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An Outline of General System Theory
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AN OUTLINE OF GENERAL SYSTEM THEORY

1 *Parallel Evolution in Science*

As we survey the evolution of modern science, we find the remarkable phenomenon that similar general conceptions and viewpoints have evolved independently in the various branches of science, and to begin with these may be indicated as follows : in the past centuries, science tried to explain phenomena by reducing them to an interplay of elementary units which could be investigated independently of each other. In contemporary modern science, we find in all fields conceptions of what is rather vaguely termed ' wholeness.'

It was the aim of classical physics eventually to resolve all natural phenomena into a play of elementary units, the characteristics of which remain unaltered whether they are investigated in isolation or in a complex. The expression of this conception is the ideal of the Laplacean spirit, which resolves the world into an aimless play of atoms, governed by the laws of nature. This conception was not changed but rather strengthened when deterministic laws were replaced by statistical laws in Boltzmann's derivation of the second principle of thermodynamics. Physical laws appeared to be essentially ' laws of disorder,' a statistical result of unordered and fortuitous events. In contrast, the basic problems in modern physics are problems of organisation. Problems of this kind present themselves in atomic physics, in structural chemistry, in crystallography, and so forth. In microphysics, it becomes impossible to resolve phenomena into local events, as is shown by the Heisenberg relation and in quantum mechanics.

Corresponding to the procedure in physics, the attempt has been made in biology to resolve the phenomena of life into parts and processes which could be investigated in isolation. This procedure is essentially the same in the various branches of biology. The organism is considered to be an aggregate of cells as elementary life-units, its activities are resolved into functions of isolated organs and finally physico-chemical processes, its behaviour into reflexes, the material substratum of heredity into genes, acting independently of each other, phylogenetic evolution into single fortuitous mutations, and so on. As opposed to the analytical, summative and machine theoretical viewpoints, organismic conceptions[1] have evolved in all branches of modern biology which assert the necessity of investigating not only parts but also relations of organisation resulting from a dynamic interaction and manifesting themselves by the difference in behaviour of parts in isolation and in the whole organism.

The development in medicine follows a similar pattern.[2] Virchow's programme of 'cellular pathology,' claiming to resolve disease into functional disturbances of cells, is to be supplemented by the consideration of the organism-as-a-whole, as it appears clearly in such fields as theory of human constitutions, endocrinology, physical medicine and psychotherapy.

Again we find the same trend in psychology. Classical association psychology tried to resolve mental phenomena into elementary units, sensations and the like, psychological atoms, as it were. *Gestalt* psychology has demonstrated the existence and primacy of psychological entities, which are not a simple summation of elementary units, and are governed by dynamical laws.

Corresponding developments are found in the social sciences. In classical economic doctrine, society was considered as a sum of human individuals as social atoms. At present there is a tendency to consider a society, an economy, or a nation, as a whole which is superordinated to its parts. This conception is at the basis of all the various forms of collectivism, the consequences of which are often disastrous for the individual and, in the history of our times, profoundly influence our lives.[3] Civilisations appear, if not as superorganisms, as was maintained by Spengler, at least as superindividual units or systems, as expressed in Toynbee's conception of history.

In philosophy, the same general trend is manifest in systems so radically different as Nicolai Hartmann's theory of categories, the doctrine of emergent evolution, Whitehead's 'organic mechanism,' and dialectic materialism ; all these are systems which are diametrically opposed in their scientific, metaphysical and social backgrounds, but agree in maintaining that principles of dynamic wholeness are basic in the modern conception of the world.

Thus, similar fundamental conceptions appear in all branches of science, irrespective of whether inanimate things, living organisms,

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[1] L. von Bertalanffy, *Das biologische Weltbild*, Band I. Die Stellung des Lebens in Natur und Wissenschaft, Bern, 1949

[2] L. von Bertalanffy, *Biologie und Medizin*, Wien, 1946

[3] F. A. Hayek, *The Road to Serfdom*, Chicago, 1944

or social phenomena are the objects of study. This correspondence is the more striking because these developments are mutually independent, largely unaware of each other, and based upon totally different facts and contradicting philosophies. They open new perspectives in science and life, but also involve serious danger.

Thus it appears that there is a general change in the scientific attitude and conceptions, and the question arises : what is the origin of these correspondences ?

2 *Isomorphic Laws in Science*

Not only are general aspects and viewpoints alike in different fields of science ; we find also formally identical or isomorphic laws in completely different fields. This is a well-known fact in physics where the same differential equations apply, for example, to the flow of liquids, of heat, and of electric currents in a wire. But it appears that the significance of this fact, and the possibilities it opens in fields outside physics, have hardly been considered.

For example, the exponential law or law of compound interest applies, with a negative exponent, to the decay of radium, the monomolecular reaction, the killing of bacteria by light or disinfectants, the loss of body substance in a starving animal, and to the decrease of a population where the death rate is higher than the birth rate. Similarly, with a positive exponent, this law applies to the individual growth of certain micro-organisms, the unlimited Malthusian growth of bacterial, animal, or human populations, the growth curve of human knowledge (as measured by the number of pages devoted to scientific discoveries in a textbook on the history of science), and the number of publications on *Drosophila*.[1] The entities concerned—atoms, molecules, bacteria, animals, human beings, or books—are widely different, and so are the causal mechanisms involved. Nevertheless, the mathematical law is the same. Another equation, the logistic law of Verhulst, is, in physical chemistry, the equation of autocatalytic reaction, and in biology, it describes certain cases of organic growth. It was first stated in demography to describe the growth of human populations in a limited space of living. It governs also the advancement of technical inventions, such as the growth of the railway system in the United States during the last century, or of the number of wireless sets in

[1] A. H. Hersh, ' Drosophila and the Course of Research,' *Ohio J. of Science*, 1942, 42, 198-200

operation. What is known in national economy as Pareto's law[1] of the distribution of income within a nation, represents, in biology, the law of allometric growth, describing the relative increase of organs, chemical compounds, or physiological activities with respect to body size. Volterra[2] has developed a population dynamics, comparable to mechanical dynamics, working with homologous concepts such as demographic energy and potential, life action, etc., and leading to a principle of minimum vital action, corresponding to the principle of minimum action in mechanics. Actually, principles of minimum action appear in widely different fields besides mechanics, for example, in physical chemistry as the principle of Le Chatelier and in electrodynamics as Lenz' rule. Again, the principle of relaxation oscillations governs the neon lamp, but also important phenomena in nerve physiology and certain phenomena of biocoenoses or organic communities.

The same is true for phenomena where the general principles can be described in ordinary language though they cannot be formulated in mathematical terms. For instance, there are hardly processes more unlike phenomenologically and in their intrinsic mechanisms, than the formation of a whole animal out of a divided sea-urchin or newt germ, the re-establishment of normal function in the central nervous system after removal or injury to some of its parts, and *gestalt* perception in psychology. Nevertheless, the principles governing these different phenomena show striking similarities.

Again we ask : what is the origin of these isomorphisms ?

There are three obvious reasons. The first is in the trivial fact that while it is easy to write down any complicated differential equation yet even innocent-looking expressions may be hard to solve, or give, at least, cumbersome solutions. The number of simple differential equations which are available and which will be preferably applied to describe natural phenomena is limited. So it is no wonder that laws identical in structure will appear in intrinsically different fields. A similar consideration holds for statements formulated not in mathematical but in ordinary language : the number of intellectual schemes available is rather restricted, and they will be applied in quite different realms.

However, these laws and schemes would be of little help if the world (i.e. the totality of observable events) was not such that they

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[1] W. Pareto, *Cours de l'Économie Politique*, 1897

[2] V. Volterra, *Lécons sur la Théorie Mathématique de la Lutte pour la Vie*, Paris, 1921

could be applied to it. We can imagine a chaotic world or a world which is too complicated to allow the application of the relatively simple schemes which we are able to construct with our limited intellect. Fortunately, the actual world is not of this sort, and does allow the application of our intellectual constructions.

But there is yet a third reason for the isomorphism of natural laws and this is most important for our present purpose. Laws of the kind considered are characterised by the fact that they hold generally for certain classes of complexes or systems, irrespective of the special kind of entities involved. For instance, the exponential law states that, given a complex of a number of entities, a constant percentage of these elements decay or multiply per unit time. Therefore this law will apply to the pounds in a banking account as well as to radium atoms, molecules, bacteria, or individuals in a population. The logistic law says that the increase, originally exponential, is limited by some restricting conditions. Thus in autocatalytic reactions, a compound formed catalyses its own formation ; but since the number of molecules is finite in a closed reaction vessel, the reaction must stop when all molecules are transformed, and must therefore approach a limiting value. A population increases exponentially with the increasing number of individuals, but if space and food are limited, the amount of food available per individual decreases ; therefore the increase in number cannot be unlimited, but must approach a steady state defined as the maximum population compatible with resources available. Railway lines which already exist in a country lead to the intensification of traffic and industry which, in turn, make necessary a denser railway network, till a state of saturation is eventually reached ; thus, railways behave like autocatalysers accelerating their own increase, and their growth follows the autocatalytic curve. The parabolic law is an expression for competition within a system, each element taking its share according to its capacity as expressed by a specific constant. Therefore the law is of the same form whether it applies to the competition of individuals in an economic system, following Pareto's law, or to organs competing within an organism for nutritive material and showing allometric growth.

There exist therefore *general system laws* which apply to any system of a certain type, irrespective of the particular properties of the system or the elements involved. We may say also that there is a structural correspondence or logical homology of systems in which the entities concerned are of a wholly different nature. This is the reason why we find isomorphic laws in different fields.

The need for a general superstructure of science, developing principles and models that are common to different fields, has often been emphasised in recent years, for instance, by the Cybernetics group of N. Wiener, by the General Semantics of Count Korzybski,[1] in the claim for ' Scientific Generalists ' as recently advanced by Bode and others [2] and in many other publications. But a clear statement of the problem and a systematic elaboration has apparently never been made.

3. *General System Theory*

Such considerations lead us to postulate a *new basic scientific discipline* which we call *General System Theory*.[3] It is a logico-mathematical field, the subject matter of which is the formulation and deduction of those principles which are valid for ' systems ' in general. There are principles which apply to systems in general, whatever the nature of their component elements or the relations or ' forces ' between them. The fact that all sciences mentioned above are concerned with systems, leads to a formal correspondence or logical homology in their general principles, and even in their special laws if the conditions of the systems correspond in the phenomena under consideration.

General System Theory is a logico-mathematical discipline, which is in itself purely formal, but is applicable to all sciences concerned with systems. Its position is similar to that, for example, of probability theory, which is in itself a formal mathematical doctrine but which can be applied to very different fields, such as thermodynamics, biological and medical experimentation, genetics, life insurance statistics, etc.

The significance of the General System Theory may be characterised in different ways.

So far, exact science, meaning a mathematical hypothetico-deductive system, has been almost identical with theoretical physics, and the only systematic scientific laws that have been acknowledged

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[1] A. Korzybski, *Science and Sanity*, 2nd ed. New York, 1941

[2] H. Bode, *et al.*, ' The Education of a Scientific Generalist,' *Science*, 1949, **109**, 553

[3] L. von Bertalanffy, ' Zu einer allgemeinen Systemlehre,' *Blätter f. dtsche Philos.*, 1945, **18**, No. 3/4. (Not known if published.) ' Zu einer allgemeinen Systemlehre,' *Biologia Generalis*, 1949, **19**, 114–129.

universally and without restriction have been the laws of physics and chemistry. To be sure, there are rudiments of systems of laws, i.e. hypothetico-deductive systems, also in other realms such as national economy, demography, and certain fields of biology. For example, references are often made to biological or economical ' equilibria.'[1] But it remains somewhat obscure what the concept of ' equilibrium ' means, if applied outside the fields of physical magnitudes, and so conceptions of this and similar kinds have remained little more than loose, if ingenious, metaphors. Few attempts to state exact laws in non-physical fields have gained universal recognition ; they lack the consistency of the system of physics, and their methodological background remains obscure.

In consequence of the predominant development of the physical sciences, it was thought that, in order to state exact laws for any field, and to render it an exact science, it had to be reduced to physics and chemistry. This is, of course, the methodological principle of the so-called mechanistic view.

Quite apart from the question whether the mechanistic principle is justified in the last resort and for some remote future, it appears, however, that it does not in fact work in wide fields of science. For example, we can isolate processes occurring in the living organism and describe them in the terms and laws of physico-chemistry. This is done, with enormous success, in modern biophysics and biochemistry. But when it comes to the properly ' vital ' features, it is found that they are essentially problems of organisation, orderliness, and regulation, resulting from the interaction of an enormous number of highly complicated physico-chemical events. To grasp in detail the physico-chemical organisation of even the simplest cell is far beyond our capacity. So we come to the conclusion that it is not possible to state exact laws for the basic biological phenomena, such as self-regulation in metabolism, growth, morphogenesis, behaviour, etc., because they are much too complicated to allow a thorough understanding and an analysis of all the processes involved. This is, in fact, the common opinion in present biology. The same applies, of course, even more to sociological phenomena, because of their even higher complexity and the impossibility of resolving them into physico-chemical events.

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[1] H. Dotterweich, *Das biologische Gleichgewicht und seine Bedeutung für die Hauptprobleme der Biologie*, Jena, 1940

J. Dumontier, *Equilibre Physique, Equilibre Biologique, Equilibre Economique*, Paris, 1949.

Thus it seems necessary to expand our conceptual schemes if we wish to deal with these complex realms, and to make it possible for them to be included in the exact sciences; to establish systems of exact laws also in those fields where an application of the laws of physics or chemistry is not sufficient or even possible. Even physical concepts need to, and in fact do undergo expansion and far-reaching modifications when applied to new realms, as we shall see when considering the recent extension of kinetics and thermodynamics to open systems.

As opposed to the mechanistic conception, we are led to a different view. The task of science is to state laws for the different strata of reality. Even in physics, quantum statistics, molecular statistics, and macrophysical laws represent different strata. Similarly, we may apply statistical values and laws on any level, if this gives results consistent with experience and within a theoretical system. If you cannot run after each molecule and describe the state of a gas in a Laplacean formula, take, with Boltzmann, a statistical law describing the average result of the behaviour of a great many individual molecules. If you cannot follow the enormous number of processes in intermediary metabolism, use average values such as total metabolism quotients of anabolism and catabolism, representing the outcome of all these processes, and you may be able to state exact laws for phenomena such as metabolism, growth, and morphogenesis of the organism as a whole, without the hopeless undertaking to press all individual physico-chemical processes into a gigantic formula. You cannot resolve the individuals within a biocoenosis or a social unit into cells and finally into physico-chemical processes. Very well, take the individuals as units, and eventually you will get a system of laws which is not physics but is of the same form as exact physical science, that is a mathematical hypothetico-deductive system.

However, to apply the procedure consistently, it seems necessary to establish the principles which apply to those entities which are called 'systems,' and of which physical systems are only a subclass. Thus, we are led again to the conception of a General System Theory, as a doctrine which is generalised with respect to physics. 'Kinetics' and 'dynamics' have been, as yet, branches of physics concerned with entities such as molecules, energy, and the like. We ask for a generalised kinetics and dynamics, where the entities concerned can be interpreted as any entities that present themselves in different fields.

General System Theory is not a mere catalogue of well-known differential equations and their solutions. On the contrary, the general system conception raises new and well-defined problems which do not appear in physics, because they are not met with in its usual problems, but which are of basic importance in non-physical fields. Just because the phenomena concerned are not dealt with in ordinary physics, these problems have often appeared as metaphysical or vitalistic. It will be an important task to generalise physical principles such as those of minimum action, of Le Chatelier, or the conditions of the existence of stationary and periodic solutions and of steady states, etc., in such a way that they apply to systems in general. Problems and concepts such as progressive mechanisation, centralisation, individuality, leading part, competition, etc., are unfamiliar to the physicist, but they are basic in the biological and sociological realms, and require exact treatment.

Moreover, General System Theory should be an important regulative device in science. The existence of laws of similar structure in different fields enables the use of systems which are simpler or better known as models for more complicated and less manageable ones. Therefore General System Theory should be, methodologically, an important means of controlling and instigating the transfer of principles from one field to another, and it will no longer be necessary to duplicate or triplicate the discovery of the same principles in different fields isolated from each other. At the same time, by formulating exact criteria, General System Theory will guard against superficial analogies which are useless in science and harmful in their practical consequences.

The central position of the concept of wholeness in biology, psychology, sociology and other sciences is generally acknowledged. What is meant by this concept is indicated by expressions such as ' system,' '*gestalt*,' ' organism,' ' interaction,' ' the whole is more than the sum of its parts ' and the like. However, these concepts have often been misused, and they are of a vague and somewhat mystical character. The exact scientist therefore is inclined to look at these conceptions with justified mistrust. Thus it seems necessary to formulate these conceptions in an exact language. General System Theory is a new scientific doctrine of ' wholeness '—a notion which has been hitherto considered vague, muddled and metaphysical.

Considered from the viewpoint of philosophy, General System Theory is to replace that field which is known as ' theory of categories '[1] by an exact system of logico-mathematical laws. Those general notions, which as yet have been formulated only in common language, will acquire, by the General System Theory, that unambiguous and exact expression which is possible only in mathematical language.

4 *The System Concept*

In the following, we shall outline a few general system principles and characteristics in order to illustrate the programme indicated above.

A system can be defined as a complex of interacting elements $p_1, p_2 \ldots p_n$. Interaction means that the elements stand in a certain relation, R, so that their behaviour in R is different from their behaviour in another relation, R′. On the other hand, if the behaviour in R and R′ is not different, there is no interaction, and the elements behave independently with respect to the relations R and R′.

If we denote the measure of some quantitative aspect of the elements p by $Q_1, Q_2 \ldots Q_n$, its variation may be defined by a system of simultaneous differential equations which, for a finite number of elements and in the simplest case, will be of the form :

$$\left.\begin{aligned} \frac{dQ_1}{dt} &= f_1\,(Q_1, Q_2, \ldots Q_n) \\ \frac{dQ_2}{dt} &= f_2\,(Q_1, Q_2, \ldots Q_n) \\ \frac{dQ_n}{dt} &= f_n\,(Q_1, Q_2, \ldots Q_n) \end{aligned}\right\} \quad . \quad . \quad . \quad (1)$$

Equations (1) can be considered as expressing a general principle of kinetics. Systems of equations of this kind are found in many fields. In *Simultankinetik*, as developed by Skrabal,[2] it is the general expression of the law of mass action. The same system has been used by Lotka [3] in a rather broad sense, and especially with respect to demographic problems. The equations for biocoenotic systems, as given by Volterra, Lotka, D'Ancona, Gause and others, are special cases of the

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[1] N. Hartmann, 'Neue Wege der Ontologie,' in *Systematische Philosophie*, ed. N. Hartmann, Stuttgart and Berlin, 1942.

[2] A. Skrabal, 'Von den Simultanreaktionen,' *Ber. dtsch. chem. Ges.* (A), 1944, **77**, 1-12 ; 'Die Kettenreaktionen anders gesehen,' *Mh. Chemie*, 1949, **80**, 21-57

[3] A. J. Lotka, *Elements of Physical Biology*, Baltimore, 1925

general system of equations (1). So are the equations used by Spiegelman[1] for kinetics of cellular processes and the theory of competition within an organism. Werner[2] has stated a similar though somewhat more general system (considering the system as continuous, and using therefore partial differential equations with respect to x, y, z, and t) as the basic law of pharmacodynamic action from which the various laws of drug action can be derived by introducing the corresponding special conditions.

Although nothing has been said about the nature of the elements or about the functions $f_1, f_2 \ldots f_n$, i.e. about the relations or interactions within the system, certain general principles can be deduced. We may use our equations (1) in order to show the structural isomorphism in different fields and levels of reality; or, in other words, in order to demonstrate the possibility of a General System Theory whose fields of application are to be found in various sciences. The parameters and variables will have, of course, a different meaning in each case of application.

We may first consider the simplest case, viz, that the system consists of elements of only one kind. In this case our system of equations is reduced to a single equation:

$$\frac{dQ}{dt} = f(Q), \quad . \quad . \quad . \quad . \quad (2)$$

which may be developed into a Taylor series:

$$\frac{dQ}{dt} = a_1Q + a_{11}Q^2 + \ldots \quad . \quad . \quad . \quad (3)$$

This series does not contain an absolute term in the case in which there is no 'spontaneous generation' of elements. Then dQ/dt must disappear, for $Q = 0$, which is possible only if the absolute term is equal to zero.

The simplest possibility is realised when we retain only the first term of the series:

$$\frac{dQ}{dt} = a_1Q, \quad . \quad . \quad . \quad . \quad (4)$$

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[1] S. Spiegelman, 'Physiological Competition as a Regulatory Mechanism in Morphogenesis,' *Quart. Rev. Biol.*, 1945, **20**, 121

[2] G. Werner, 'Beitrag zur mathematischen Behandlung pharmakologischer Fragen.' *Sitz. Akad. Wiss. Wien, Math.-naturw. Kl.*, 1947, Abt. IIa, **156**, 457–467

This signifies that the growth of the system is directly proportional to the number of elements present. Depending on whether the constant a_1 is positive or negative, the growth of the system is positive or negative, and the system increases or decreases. The solution is :

$$Q = Q_0 e^{a_1 t}, \quad . \quad . \quad . \quad . \quad (5)$$

Q_0 signifying the number of elements at $t = 0$. This is the *exponential law* which, as already said (p. 136), is found in many fields.

Going back to equation (3) and retaining two terms, we have :

$$\frac{dQ}{dt} = a_1 Q + a_{11} Q^2. \quad . \quad . \quad . \quad . \quad (6)$$

A solution of this equation is :

$$Q = \frac{a_1 C e^{a_1 t}}{1 - a_{11} C e^{a_1 t}} \quad . \quad . \quad . \quad . \quad (7)$$

Keeping the second term has an important consequence. The simple exponential (5) shows an infinite increase ; taking into account, however, the second term, we obtain, according to (7), a curve which is sigmoid and attains a limiting value. This curve is the so-called *logistic* curve, and is also of wide application (p. 136).

If the system consists of elements of two or more different varieties, its evolution can follow different lines. This may be illustrated by the simplest case, i.e. a system consisting of two kinds of elements, Q_1 and Q_2 :

$$\left.\begin{aligned} \frac{dQ_1}{dt} &= f_1(Q_1, Q_2) \\ \frac{dQ_2}{dt} &= f_2(Q_1, Q_2) \end{aligned}\right\} \quad . \quad . \quad . \quad (8)$$

Provided that the functions can be developed into Taylor series, the solution is of the form :

$$\left.\begin{aligned} Q_1 &= Q_1{}^* - G_{11}e^{\lambda_1 t} - G_{12}e^{\lambda_2 t} - G_{111}e^{2\lambda_1 t} - \ldots \\ Q_2 &= Q_2{}^* - G_{21}e^{\lambda_1 t} - G_{22}e^{\lambda_2 t} - G_{211}e^{2\lambda_1 t} - \ldots \end{aligned}\right\} \quad . \quad (9)$$

where $Q_1{}^*$, $Q_2{}^*$ are the stationary values of Q_1, Q_2, obtained by setting $f_1 = f_2 = 0$; the G's are integration constants ; and the λ's are roots of the characteristic equation :

$$\begin{vmatrix} a_{11} - \lambda & a_{12} \\ a_{21} & a_{22} - \lambda \end{vmatrix} = 0,$$

or developed :

$$(a_{11} - \lambda)\ (a_{22} - \lambda) - a_{12}a_{21} = 0,$$

$$\lambda^2 - \lambda C + D = 0,$$

$$\lambda = \frac{C}{2} \pm \sqrt{-D + \left(\frac{C}{2}\right)^2},$$

with

$$C = a_{11} + a_{22}\ ;\ D = a_{11}a_{22} - a_{12}a_{21}.$$

In the case :

$$C < 0, D > 0, E = C^2 - 4D > 0,$$

both solutions of the characteristic equation are negative. Therefore the system will approach a stable stationary state where $Q_1 = Q_1^*$, $Q_2 = Q_2^*$, since $e^{-\infty} = 0$, and therefore the second and following terms continually decrease.

In the case :

$$C = 0, D > 0, E < 0,$$

both solutions are imaginary. Therefore the system contains periodic terms, and there will be oscillations or cycles around the stationary values.

Finally in the case :

$$C > 0, D < O, E > 0,$$

both solutions are positive, and there is no stationary state.

Similar considerations apply to systems with n components.

5 *Wholeness, Sum, Mechanisation, Centralisation*

The concepts just indicated have often been considered to describe characteristics only of living beings, or even to be a proof of vitalism. In actual fact they are formal properties of systems.

I Let us assume again that the equations (1) can be developed into Taylor series :

$$\frac{dQ_i}{dt} = a_{i1}Q_1 + a_{i2}Q_2 + \ldots a_{in}Q_n + a_{i11}Q^2 + \ldots. \quad (10)$$

We see that any change in some quantity, Q_1, is a function of the quantities of all elements, Q_1 to Q_n. On the other hand, a change in a certain Q_i causes a change in all other elements and in the total system. The system therefore behaves as a *whole*, the changes in every element depending on all the others.

II Let the coefficients of the variables Q_j $(j \neq i)$ now become zero. The system of equations degenerates into :

$$\frac{dQ_i}{dt} = a_{i1}Q_i + a_{i11}Q_i^2 + \dots \qquad (11)$$

This means that a change in each element depends only on that element itself. Each element can therefore be considered independent of the others. The variation of the total complex is the (physical) sum of the variations of its elements. We may call such behaviour *physical summativity* or *independence.*

We may define summativity by saying that a complex can be built up, step by step, by putting together the first separate elements ; conversely, the characteristics of the complex can be analysed completely into those of the separate elements. This is true for those complexes which we may call ' heaps,' such as a heap of bricks or odds and ends, or for mechanical forces, acting according to the parallelogram of forces. It does not apply to those systems which were called *Gestalten* in German. Take the most simple example ; three electrical conductors have a certain charge which can be measured in each conductor separately. But if they are connected by wires, the charge in each conductor depends on the total constellation, and is different from its charge when insulated.

Though this is trivial from the viewpoint of physics, it is still necessary to emphasise the non-summative character of physical and biological systems because the methodological attidude has been, and is yet to a large extent, determined by the mechanistic programme.[1] In Lord Russell's latest book [2], we find a rather astonishing rejection of the ' concept of organism.' This concept states, according to Russell, that the laws governing the behaviour of the parts can be stated only by considering the place of the parts in the whole. Russell rejects this view. He uses the example of an eye, the function of which as a light receptor can be understood perfectly well if the eye is isolated and if only the internal physico-chemical reactions, and the incoming stimuli and outgoing nerve impulses, are taken into account. ' Scientific progress has been made by analysis and artificial isolation. . . . It is therefore in any case prudent to adopt the mechanistic view as a working hypothesis, to be abandoned only where there is clear evidence against it. As regards biological phenomena, such evidence, so far,

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[1] L. von Bertalanffy, *Das biologische Wellbied*, I

[2] B. Russell, *Human Knowledge, Its Scope and Limits*, London, 1948

is entirely absent.' It is true that the principles of summativity are applicable to the living organism to a certain extent. The beat of a heart, the twitch of a nerve-muscle preparation, the action potentials in a nerve are much the same if studied in isolation or within the organism as a whole. This applies to those phenomena we shall define later as occurring in highly 'mechanised' partial systems. But Russell's statement is profoundly untrue with respect exactly to the basic and primary biological phenomena. If you take any realm of biological phenomena, whether embryonic development, metabolism, growth, activity of the nervous system, biocoenoses, etc., you will always find that the behaviour of an element is different within the system from what it is in isolation. You cannot sum up the behaviour of the whole from the isolated parts, and you have to take into account the relations between the various subordinated systems and the systems which are super-ordinated to them in order to understand the behaviour of the parts. Analysis and artificial isolation are useful, but in no way sufficient, methods of biological experimentation and theory.

III There is a further case which appears to be unusual in physical systems but is very common and basic in biological, psychological and sociological systems. This case is that in which the interactions between the elements decrease with time. In terms of our basic model equation (1), this means that the coefficients of the Q_i are not constant, but decrease with time. The simplest case will be :

$$\lim_{t \to \infty} a_{ij} = 0 \qquad . \quad . \quad . \quad . \quad . \quad (12)$$

In this case the system passes from a state of wholeness to a state of independence of the elements. The primary state is that of a unitary system which splits up gradually into independent causal chains. We may call this *progressive segregation.*

As a rule, the organisation of physical wholes, such as atoms, molecules, or crystals, results from the union of pre-existing elements. In contrast, the organisation of biological wholes is built up by the differentiation of an original whole which segregates into parts. An example is determination in embryonic development, when the germ passes from a state of equipotentiality to a state where it behaves like a mosaic or sum of regions which develop independently into definite organs. The same is true in the development and evolution of the nervous system and of behaviour starting with actions of the whole body or of large regions and passing to the establishment of definite centres and localised reflex arcs, and for many other biological phenomena.

The reason for the predominance of segregation in living nature seems to be that segregation into subordinate partial systems implies an increase of complexity in the system. Such transition towards higher order presupposes a supply of energy, and energy is delivered continuously into the system only if the latter is an open system, taking energy from its environment. We shall come back to this question later on (p. 158).

The principle of progressive segregation has peculiar implications. Progress is possible in any biological, psychological, or sociological organisation, only by passing from a state of undifferentiated wholeness to differentiation of the parts. This implies, however, that the parts become fixed with respect to a certain action. Therefore progressive segregation also means progressive mechanisation.

Progressive mechanisation, however, implies loss of ability to be regulated. As long as a system is a unitary whole, a disturbance will be followed by the attainment of a new stationary state, due to the interactions within the system. The system will 'regulate' itself. If, however, the system is split up into independent causal chains, regulability disappears. The partial processes will go on irrespective of each other. This is the behaviour we find, for example, in embryonic development, determination going hand in hand with decrease of regulability.

In this duality of segregation, implying progressive differentiation and mechanisation, lies the tragic character of every evolution. Progress is possible only by subdivision of an initially unitary action into actions of specialised parts. This, however, means at the same time loss in other respects. The more parts are specialised in a certain direction, the more they are irreplaceable, and loss of parts leads to the breakdown of the whole system. To speak in Aristotelian language, every evolution, by unfolding some potentiality, nips in the bud many other possibilities. We may find this in embryonic development as well as in phylogenetic specialisation, or in specialisation in science or daily life[1].

Behaviour as a whole and summative behaviour, unitary and elementalistic conceptions, are usually regarded as being antitheses. But it is frequently found that there is no opposition between them, but a gradual transition from behaviour as a whole to summative

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[1] L. von Bertalanffy, *Das biologische Weltbild*, I, pp. 50 ff.

behaviour. This insight is important for the clarification of many biological concepts. As can easily be shown many controversies about concepts like those of the gene or the nerve centre have arisen because only the limiting cases, namely, complete interaction or independence of causal trains, have been taken into account, and not the intermediates which have a wide application.[1]

IV Connected with this is yet another principle. Suppose that the coefficients of one element, p_s, are large in all equations while the coefficients of the other elements are considerably smaller or even equal to zero. In this case the system may look like this :

$$\left.\begin{aligned} \frac{dQ_1}{dt} &= a_{11}Q_1 + \;.\;.\;.\; a_{1s}Q_s + \;.\;.\;. \\ \frac{dQ_s}{dt} &= a_{s1}Q_s + \;.\;.\;. \\ \frac{dQ_n}{dt} &= a_{ns}Q_s + \;.\;.\;.\; a_{n1}Q_n + \;.\;.\;. \end{aligned}\right\} \quad . \qquad . \quad (13)$$

if we write the linear members only, for simplicity.

We may call the element p_s a *leading part*, or say that the system is *centred* around p_s. If the coefficients a_{is} of p_s in some or all equations are large while the coefficients in the equation of p_s itself are small, a small change in p_s will cause a considerable change in the total system. p_s may be then called a *trigger*. A small change in p_s will be ' amplified ' in the total system. From the energetic viewpoint, in this case we do not find ' conservation causality ' (*Erhaltungskausalität*) where the principle ' *causa aequat effectum* ' holds, but ' instigation causality ' (*Anstosskausalität*),[2] an energetically insignificant change in p_s causing a considerable change in the total system.

The principle of centralisation is especially important in the biological realm. Progressive segregation is often connected with progressive centralisation, the expression of which is the time-dependent evolution of a leading part, i.e. a combination of the schemes (12) and (13). At the same time, the principle of progressive centralisation is that of progressive individualisation. An ' individual ' can be defined as a centralised system. Strictly speaking this is, in the biological realm, a limiting case, only approached ontogenetically

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[1] L. von Bertalanffy, *Das biologische Weltbild*, I, pp. 73 ff., 111 ff.

[2] A. Mittasch, *Von der Chemie zur Philosophie.* Ausgewählte Schriften und Vorträge, Ulm, 1948

and phylogenetically, the organism growing through progressive centralisation more and more unified and ' more indivisible.'[1]

V In many systems the components are themselves systems of a next lower order. This means that any Q_i is itself a system of elements, R_i, where R_i may be defined by a system of equations like (1). This is called *hierarchical order.*

6 *Competition*

Our system of equations also indicates the competition between the parts.

The simplest possible form is, again, that all coefficients $(a_{j \neq i}) = 0$ i.e. that the increase in each element depends only on this element itself. Then we have, for two elements :

$$\left.\begin{aligned} \frac{dQ_1}{dt} &= a_1 Q_1 \\ \frac{dQ_2}{dt} &= a_2 Q_2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (14)$$

or

$$\left.\begin{aligned} Q_1 &= c_1 e^{a_1 t} \\ Q_2 &= c_2 e^{a_2 t} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (15)$$

Eliminating time, we obtain :

$$t = \frac{\ln Q_1 - \ln c_1}{a_1} = \frac{\ln Q_2 - \ln c_2}{a_2}, \quad . \quad . \quad (16)$$

and

$$Q_1 = BQ_2{}^A, \quad . \quad . \quad . \quad . \quad (17)$$

with $A = \frac{a_1}{b_1}$, $B = \frac{c_1}{c_2{}^A}$.

This is the equation known in biology as the *allometric equation.* In this discussion, the simplest form of growth of the parts, viz, the exponential, has been assumed (14 and 15). The allometric relation holds, however, also for somewhat more complicated cases, such as growth according to the parabola, the logistic, the Gompertz function, either strictly or as an approximation.[2]

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[1] L. von Bertalanffy, *Das biologische Weltbild,* I, pp. 55 ff.

[2] H. Lumer, 'The Consequences of Sigmoid Growth Curves for Relative Growth Functions,' *Growth,* 1937, I

The allometric equation applies to a wide range of morphological, biochemical, physiological and phylogenetic data. It means that a certain characteristic, Q_1, can be expressed as a power function of another characteristic, Q_2. Take, for instance, morphogenesis. Then the length or weight of a certain organ, Q_1, is, in general, an allometric function of the size of another organ, or of the total length or weight of the organism in question, Q_2. The meaning of this becomes clear if we write equations (14) in a slightly different form :

$$\frac{dQ_1}{dt} \cdot \frac{1}{Q_1} : \frac{dQ_2}{dt} \cdot \frac{1}{Q_2} = A, \quad . \quad . \quad . \quad (18)$$

or

$$\frac{dQ_1}{dt} = A \cdot \frac{Q_1}{Q_2} \cdot \frac{dQ_2}{dt} \quad . \quad . \quad . \quad (19)$$

Equation (18) states that the relative growth rates (i.e. increase calculated as a percentage of the actual size) of the parts under consideration, Q_1 and Q_2, stand in a constant proportion throughout the life, or during a life cycle for which the allometric equation holds. This rather astonishing relation (because of the immense complexity of growth processes it would seem, at first, unlikely that the growth of parts is governed by an algebraic equation of such simplicity) is explained by equation (19). According to this equation, it can be interpreted as a result of a process of distribution. Take Q_2 for the whole organism ; then equation (19) states that the organ Q_1 takes, from the increase resulting from the metabolism of the total organism $\left(\frac{dQ_2}{dt}\right)$, a share which is proportional to its actual proportion to the latter $\left(\frac{Q_1}{Q_2}\right)$. A is a partition coefficient indicating the capacity to seize its share of the organ. If $a_1 > a_2$, i.e. if the growth intensity of Q_1 is greater than that of Q_2, then $A = \frac{a_1}{a_2} > 1$; the organ captures more than other parts ; it grows therefore more rapidly than these or with positive allometry. Conversely, if $a_1 < a_2$, it is $A > 1$, the organ grows more slowly, or shows negative allometry. Similarly, the allometric equation applies to biochemical changes in the organism, and to physiological functions. For instance, basal metabolism increases, in wide groups of animals, with $A = \frac{2}{3}$ with respect to body weight if growing animals of the same species, or animals of related species, are compared; this means that basal metabolism is, in general, a surface function of body weight. In certain cases, such as insect larvae and snails, $A = 1$, i.e. basal metabolism is proportional to weight itself.

In sociology, the expression in question is *Pareto's law*, [1] which we have already mentioned (p. 137). Pareto's law (1897) is $Q_1 = BQ_2^A$, with Q_1 = number of individuals gaining a certain income, Q_2 = amount of the income, and B and A constants. The explanation is similar to that given above, substituting for 'increase of the total organism' the national income, and for 'distribution constant' the economic abilities of the individuals concerned.

The situation becomes more complex if interactions between the parts of the system are assumed, i.e. if $a_{j \neq i} \neq 0$. Then we come to those systems of equations which have been stated by Volterra [2] for competition among species, and, correspondingly, by Spiegelman [3] for competition within an organism. Since these cases are fully discussed in the literature,[4] we shall not enter into a detailed discussion. Only one or two points of general interest may be mentioned.

Thus, it is an interesting consequence that, in Volterra's equations, competition of two species for the same resources is, in some way, more fatal than a predator-prey relation, i.e. partial annihilation of one species by the other. For competition eventually leads to the extermination of the species with the smaller growth capacity; a predator-prey relation only leads to periodic oscillation of the numbers of the species concerned around a mean value. These relations have been stated for biocoenotic systems, but it may well be that they have also sociological implications.

Another point of philosophical interest should be mentioned. If we are speaking of 'systems,' we mean 'wholes' or 'unities.' Then it seems paradoxical at first that, with respect to a whole, the concept of competition between its parts is introduced. In fact, however,

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[1] W. Pareto, *Cours de l'Économic Politique*

[2] V. Volterra, *Leçons sur la Théorie Mathématique de la Lutte pour la Vie*

[3] S. Spiegelman, 'Physiological Competitions as a Regulatory Mechanism in Morphogenesis'

[4] L. von Bertalanffy, *Theoretische Biologie*, Band II, Stoffwechsel, Wachstum, Berlin, 1942; 2nd edition, Bern (in press)

U. D'Ancona, *La Lotta per l'Esistenza*, Torino, 1942; German Translation, *Der Kampf ums Dasein*, Abh. z. exakten Biologie, ed. by L. von Bertalanffy, Heft 1, Berlin, 1939 these apparently contradictory statements both belong to the essentials of systems. Every whole is based upon the competition of its elements, and presupposes the 'struggle between parts' (Roux). The latter is a general principle of organisation in simple physico-chemical systems as well as in organisms and social units, and it is, in the last resort, an expression of the *coincidentia oppositorum* that reality presents.[1]

7 *Finality*

As we have seen, systems of equations of the type considered may have three different kinds of solution. The system in question may asymptotically attain a stable stationary state with increasing time; or it may never attain a stable stationary state; or there may be periodic oscillations. In the case in which the system approaches a stationary state, its variation can be expressed not only in terms of the actual conditions but also in terms of the distance from the stationary state. If Q_i^* are the solutions for the stationary state, new variables:

$$Q_i = Q_i^* - Q_i'$$

can be introduced so that

$$\frac{dQ_i}{dt} = f\,(Q_1^* - Q_1')\,(Q_2^* - Q_2')\,\ldots\,(Q_n^* - Q_n') \qquad (20)$$

Thus it seems as if the system would 'aim toward' an equilibrium to be reached only in the future. This is especially obvious when we consider the integral of such equations: it may always be written in a form containing the final values. It looks therefore as if the actual process were determined by final values to be reached in infinite time only. But this final value is, of course, simply a limit which we obtain by equating the derivatives to zero so that it drops out. The 'teleological' final value formula is only a transformation of the differential equation indicating the actual conditions; the 'directiveness' of the process toward a final state is not different from causality, but another expression of it.

Although this consideration is obvious from the mathematical and physical standpoints, the point in question has been often misunderstood. Philosophers have asked how it is possible that a state A depends upon a state B which does not yet exist. Similarly,

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[1] L. von Bertalanffy, *Das biologische Weltbild*, I, pp. 60 ff.

biologists, under the influence of the tendency to make analogies between finalistic events and human actions which are determined by the foresight of a goal, have rejected expressions containing final values or, conversely, have seen in this finality a proof of vitalism.

Thus a number of concepts follow from the definition of systems which, like non-summativity, wholeness, centralisation, individuality, finality, have often been considered as anthropomorphic, vitalistic or metaphysical, but which are, in fact, consequences of the formal characters and certain conditions of systems.

8 *Closed and Open Systems*

We now come to a consideration which leads to important problems and discoveries in physics, biology and other fields.

It is the basic characteristic of every organic system that it maintains itself in a state of perpetual change of its components. This we find at all levels of biological organisation. In the cell there is a perpetual destruction of its building materials through which it endures as a whole. Recent research, the investigations with isotope-tracers, have shown that this exchange of building materials goes on at a rate much higher than was formerly supposed. In the multicellular organism, cells are dying and are replaced by new ones, but it maintains itself as a whole. In the biocoenosis and the species, individuals die and others are born. Thus every organic system appears stationary if considered from a certain point of view. But what seems to be a persistent entity on a certain level, is maintained, in fact, by a perpetual change, building up and breaking down of systems of the next lower order : of chemical compounds in the cell, of cells in the multicellular organism, of individuals in ecological systems.

The characteristic state of the living organism is that of an open system. We call a system closed if no materials enter or leave it. It is open if there is inflow and outflow, and therefore change of the component materials.

So far, physics and physical chemistry have been almost exclusively concerned with closed systems. However, the consideration of organisms and other living systems makes necessary an extension and generalisation of theory. The kinetics and thermodynamics of open systems have been developed in recent years. The present writer has advanced since 1932 the conception of the organism as an open system and has stated general kinetic principles and their biological implications.[1, 2] Similar investigations have been made by Burton,[3] Dehlinger and Wertz,[4] Skrabal,[5] Reiner and Spiegelman,[6] Denbigh,[7] and others. The thermodynamic of open systems has been developed by Prigogine,[8] and Prigogine and Wiame.[9] Since a survey of the theory of open systems has been given recently[10] we mention here only a few points of general and philosophical significance.

The consideration of open systems is more general in comparison with that of closed systems ; for it is always possible to come from open to closed systems by equating the transport terms to zero, but not *vice versa*. In physics, the theory of open systems leads to basically new, and partly revolutionary, consequences and principles. In biology it accounts, first, for many characteristics of living systems which have appeared to be in contradiction with the laws of physics, and have been considered hitherto as vitalistic features. Secondly, the consideration of organisms as open systems yields quantitative laws of basic biological phenomena, such as metabolism and growth, form development, excitation, etc.

In the case in which the variations in time disappear, systems become stationary. Closed systems thus attain a time-independent state of equilibrium where the composition remains constant. In fact, closed systems *must* eventually reach a state of equilibrium, according to the second law of thermodynamics. Open systems *may*, provided certain conditions are given, attain a stationary state. Then

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[1] L. von Bertalanffy, *Theoretische Biologie*, Band II

[2] L. von Bertalanffy, 'Der Organismus als physikalisches System betrachtet,' *Naturwissenschaften*, 1940, **28**, 521-531

[3] A. C. Burton. 'The Properties of the Steady State as Compared to those of Equilibrium as Shown in Characteristic Biological Behavior,' *J. cell. comp. Physiol.*, 1939, **14**, 327

[4] U. Dehlinger and E. Wertz, 'Biologische Grundfragen in physikalischer Betrachtung,' *Naturwissenschaften*, 1942, **30**, 250

[5] A. Skrabal, 'Das Reaktionsschema der Waldenschen Umkehrung. III,' *Oesterr. Chemiker Ztg.*, 1947, **48**, 158-163

[6] J. M. Reiner and S. Spiegelman, 'The Energetics of Transient and Steady States,' *J. phys. Chem.*, 1945, **49**, 81

[7] K. G. Denbigh, *et al.* 'The Kinetics of Open Reaction Systems,' *Trans. Faraday Soc.*, 1948, **44**, 479-494

[8] I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*, Paris, 1947

[9] I. Prigogine and J. M. Wiame, 'Biologie et Thermodynamique des phénomènes irréversibles,' *Experientia* (Basel), 1946, **2**, 450-451

[10] L. von Bertalanffy, 'The Theory of Open Systems in Physics and Biology,' *Science*, 1950, **3**, 23-29

the system appears also to be constant, though this constancy is maintained in a continuous change, inflow and outflow of materials. This is called a *steady* state. Since there is no equivalent for this expression in German, the term *Fliessgleichgewicht* was introduced by the author. Steady states can be realised in certain physico-chemical arrangements and are, in fact, widely used in technological chemistry. Living systems are the most important examples of open systems and steady states.

9 *Equifinality*

A profound difference between most inanimate and living systems can be expressed by the concept of *equifinality*. In most physical systems the final state is determined by the initial conditions. Take, for instance, the motion in a planetary system where the positions at a time t are determined by those of a time t_0, or a chemical equilibrium where the final concentrations depend on the initial ones. If either the initial conditions or the process is modified, the final state is changed.

Vital phenomena show a different behaviour. Here, to a wide extent, the final state may be reached from different initial conditions and in different ways. Such behaviour we call equifinal. Thus, for instance, the same final result, namely a typical larva, is achieved by a complete normal germ of the sea urchin, by a half germ after experimental separation of the cells, by two germs after fusion, or after translocations of the cells. It is well-known that it was just this experiment which was considered, by Driesch, the main proof of vitalism. According to Driesch, such behaviour is inexplicable in physico-chemical terms. For a physico-chemical system cannot achieve the same performance, in this case the production of a whole organism, if divided or injured. This extraordinary performance can be accomplished only by the action of a vitalistic factor, entelechy, essentially different from physico-chemical forces and governing the processes in foresight of the goal to be reached. It is therefore a question of basic importance whether equifinality is a proof of vitalism. The answer is that it is not.

Analysis shows that closed systems cannot behave equifinally. This is the reason why equifinality is found in inanimate nature only in exceptional cases. However, in open systems, which are exchanging materials with the environment, in so far as they attain a steady state, the latter is independent of the initial conditions, or is equifinal. Thus, in an open kinetic system, irrespective of the content in the beginning or any other time, the steady state values will always be the same because they are determined only by the constants of reaction and of inflow and outflow. Steady state systems show equifinality, in sharp contrast to closed systems in equilibrium where the final state depends on the components given at the beginning of the process.

Equifinality can be formulated quantitatively in certain biological cases. Thus growth is equifinal : the same final size which is characteristic for the species can be reached from different initial sizes (e.g. in litters of different numbers of individuals) or after a temporary suppression of growth (e.g. by a diet insufficient in quantity or in vitamins). According to the quantitative theory advanced by the author[1] growth can be considered the result of a counteraction of the anabolism and catabolism of building materials. Since in the most common type of growth, anabolism is a function of surface, catabolism of body mass, the surface-volume ratio is shifted in disfavour of surface with increasing size. Therefore a balance between anabolism and catabolism will eventually be reached which is independent of the initial size and depends only on the species-specific ratio of the metabolic constants. It is therefore equifinal.

Equifinality is at the basis of organic regulations. We find it everywhere where biological events are determined by the dynamic interactions of parts ; it becomes progressively restricted and finally impossible when the originally unitary system segregates into separate causal chains determined by fixed structures, that is to say, with progressive segregation. There are two general restrictions of regulation. The first is the incompleteness of the open-system-character of the organism. For instance, the growth regulations mentioned will not be possible if insufficient diet has caused lasting irreversible disturbances, for example, in the ossification of bones. The second limitation of regulation lies in the hierarchical order, namely, in the progressive segregation of the organism into subordinate systems which gain a certain independence of each other. The extreme case is a tumour which behaves as if it were an independent organism, and thus destroys the whole of which it is a part.

Thus the investigation of open systems leads to a conclusion which is very remarkable for the philosophy of science. The equifinal form

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[1] L. von Bertalanffy, ' Das organische Wachstum und seine Gesetzmässigkeiten,' *Experientia* (Basel), 1948, **4**, 255-269

L. von Bertalanffy, ' Problems of Organic Growth,' *Nature*, London, 1949, **163**, 156-158 of directiveness which is so characteristic for biological phenomena that it has been considered the vitalistic essence of life is, in fact, a necessary consequence of the steady state in organisms.

10 *Types of Finality*

Since it is not possible to enter here into a detailed discussion of the problem of finality, we are merely enumerating the different types found in experience. Thus we can distinguish :

I. Static teleology or fitness, meaning that an arrangement seems to be useful for a certain ' purpose.' Thus a fur coat is fit to keep the body warm, and so are hairs, feathers, or layers of fat in animals. Thorns may protect plants against grazing cattle, or imitative colourations and mimicries may be advantageous to protect animals against enemies.

II. Dynamic teleology, meaning a directiveness of processes. Here different phenomena can be distinguished which are often confused :

(i) Direction of events towards a final state which can be expressed as if the present behaviour were dependent on that final state. Every system which attains a time-independent condition behaves in this way.

(ii) Directiveness based upon structure, meaning that an arrangement of structures leads the process in such a way that a certain result is achieved. This is true, of course, of the function of man-made machines yielding products or performances as desired. In living nature we find a structural order of processes that in its complication widely surpasses all man-made machines. Such order is found from the function of macroscopic organs, such as the eye as a sort of camera, or the heart as a pump, to the microscopic cell structures responsible for metabolism, secretion, excitability, heredity and so forth. Whilst man-made machines work in such a way as to yield certain products and performances, for example, fabrication of airplanes or moving a railway train, the order of process in living systems is such as to maintain the system itself. An important part of these processes is represented by homeostasis (Canon), i.e. those processes through which the material and energetical situation of the organism is maintained constant. Examples are the mechanisms of thermoregulation, of maintenance of osmotic pressure, of pH, of salt concentration, the regulation of posture and so forth. These regulations are governed, in a wide extent, by feed-back mechanisms. Feed-back means that from the output of a machine a certain amount is monitored back, as 'information,' to the input so as to regulate the latter and thus to stabilise or direct the action of the machine. Mechanisms of this kind are well known in technology, as, for instance, the governor of the steam-engine, self-steering missiles and other 'servomechanisms.' Feed-back mechanisms appear to be responsible for a large part of the organic regulations and phenomena of homeostasis, as recently emphasised by Cybernetics.[1]

(iii) There is, however, yet another basis for organic regulations. This is equifinality, i.e. the fact that the same final state can be reached from different initial conditions and in different ways. This is found to be the case in open systems, in so far as they attain a steady state. It appears that equifinality is responsible for the primary regulability of organic systems, i.e. for all those regulations which cannot be based upon predetermined structures or mechanisms but, on the contrary, exclude such mechanisms and were regarded therefore as arguments for vitalism.

(iv) Finally, there is true finality or purposiveness, meaning that the actual behaviour is determined by the foresight of the goal. This is the original Aristotelian concept. It presupposes that the future goal is already present in thought, and directs the present action. True purposiveness is characteristic of human behaviour, and it is connected with the evolution of the symbolism of language and concepts.[2]

The confusion of these different types of finality is one of the factors responsible for the confusion occurring in epistemology and theoretical biology. In the field of man-made things, fitness (I) and teleological working of machines (II, ii) are, of course, due to a planning intelligence (II, iv). Fitness in organic structures (I) can probably be explained by the causal play of random mutations and natural selection. This explanation is, however, much less plausible for the origin of the very complicated organic mechanisms and feed-back systems (II, ii). Vitalism is essentially the attempt to explain organic directiveness (II, ii and iii) by means of intelligence in foresight of the goal (II, iv). This leads, methodologically, beyond the limits of natural science, and is empirically unjustified, since we have, even

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[1] L. K. Frank, *et al.* 'Teleological Mechanisms,' *Ann. N.Y. Acad. Sci.*, 1948, **50**
N. Wiener, *Cybernetics*, New York and Paris, 1948

[2] L. von Bertalanffy, 'Das Weltbild der Biologie,' in *Weltbild und Menschenbild*, III. Internat. Hochschulwochen. des Oesterr. College, Salzburg, 1948, pp. 251-274

in the most astonishing phenomena of regulation or instinct, no justification for, but most definite reasons against, the assumption that, for example, an embryo or an insect is endowed with superhuman intelligence. A most important part of those phenomena which have been advanced as ' proofs of vitalism,' such as equifinality and anamorphosis (see below), are consequences of the characteristic state of the organism as an open system, and thus accessible to scientific interpretation and theory.

11 *Catamorphosis and Anamorphosis*

' According to definition, the second law of thermodynamics applies only to closed systems, it does not define the steady state.'[1] The expansion of thermodynamics to include open systems was elaborated by Prigogine[2] and has led to most important results of which we shall discuss only a few of far-reaching significance.

The direction of happenings in closed systems is towards states of maximum entropy since, according to the second law, entropy must increase in all irreversible processes. But this is not true in open systems. In an open system, and especially in a living organism, there is not only a production of entropy due to irreversible processes, but the organism ' feeds,' to use an expression of Schrödinger's, ' from negative entropy.' It imports complex organic molecules, uses their energy, and renders back the simpler end-products to the environment. Therefore the total change of entropy can be negative as well as positive. Though the second law is not violated, more strictly speaking, though it holds for the system plus its environment, it does not hold for the open system itself. Entropy may decrease in such systems, and their steady states are not defined by maximum entropy but, as demonstrated by Prigogine, by minimum entropy production.

As is well known, the significance of the second law can be expressed also in another way. It states that the general tendency of events is towards a state of maximum disorder. According to the second law, higher forms of energy such as mechanical energy, light, electricity and so forth, are continually and irreversibly degraded to undirected heat movement. Heat gradients, in turn, are gradually levelled down, and so the Universe approaches entropy death as its irrevocable fate when all energy is converted into heat of low

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[1] L. von Bertalanffy, *Theoretische Biologie*, Band II

[2] I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*

temperature, and the world process comes to a stop. There may be exceptions to the second law in microphysical dimensions since in the interior of stars, under very high temperatures, higher atoms are built up from simpler ones, especially helium from hydrogen. These processes are the source of sun radiation and are the basis of the hydrogen bomb. But on the macrophysical level, the second law seems essentially to command a transition toward maximum disorder and degradation.

But here a striking contrast between inanimate and animate nature seems to exist. According to the second law, physical events are directed towards a levelling down of differences and states of maximum disorder. In organic development and evolution, a transition towards states of higher order and differentiation seems to occur. It has often been assumed therefore that a tendency toward increasing complication is a primary characteristic of the living, in contrast to inanimate nature. This was called anamorphosis by Woltereck.[1]

These problems gain new aspects if we pass from closed systems, which alone are taken into account by classical thermodynamics, to open systems. Entropy may decrease in the evolution of such systems; in other words, such systems may spontaneously develop towards greater heterogeneity and complexity. Probably it is just this thermodynamical characteristic of organisms as open systems which is at the basis of the apparent contrast of catamorphosis in inorganic, and anamorphosis in living nature. This is obviously so in the transition towards higher complexity in organic development which is possible only at the expense of energies yielded by oxidation and other energy-yielding processes. The transition toward higher complexity is connected with the splitting up of a primary unitary system into partial systems. This seems to be the reason why we find what we have called progressive segregation only in the organic realm. With respect to evolution, these considerations show that the supposed violation of physical laws does not exist, or more strictly speaking, that it disappears by the extension of physical theory.

It is outside our present task to discuss the application of the theory of open systems to special problems in physics and biology.[2, 3] But it may be emphasised that just the peculiar and supposedly vitalistic

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[1] R. Woltereck, *Ontologie des Lebendigen*, Stuttgart, 1939

[2] L. von Bertalanffy, 'The Theory of Open Systems in Physics and Biology.' *Theoretische Biologie*, Band II

[3] I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*

characteristics of vital phenomena take on a new appearance in the theory of open systems. Equifinality, which was brought forward by Driesch as the 'first proof' of vitalism, is a consequence of steady state conditions. Similarly, self-regulation in metabolism was considered as explicable only by a governing entelechy; but its general characteristics follow from the laws of steady states. Anamorphosis conflicts with classical thermodynamics, but is in accordance with thermodynamics of open systems. Self-multiplication of biological elementary units, such as genes and chromosomes, was offered by Driesch as a 'second proof' of vitalism. If a hypothesis, advanced by the author[1] should prove to be correct, it would also be a consequence of the fact that these units are metabolising systems. I think therefore that we do not go far astray if we suppose that the principles of open systems are near the very root of the central biological problems.

12 *The Unity of Science*

We may summarise the main results of this presentation as follows:

(*i*) The analysis of general system principles shows that many concepts which have often been considered as anthropomorphic, metaphysical, or vitalistic, are accessible to exact formulation. They are consequences of the definition of systems or of certain system conditions.

(*ii*) Such investigation is a useful prerequisite with respect to concrete problems in science. In particular, it leads to the elucidation of problems which, in the usual schematisms and pigeonholes of the specialised fields, are not envisaged. Thus system theory should prove an important means in the process of developing new branches of knowledge into exact science, i.e. into systems of mathematical laws.

(*iii*) This investigation is equally important to Philosophy of Science, major problems of which gain new and often surprising aspects.

(*iv*) The fact that certain principles apply to systems in general, irrespective of the nature of the systems and of the entities concerned, explains that corresponding conceptions and laws appear independently in different fields of science, causing the remarkable parallelism in their

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[1] L. von Bertalanffy. 'Bemerkungen zum Modell der biologischen Elementareinheiten,' *Naturwissenschaften*, 1944, **32**, 26-32

modern development. Thus, concepts such as wholeness and sum, mechanisation, centralisation, hierarchical order, stationary and steady states, equifinality, etc., are found in different fields of natural sciences, as well as in psychology and sociology.

These considerations have a definite bearing on the question of the Unity of Science. The current opinion has been well represented by Carnap.[1] As he states, Unity of Science is granted by the fact that all statements in science can ultimately be expressed in physical language, i.e. in the form of statements that attach quantitative values to definite positions in a space-time system of co-ordinates. In this sense, all seemingly non-physical *concepts*, for instance specifically biological notions such as ' species,' ' organism,' ' fertilisation,' and so forth, are defined by means of certain perceptible criteria, i.e. qualitative determinations capable of being physicalised. The physical language is therefore the universal language of science. The question whether biological *laws* can be reduced to physical ones, i.e. whether the natural laws sufficient to explain all inorganic phenomena are also sufficient to explain biological phenomena, is left open by Carnap, though with preference given to an answer in the affirmative.

From our point of view Unity of Science wins a much more concrete and, at the same time, profounder aspect. We too leave open the question of the ' ultimate reduction ' of the laws of biology (and the other non-physical realms) to physics, i.e. the question whether a hypothetico-deductive system embracing all sciences from physics to biology and sociology may ever be established. But we are certainly able to establish scientific laws for the different levels or strata of reality. And here we find, speaking in the ' formal mode ' (Carnap), a correspondence or isomorphy of laws and conceptual schemes in different fields, granting the Unity of Science. Speaking in ' material ' language, this means that the world (i.e. the total of observable phenomena) shows a structural uniformity, manifesting itself by isomorphic traces of order in its different levels or realms.

Reality, in the modern conception, appears as a tremendous hierarchical order of organised entities, leading, in a superposition of many levels, from physical and chemical to biological and sociological systems. Unity of Science it granted, not by a utopian reduction of all sciences to physics and chemistry, but by the structural uniformities of the different levels of reality.

Especially the gap between natural and social sciences or, to use

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[1] R. Carnap, *The Unity of Science*, London, 1934

the more expressive German terms, of *Natur- und Geisteswissenschaften* is widely diminished, not in the sense of a reduction of the latter to biological conceptions but in the sense of structural similarities. This is the cause of the appearance of corresponding general viewpoints and notions in both fields, and may eventually lead to the establishment of a system of laws in the latter.

The mechanistic world-view found its ideal in the Laplacean spirit, i.e. in the conception that all phenomena are ultimately aggregates of fortuitous actions of elementary physical units. Theoretically, this conception did not lead to exact sciences outside the field of physics, i.e. to laws of the higher levels of reality, the biological, psychological and sociological. Practically, its consequences have been fatal for our civilisation. The attitude that considers physical phenomena as the sole standard-measure of reality, has lead to the mechanisation of mankind and to the devaluation of higher values. The unregulated domination of physical technology finally ushered the world into the catastrophical crises of our time. After having overthrown the mechanistic view, we are careful not to slide into 'biologism,' that is, into considering mental, sociological and cultural phenomena from a merely biological standpoint. As physicalism considered the living organism as a strange combination of physico-chemical events or machines, biologism considers man as a curious zoological species, human society as a bee-hive or a stud-farm. Biologism has, theoretically, not proved its theoretical merits, and has proved fatal in its practical consequences. The organismic conception does not mean a unilateral dominance of biological conceptions. When emphasising general structural isomorphies of different levels, it asserts, at the same time, their autonomy and possession of specific laws.

We believe that the future elaboration of General System Theory will prove to be a major step towards the unification of science. It may be destined, in the science of the future, to play a role similar to that of Aristotelian logic in the science of antiquity. The Greek conception of the world was static, things being considered to be a mirroring of eternal archetypes or ideas. Therefore classification was the central problem in science, the fundamental organon of which is the definition of subordination and superordination of concepts. In modern science, dynamic interaction appears to be the central problem in all fields of reality. Its general principles are to be defined by System Theory.

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