celled organisms, there is a greater element of uncertainty in undertaking a unitary analysis. This is not merely on account of the smallness of many of these primitive organisms. The difficulty arises because in these systems the different components of the unitary process are separated little, if at all, into differentiated tissues and organs. A primitive organism is not necessarily simpler than a multicellular organism, but is one in which processes that are separated in differentiated organisms go on everywhere simultaneously, or more nearly so.

We shall here neglect the various types of virus, which possess no respiratory systems and can only reproduce themselves within living cells. In unitary theory they represent self-multiplying components of the field of a living cell.

A primitive bacterium, such as a small bacillus, is one of the smallest known types of self-reproducing entity which can survive and multiply in a variety of environments and is not dependent on other living cells. A bacterium is capable of synthesis of its own proteins, carbohydrates, etc., (including basic synthesis, some condensation, and specific synthesis), of the necessary respiratory process, of chemical adaptation to different nutrient media, of sustaining its own organization, and of identical multiplication. Thus a bacterium may be regarded as a combination, in one unit, of a growing point and a synthetic region of a plant. The bacterium synthesizes, grows, multiplies, and does little else, though some can perform movements in a relatively uncontrolled manner.

A small bacillus may have the form of a cylinder about 10^{-4} cm. in length, and fifth of this in diameter. If for the sake of illustration a protein molecule is imagined as a cube with sides of 10^{-6} cm. or thirty peptide links, then the length of this bacillus is equivalent to a hundred such molecules, and the diameter to only twenty. The bacillus may therefore contain something over 10,000 such protein molecules, and some hundreds of these molecules may constitute the primary hereditary units or genes. But it is probably wrong to regard the system as organized in separable molecules, for there must be a continuous self-stabilizing and elastic framework.

The main chemical constituents are amino acids, protein, carbohydrate, and nucleic acids. A few hundred chemical reactions are regularly carried out, but these may be reducible to a smaller number of fundamental chemical steps. The complete cycle of duplication of the system, including division, may be completed in half an hour.

This minute cylinder could only contain about ten or twenty cubes with ten such protein molecules along each side. Yet some hundreds of different processes of intake and breakdown of foods, basic synthesis, condensation of polysaccharides, specific synthesis of proteins, carbohydrates, etc., respiration, excretion, and ultimately of division, are performed in a co-ordinated manner. It is clear that even if all these processes are theoretically separable (or partially separable) in larger organisms, they must co-operate in the most intimate manner in so small a system. There is no room for the differentiated stabilization and isolation of the different components of the normalizing process; all the components must occur side by side. Apart from a carbohydrate shell there is no room for extended uniform tissues; so many different things have to be crowded in that the system, or substantial parts of it, must be heterogeneous throughout. Moreover, there is no room for disorder; each hereditary unit must possess its own normal site.

At any moment, other than that of division, the processes of digestion, multiplicative synthesis, respiration, and excretion are proceeding continuously, without any stimulus from the environment (other than the presence of nutrients). There is thus a continuous one-way process culminating in repeated specific synthesis (and multiplication), and in no other internal result. There are no functional cycles as in the animal, and no externally controlled rhythms as in the plant. Indeed, there is probably no differentiation of independent stable structures, except for a shell or flagella.

Every internal component of the system is always in process, nothing is intrinsically stable, nothing is fully differentiated, nothing is oriented in relation to the environment. The process is nothing other than the continuous normalizing of a field of hereditary units, and even the hereditary units themselves are only stable as components of this perpetual process.

The formula for the most primitive type of organism is therefore: *a continuous normalizing process of a heterogeneous field of hereditary units.* A primitive organism is not necessarily simpler, and a differentiated organism more complex; the primitive is merely more heterogeneous.

In the functional units of such a system there are probably no two protein molecules identical both in their internal structure and in possessing the same immediate neighbors. There is heterogeneity throughout, and there may be no transport of chemical units without simultaneous transformation. When the one-way process has eliminated this absolute heterogeneity by duplicating every unit, the system is unstable and divides.

If the nutrient medium is altered, different digestive and synthetic processes latent in the system are evoked, and the processes which lead to the most rapid synthesis under the new situation are those which then dominate the system.

45. General Formula for Organism

We are now in a position to collect the conclusions of the previous sections, and to summarize the unitary theory of organism in a general formula, showing how it applies to animal organisms, to green plants, and to primitive organisms. The theory as presented here is concerned with the nature of biological organization in the individual organism and its development in the life history of the individual. The processes of reproduction, heredity, and of the origin and evolution of species are excluded, as are also various mixed, transitional, and anomalous types.

General Formula for Organism:

An organism is a continuous normalizing process in a field of hereditary units.

Formula for Primitive Organisms:

A primitive organism is a continuous normalizing process in a heterogeneous field of hereditary units.

Formula for Green Plants:

A green plant is a continuous normalizing process of local chiral fields stabilized by hereditary units and supported by stationary structures conforming to an external axis.

Formula for Animal Organisms:

An animal organism is a continuous normalizing process of extended nonchiral fields stabilized by hereditary units and an outer boundary.

These formulae are logically related as follows:

General Formula

Primitive Organism

Green Plant　　　　Animal Organism

The following comparative table summarizes the main properties of the three groups which are derivable as consequences of the formulae. For the sake of clarity the contrasts are presented as tendencies toward a sharp divergence of the three groups. But the interrelationships of the organic realm are profound, through a common evolutionary origin and extensive mutual dependence. It is therefore probable that numerous exceptions exist which do not fall into the three discrete categories which are presented here to facilitate research. The table is a heuristic hypothesis, not a postulation of ultimate categories.

	Primitive Organism
Formula: A continuous normalizing process of:	A heterogeneous field of hereditary units.
stabilized by:	(no true stability).
supported by: ...	(? stationary shell).
Structures and processes are oriented:	As components of internal normalizing process.
Normalizing of:	One heterogeneous field, resulting in respiration, synthesis, and ultimate division.
Primary result of local processes:	Basic and specific synthesis, multiplication.
Secondary result of extended processes:	—
Inner multiplicative rhythm:	Rhythmic synthetic multiplication of all components.
Environmentally determined multiplicative rhythm:	—
Functional cycles:	—
Relation to environment: ...	Intake and Excretion.
Differentiation of extended tissues:....................	—
Activity of cell nucleus:	Continuous; nucleus not differentiated.
General or macroscopic form of organism:	Various.

Adult Stage:	No adult stage, except at moment of division.
Green Plant	*Animal Organism*
Local chiral fields.	Extended nonchiral fields.
Hereditary units.	Hereditary units and outer boundary.
Polysaccharide shells.	—
In relation to external factors.	As components of internal normalizing process and resulting internal organization.
Local chiral fields, resulting in respiration, synthesis, condensation, and ultimate reproduction.	Extended uniform fields, resulting in respiration, specific synthesis, condensation, and ultimate reproduction, but also in repolarization of cyclic structures.
Basic and specific synthesis; condensation, multiplication.	Specific synthesis, condensation, multiplication.
—	Adaptive modification and behavior.
—	Inner multiplicative rhythm in growth.
Environmentally determined synthetic multiplication in special regions (sunlight necessary).	—
—	Environmentally evoked functional cycles.
Intake and Excretion.	Intake and Excretion.
Curvature of stationary polysaccharide structures under external influences.	Adaptive response of protein modifications to external stimuli.

Stationary polysaccharide tissues.	Cyclic protein tissues, supported by stationary protein tissues.
Periodic, determined by external factors.	Periodic, determined by internal factors.
Tubular spiral, oriented in relation to external vector axis (vertical).	Various.
Adult is a pattern open to further rhythmic growth.	Adult is a stabilized but adaptive pattern.

This classification of properties enables a comparison of the three groups to be made at a glance. But it does not reveal the role of the *formative* property of the unitary process in biological organization as in inorganic processes, which is shown in the following analysis:

	The formative character of natural process evidenced in inorganic, organic, and mental processes:
Inorganic: The formation of static or stationary symmetrical structures.	The separating out and persistence of stationary fundamental structures (symmetrical atoms and molecules). The drawing into regular orientation and position of structures extending an existing structure (crystallization, condensation, etc.). The association of mutually complementary structures completing the pattern of a closed structure. The tendency of an open structure to extend its pattern by inducing the repetition of the process which formed it (*facilitation*).
Organic: The continued normalizing and extension of a field of hereditary units.	The *multiplication* of hereditary units. The *condensation* of stationary structures. The *modification* of systems of cyclic structures improving their arrangement and orientation. The tendency of cyclically worked structures to adjust themselves so as to facilitate the cycles (*cyclic facilitation*). The *formation of co-operative systems* of units mutually facilitating their cyclic processes as

components of a comprehensive one-way process.

The *tendency for order to increase,* and for graded steps reducing field gradients to be introduced, resulting in an increasing ratio of directed to disordered induction (*increasing biological efficiency*).

(The negative principle, with great positive consequences, that exhausted functions come to an end.) The propagation of pulses of normalization in appropriate linear tissues (*nervous "conduction"*).

The *production and operation of specificity* of all kinds, in similar or complementary patterns.

Mental: Pattern-formative properties of one-many induction. — The *clarification and stabilization of patterns* with minimal field gradients, in sheets of appropriate tissue (the formative or Gestalt property of perception, memory, posture, behavior, and of mental processes, both intuitive and rational).

This theory of organism is unitary in several respects: it interprets all phenomena as aspects of one universal process; it identifies that universal process by looking beneath contemporary physics and biology to discover their common foundation; and in doing so it transcends the dualism of a conserved "matter-energy" and a formative "mind."

The unitary formula for organism is neither mechanical nor teleological. It discards the conception of permanent localized entities subject to conservation principles, but it does not treat present processes as determined by future events.

The clue to this transformation lies in the unitary concept of tendency, as the isolable one-way process which leads toward symmetry and stability. As Mach pointed out, the concept of a one-way tendency, or directed process, is no more teleological in an adverse sense than is the concept of gravitational or electrical "attraction."

But the concept of tendency does imply the existence and identification of a unique end-state representing the ideal terminus of any isolable process, the state in which the distorting effects of an earlier environment have been eliminated. Thus unitary processes have a finalistic character and bear a special relation to possible future events, and the unitary concept of tendency provides the solution of the biological problem that "phenomena unaccountably precede that to which they are unquestionably related" (L. J. Henderson).

The unitary theory of organism provides a theoretical system which may prove to be adequate for an exact science of life. In particular it clarifies many special research problems whose solution may lead in that direction.

46. Evolution

A MAJOR GROUP of outstanding biological problems concerns the evolution of species in the widest sense; this includes: the origin of life; the conditions determining changes in the number, character, and arrangement of the hereditary units; the factors which led to the differentiation of green plants and of animals; and finally the appearance of a species with the unique individual and social potentialities of *homo sapiens*.

If the unitary method is applicable to all one-way processes it must be capable of throwing light on these issues, after the theory of organism has been adequately tested and developed. But certain points bearing on the problem of the evolution of species are closely connected with the argument of this work.

1. Until a general theory of biological organization has been formulated and confirmed, and the laws governing the number, structure, and arrangement of the hereditary units are known, theories of the origin and evolution of organisms are liable to contain fundamental errors. The description of a past evolutionary process involves statistical and other methodological problems of such an exceptional character as to render advance uncertain until all theoretically prior problems have been clarified.

2. If the possible changes in the patterns and arrange-

ment of the hereditary units are restricted by symmetry conditions determining their stability, there may be no mutations which can be fully ascribed to "chance." All mutations to new stable patterns may necessarily possess favorable or unfavorable properties in relation to the self-stabilizing organization of the system. Indeed it may prove that what are now called "chance" mutations, because they are caused by arbitrary external factors, are none the less necessarily favorable to survival during certain evolutionary periods, necessarily unfavorable during others, and neutral in yet others. The actual course of the historical process of the evolution of species may have been determined in some periods and in some lines by true Darwinian competitive selection of *relatively* arbitrary mutations, and in others by an internal tendency for stable changes in the chromosomes to possess a stabilizing effect on the organization of the system.

3. But even these alternatives do not exhaust the possibilities. It may be that the actual historical evolution of species could not have occurred without the constant interplay of both factors: (a) the internal formative tendency to establish stable symmetrical units and co-ordinated patterns of such units; and (b) external, competitive, post-hoc selection. We may ask the question: if the formative, self-facilitating, and developing property of protein processes is operative in guiding the (ontogenic) development of the individual organism, has it or has it not played a guiding role in the (phylogenetic) evolution of the species? But no answer can be given at this stage.

4. Finally, in view of the importance of biological theory in relation to man's conception of himself, it appears desirable that the term *evolution* should be restricted to the relatively slow changes in species characters due to changes in the hereditary equipment, and that *social development* (or some equivalent) be used to refer to the more rapid changes during the recent history of *homo sapiens,* mainly in the last 50,000 years. This social development results from the progressive evocation by a developing social tradition of the potentialities of a relatively constant heredi-

tary constitution. *Homo sapiens* has apparently still to reach the mature biological norm (and social pattern) corresponding to the proper realization of the potentialities of his hereditary constitution. This process of social development toward the mode proper to the species character of man (if such a mode exists) is of a different nature to the long-term genetic changes underlying the evolution of species.

47. Research Problems

THE UNITARY PRINCIPLE is an instrument for organizing existing knowledge and for guiding theoretical and practical research. If successful, unitary theory may prove to be distinguished from previous theories in the following ways. It may provide:

1. *More comprehensive unified theory.* This may include a theory of mathematical physics and of all nondimensional constants; a theory of organism, such as that presented here, supplemented by a theory of heredity and evolution; and a theory of man transcending the mind-body dualism.

2. *Special theories hitherto lacking.* Examples are theories of nuclear and low-temperature properties; of many special biological phenomena (see below); and of psychological processes.

3. *Improvements of existing theories.* The method may lead to the following kinds of improvements in special theories which are adequate in the sense that they are not disproved by any of the facts of a limited field: simpler theory, easier and more accurate calculation, clarified relationships with related fields.

These advantages which the unitary principle may offer all consist in the unification, extension, and improvement of existing scientific theory. They do not involve the positive discrimination between unitary theory and existing exact theory in any field where there is already a developed theory. In fact it is improbable that single experimental results will ever be capable of being used to distinguish between general unitary theory and any exact preunitary theory of a special field of phenomena, except on grounds of greater simplicity.

The general reason for this is that unitary theory is a comprehensive method which includes all possible exact theories as special cases. But the issue can also be viewed from another side. *It is intrinsically impossible for unitary and preunitary theory to stand in strict contradiction to one another on special problems because the two types of theory use different criteria in selecting processes which can be treated as isolable.* Unitary theory treats one-way processes of a certain kind as isolable for the purpose of scientific description, while preunitary exact theory regards the conservation of energy-mass as the condition which must be satisfied by systems which can be treated as isolated. The two methods cannot lead to opposite conclusions about one and the same phenomenon, because they isolate different classes of phenomena and where one method is applicable the other cannot be.

This intrinsic logical independence of preunitary and unitary theory can only be overcome if quantitative science restricts the application of conservation principles to closed cycles, and thereby renounces the procedure of inventing new kinds of particles (e.g. neutrinos) to overcome every apparent breakdown in its conservation or other principles. Quantitative theory can always save itself from failure, i.e., from experimental disproof, by the use of new *ad hoc* hypotheses. But in doing so physical theory grows more and more complex, and the true purpose of theory is no longer served. It is evident that fundamental clarity cannot be attained until conservation principles cease to be prostituted by indiscriminate use outside the field of closed cycles where alone they possess unequivocal empirical consequences.

But if conservation principles are only to be applied to closed cycles it becomes necessary for exact science to discover a method of describing those one-way processes which do not constitute closed cycles (or parts of such cycles), and it is at this point that preunitary and unitary theory meet. For it is then evident that the exact science of conservation principles represents a logically degenerate limiting case of the more comprehensive science of one-way processes, and all possibility of their mutual contradiction disappears.

This analysis serves to emphasize the fact that the supreme criterion of scientific theory is *simplicity*. There may exist countless alternative methods of describing any phenomenon, but science advances by selecting the simplest. New conventions can always be invented, but nature enables a choice to be made by discriminating between those which lead to simpler, and those which require more complex theories to cover the facts. The title of unitary theory to provide the foundation of a unified science must ultimately be judged by its ability to provide the simplest theory of the entire field of science.

When the unitary principle is applied to any special type of process, it leads at once to the identification of clear issues for isolated examination. In the following brief list of some biological problems of outstanding importance, no attempt has been made to distinguish between those requiring only theoretical research, since sufficient reliable data already exist, and those where further experimental work is necessary.

In the transformation of scientific theory from the pre-unitary to the unitary basis the readjustment of physical and biological concepts can proceed in parallel. A few physical problems which are relevant to both the inorganic and the organic realms have therefore been included.

General research principle. The task of unitary research is to identify isolable one-way processes by discovering the particular type of decreasing asymmetry which characterizes them. This general heuristic principle supersedes the search for conserved quantities and entities, which it covers as a special case of the more general unitary method.

General physical problems. These include: (1) the identification of electrical polarization with polar asymmetry of structure, magnetic with axial, etc., and the correlation of structural polarization with the relative motions of structures; (2) structural asymmetry as the source of free or available energy; (3) the tendency for polarization to decrease in isolable systems; (4) the tendency toward uniformity of polarization in molecular systems; and (5) the conditions of the measurability of polarization. Other theoretical problems have been indicated in § 8.

General biological problems. The following interpretations of biological processes require to be developed and tested:

Synthesis: the normalization of polarization, or increase of symmetry, between a dominant structure and appropriate less stable neighbors.

Directed transfer of free energy: the induction of polarization.

Directed transport: the displacement of a mobile polarized structure as a component of a one-way pulse.

Cytoplasmic response to stimulus: the disturbance of a normalized field, releasing the inner relaxative tendencies of local structures.

Many other general problems also arise from the application of the formula for organism.

Special biological problems. Many of the special problems of biology involve the properties of particular types of living protein, and they can appropriately be classified in terms of protein structure.

Here the primary task is to identify the distinguishing characteristics, if any, of the protein in primitive organisms, green plants, and animal organisms, respectively.

This problem overlaps with the classification of protein into specific structural types, composed of chains with regularly arranged polarizable side groups providing an adequate continuity of induction of polarization to stabilize the corresponding specific types of functional process. For example, the protein and other co-operative constituents of each of the following types of functional systems must be shown to be appropriate to its function: basic synthetic; condensative; specific synthetic; nonselective (nuclear) synthetic; special formative regions in differentiation; digestive; respiratory; sensory; propagative; contractile; transportive; connective; and reproductive systems. Each of these functional systems must represent a particular space-time component of the comprehensive normalizing process of the cell or organism, and each must possess a protein with the special process and structural characteristics corresponding to that component.

This implies a parallel development of general unitary theory from its present stage as a descriptive theory of tendency, toward a rigorous mathematical theory covering the procedure and results of measurement.

An alternative method of approach is to select special regions, such as the surface of a nerve axon, and to analyze in detail on unitary principles the electrical, physicochemical, biochemical, and physiological processes involved in the conductive, respiratory, and other tissues operative in the region. A comprehensive double one-way pulse of depolarization and polarization passing through the region must produce as its components the co-operative interaction of conductive and respiratory systems. Other functional regions invite similar detailed analysis.

Finally, if unitary theory proves successful in representing the structural organization of the healthy organism, it must also be applied to clarify the processes of pathology, of aging, and of death, in which the normalizing process fails to sustain the normal unity of the organism.

71-1
73-1