The Endurance of the Mechanism—Vitalism Controversy

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Contemporary scientists and historians of science[1] have declared the mechanism–vitalism controversy a dead issue, a matter of purely historical, indeed antiquarian interest, which, like the battle over phlogiston, marks an interesting phase in the advance of science but represents no more than a closed case history. Their defense of this position reflects a progressive conception of science which represents it as advancing through the repudiation of its own mistakes. The demonstration that a particular theory or hypothesis is erroneous is supposed to mark the triumph of careful and systematic inquiry; and one more obstacle to the understanding of objective truth is supposedly broken down. The conclusion of a controversy, it is held, follows upon the demonstration of error in one or another (or both) of a set of opposed scientific theses, which are then laid to rest while new and more adequate scientific explanations come to replace them. The *raison d'être* of science, then, is to expose and repudiate the errors of the past, and the justification of contemporary science is precisely its contemporaneity which is itself sufficient to assure its superiority over historical scientific convictions. This view of science and of scientific progress requires the periodic certification of death of certain dogmas and doctrines which once were held as unassailable truths.

It is not my purpose here to examine whether or not this characterization of science is correct. I believe, however, that it is, at best, a limited conception of the process of rational

1. I have heard this opinion expressed in public discussion by Everett Mendelsohn and by Ernst Mayr, and it is affirmed with a tone of great confidence in a number of texts used in introductory courses in modern biology and biochemistry.

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inquiry, which excludes many of the enterprises which have been carried on in the name of science and which have systematically molded the patterns of Western thought about the nature of the universe.

I have argued elsewhere[2] that some historic controversies, notably that between mechanism and vitalism, do not fit the stated pattern of scientific inquiry; that is, as being settled by an appeal to evidence and critical standards acceptable to all sides of the dispute. Some controversies are meta-theoretical in character and involve fundamental commitments on the part of their antagonists which do not depend upon scientific evidence for their retention, and which will not be shaken by evidence to the contrary. I have identified such commitments as based upon primary attitudes or "political" orientations which may have a psychosociological explanation, but which are themselves not subject to rational justification. It is, in fact, one's rootedness in such attitudes and convictions that determines what sort of justification one will regard as "rational" and what sort of evidence one will accept as pertinent to the establishment of scientific conclusions. Where a dispute involves the incompatibility of such fundamental commitments, the strategic problem for the opposing antagonists is not to marshal up additional evidence in support of their own position, for this will be wholly unconvincing to opponents. It is, rather, to come to terms with what the opponents are saying to the extent that a common ground of discourse can be established from which a genuine disagreement might proceed. I have argued that the lack of recognition that the mechanism–vitalism controversy is a dispute of the meta-theoretical type, has led to a failure on the part of both mechanists and vitalists to take one another seriously, with the consequence that the controversy has not been resolved at all, but has been split apart so that both sides battle imaginary windmills and do not face the real views of their opposition. This fragmentation and compartmentalization of the differing approaches to issues rather than any actual resolution of them has invited people to claim prematurely that the dispute between mechanism and vitalism is over.

The thesis of this paper is that the controversy persists and that while modifications of both positions have followed the evolution of scientific concepts, the basic meta-theoretical commitments remain as essentially unchanged and unexam-

2. "Mechanism and Vitalism as Meta-theoretical Commitments," *The Philosophical Forum*, I, 2 (n. s.) Winter 1968.

ined foundations of contemporary differences within the field of biology.

In this paper I shall try to delineate the nature of the metatheoretical dispute and the philosophical ambiance of the opposing positions. I shall then indicate how these philosophical groundings have controlled the expression of the historical doctrines of vitalism and mechanism. Finally, I shall argue that these same philosophical bases determine the character of the opposition between organicist biology, which I identify with the vitalistic tradition, on the one hand, and molecular biology, which I link with mechanism, on the other.

II

The focal issue of the mechanism—vitalism controversy is the nature of life. The phenomenological experience of life is indisputable. We are aware of ourselves as living creatures and as sharing the attribute of life with other creatures which are patently distinguishable from inanimate objects. The crassest of mechanists is ready to acknowledge a discernible difference between the living and the nonliving. His disagreement with the vitalist is over the explanation of this phenomenon, not over its occurrence.

There is further agreement among mechanists and vitalists over many of the individual characteristics of life (or, rather, of living things). Living things have a comparatively high level of organization, which, it is often pointed out, differs from that of all but a few highly contrived inanimate organized systems in being self-maintaining and self-replicating. Living things characteristically exhibit a type of behavior which may be identified as purposive. They are goal-oriented; that is, their behavior appears not to be aimless. However, this is not to be understood to mean that animate things necessarily and invariably act toward the realization of a specific aim, or even that a particular purpose is consciously intended. The concept of purposiveness is in this application purely formal, a category without content. It describes the pattern of behavior, but does not prescribe its substance.

Mechanists and vitalists may also concur upon such features as the adaptability of organisms, their interaction with their environment and their genetic history. Their disagreement is not fundamentally over matters of description, but has to do with the accounting for that description. They disagree on *why* living things are as they are.

An explanation of why something is as it is, is first of all a statement. It refers to another statement (or set of statements) describing a state of affairs for which the explanation provides a kind of warrant of intelligibility. It does not affirm the truth of the description, but rather offers reasons for the acceptance of that description as adequate to the state of affairs at hand. But what constitutes adequacy, and what are the reasons for accepting a description as adequate? These questions, taken in the abstract are the subject of philosophy of science, and cannot here be pursued in depth. The point to be stressed here is that agreement with respect to descriptive statements does not entail agreement regarding the intelligibility of descriptions, nor even regarding the criteria by which their intelligibility might be determined. What is intelligible under one set of conditions might not be so under another. The ultimate test of intelligibility must be with the actual or potential users of an explanation. But if they are to understand each other at all, whether to agree or to disagree, there must be an initial consensus among the community of users of an explanation first as to what it is that is to be explained, the description, and second, as to what the criteria of adequacy are by which explanations produce intelligibility. If the claims made by partisans of a dispute are unintelligible to one another, regardless of how comprehensible they are to others, the dispute cannot proceed.

I have indicated, however, that there is a core of agreement between vitalists and mechanists on what is to be explained. There is, furthermore, a historical model, common to both disputants, of what an ideal explanation might be. This is the deductive pattern of reasoning. The conclusion of a deductively valid argument is explained by its premises insofar as it is logically, or tautologically entailed by them. It is, in effect, simply a more explicit restatement of the statement made by the premises. Expressed metaphorically, the elements of the conclusion are "contained in" the premises.

Translating the logical model into the context of "accounting for" phenomena, we obtain the Aristotelian notion of causal explanation, according to which an occurrence is "accounted for" (explained) when we have provided the necessary and sufficient conditions for its taking place. Given the fulfillment of conditions x, y, and z, it is necessarily the case that event-a will occur. But note the retention of deductive overtones despite the material mode of expression; for it is understood that event-a will occur *necessarily* only if the concept *a* is somehow "contained in" x or y or z, or in their conjunction.

Thus, to take up again the specific question of life, those descriptive features of organization, self-stabilization, goal orientation or whatever, can be explained only by an organizing, self-stabilizing, or goal orienting factor. The occurrence of these features is necessitated causally if the concept of these features is directly or indirectly entailed by the concept, life. Mechanists and vitalists disagree on what that goal orienting factor might be, and how it relates to those descriptive features.[3]

What is the locus of the explanatory factor, or, more directly, the 'life-making factor'? According to the traditional pattern of causal explanation which we have inherited from Greek philosophy, the moving cause of an event occurring in the physical universe is the Aristotelian efficient cause, and this is by definition external to the thing acted upon.[4] Following from the same tradition is the classic doctrine that whatever is acted upon is itself passive and incapable of initiating any movement whatsoever. This is the view which has been presupposed by all forms of vitalism.

Vitalists have fixated upon the Aristotelian conception of causality and the representation of matter which is correlative to it. Accordingly, they hold that there is a basic discontinuity between that which acts and that which is acted upon. That which receives action is itself inert and passive, lacking the spontaneity of self-movement.[5] That which acts imposes form upon matter and is itself wholly external in nature to the matter upon which it acts. Since the active is inherently su-

3. Note that both parties to the controversy hold that such a factor is present, indeed must be specified by an adequate explanation, but they do not agree on its status, logical or ontological.

4. This is not to say that internal elements of a complex entity may not causally affect that entity (as hormonal imbalance may affect the health of an organism as much as exposure to carriers of infection or to violent changes of temperature), but in such cases, we refer either to a complex or causal factor of which the internal element is only a contributor, or we make a distinction between a *condition* which is necessary or conducive to the occurrence of an event, and the *true cause* which is sufficient for its occurrence. In those instances where one part of a complex whole causes a change in another part (which ultimately brings about a change in the whole), it is clear that the externality of the efficient cause is preserved insofar as the one part is external to the other.

5. For Aristotle the term "matter" has a relativistic connotation: that which is matter in one context (e.g., a piece of cloth which is the matter of a toga) may be form in another (e.g., the wool of the sheep which is woven into cloth). But in all instances the matter is passive with respect to the form imposed upon it, and at the ultimate state of primary matter it is wholly without activity, without attributes, and receptive to form.

perior to the passive, and the cause necessarily prior to the effect, it is clear that we are here committed to a scale of values upon which matter occupies a relatively low station.

A multitude of vitalistic theories exists and some of these will be discussed in the next section. But let us note now what is common to all these theories, namely, a tolerance for radical discontinuities in nature. The vitalist is at home with the notion of an essential dualism between life and matter. The fact that this analysis evokes problems concerning the possibility of interaction of two unlike entities (matter and life, the active and the passive, mind and body) or that it represents cause and effect as wholly contingent to one another (i.e. as not *necessarily* related) does not appear as a major obstacle, for the metaphysical core of the position is the representation of matter as sheer potentiality and hence as pre-eminently receptive to being causally affected.[6]

Some mechanistic theories have also been accommodated to an Aristotelian concept of matter. They have represented life as an epiphenomenon arising from certain arrangements of matter, or have regarded it as a resultant of purely physical forces within matter. Diderot, following Cartesian mechanism, defined "life" as "a succession of actions and reactions,"[7] and much of seventeenth- and eighteenth-century experimental physiology follows the mechanical pattern of Descartes and de la Mettrie in explaining life processes as consequences of (hydraulic) engineering.

But, on the whole, mechanism has adopted a different model of matter, namely, as self-moving, i.e. as inherently possessing a productive capacity and hence not requiring shaping by an efficient cause which is external to it. This view also has Greek origins and is to be found in the "materialism" of Spinoza. But, above all, it fits the modern conception of matter as matter-energy, not correctly characterized as inert or passive, since charged particles are related to one another as the interplay of dynamic forces. The motion of matter on this view is hardly the consequence of an external force, but itself has priority over all other forms of change.

In contrast to vitalism, this form of mechanism can regard order as a necessary and natural attribute of matter, requiring no agent which imposes organization upon a primary chaos. Hence the problem of discontinuity of actor and acted-upon is

6. Indeed, it follows from the very definition of matter that it cannot exist except as acted upon by some form-imposing cause.

7. D. Diderot, *Rêve d'Alembert* (1763), cited in M. Bunge, *Causality* (Cambridge, Mass., 1959), p. 207.

avoided. If the principle of organization is inherent in the nature of matter, then, while there may be levels of complexity of objects in nature, these are not essentially discrete, and nature may be viewed as a continuous system. The apparent differences between the living and the nonliving, the conscious and the nonconscious, etc., are not denied, but they are not assigned a status of ontological ultimacy.

The unity of nature represented by this position reflects the comparative intolerance of mechanists toward pluralities of explanation. Heuristically, such explanatory economy functions to promote a model of scientific inquiry which will subordinate the widest possible range of phenomena to the fewest possible scientific principles. The counterbalancing heuristic role of vitalism is to discourage too facile acceptance of expansive generalizations. Where differences occur at the level of experience, they surely must be accounted for; but this does not warrant the invention of new explanatory principles nor of new metaphysical entities. While vitalism runs the risk of multiplying and objectifying essences, mechanism runs the risk of ignoring differences and so of oversimplification and trivial generalization.

III

Neither mechanism nor vitalism has remained static in its conceptualization of the nature of life. Although their basic distinctions as characterized above have remained fairly constant, their actual positions have altered with the general evolution of science. Vitalism may be viewed as falling into several distinct phases, each of which is less substantive in its postulations than its predecessor. To a large extent, these phases have been initiated by the retrenchments which vitalism has been forced to make in the face of inquiries sparked by mechanistic opposition.

The most extreme form of vitalism is blatantly dualistic, affirming the cohabitation of a material body which is inanimate in all respects, and a vital substance which is exclusively responsible for the life of the organism. The two are related as user and instrument, the body being wholly subject to the control of the soul (or animating subject) except as its own recalcitrant nature prohibits it. This view of life as bestowed by the soul is Platonic in its inspiration and has had an enormous impact upon Western science, philosophy, and theology. The soul is the "higher" element, which in the case of man endows him with a nature even higher than that of ordinary living organisms. As expressed by the eighteenth-century vitalist, G. E. Stahl, living things are fundamentally different in nature from nonliving ones; and the living body exists not for itself, but for the indwelling soul which controls its activities for its own uses and ends. While vital activities are carried out in and by the body, they "are carried out in corporeal instruments by a superior acting cause," and "cannot have any real likeness to such movements as, in the ordinary way, depend on the material condition of a body and take place without any direct use or end or aim." [8]

According to this formulation of vitalism, the living and the nonliving are in a very crucial sense in conflict with one another. Not merely is it false that living activities are reducible to physicochemical processes, but it is further the case that living activity is in violation of such processes.

This notion of opposition of living and nonliving things reappears even in less pronouncedly dualistic forms of vitalism. In these, the notion of a vital substance has been abandoned, but certain vital properties of organisms or a vital force which permeates the whole living creature is allegedly responsible for the phenomena of life. At the height of the eighteenth-century controversy between mechanism and vitalism, some vitalists affirmed the existence of a single vital force comparable to gravity, while other vitalists, such as Bichât, believed that organic tissues possessed vital properties which were distinct from and irreducible to their physical qualities. As such, they were also held to be immune to scientific analysis and could not be measured with mathematical exactitude.

> In considering under this head the vital laws, the first view which they offer, is the remarkable difference which distinguishes them from physical laws. The one constantly varying in their intensiveness, energy, and development, often pass with rapidity from the lowest degree of prostration to the highest point of exaltation, accumulate and diminish in the organs alternately, and assume, from the influence of the slightest cause, a thousand different modifications. Sleep, watching, exercise, rest, digestion, hunger, the passions, and the action of surrounding bodies, etc., expose them at every instant to numerous revolutions. The

8. Cited in L. R. Wheeler, *Vitalism: Its History and Validity* (London, 1939), p. 25.

> others, the same at all times, are the source of a series of phenomena always uniform. Compare the vital faculty of feeling to the physical faculty of attracting; you will see that the attraction is always in proportion to the mass of rough body in which it is observed, while the sensibility changes in proportion incessantly in the same organic part and in the same mass of matter . . . To say that physiology is the physics of animals, is to give but a very imperfect idea of it; I might say with equal propriety that astronomy is the physiology of the stars.[9]

Debates at this period were not exclusively between proponents of vitalism and defenders of mechanism. There were disagreements between different schools within each category, and the impact upon the mechanism–vitalism controversy itself was largely indirect. The arguments of Claude Bernard, for example, were largely directed against the vitalism of Bichât, according to whom the acts performed by living beings miraculously resist the universal laws of matter. Bernard insisted upon the experimental study of and extension of lawful order (determinism) to life phenomena as well as to the inanimate; yet he was no reductionist. He believed that the phenomena of life have their special law, as deterministic as that which applies to the inorganic domain. It is not wholly clear whether the "specialness" of the law is purely a consequence of the complexity of the phenomena to which it applies, or whether the "pre-established design" of organisms has a more ultimate ground. To answer this question would require knowledge of first causes, and these, according to Bernard "are outside the realm of science; they forever escape us in the sciences of living as well as in those of inorganic bodies."[10] In terms of his partisanship, perhaps Bernard should be identified as neither mechanist nor vitalist, but as agnostic; for, while he agrees with the vitalists "that living beings exhibit phenomena peculiar to themselves and unknown in inorganic nature," he believed that to the extent that these can be understood, they can be studied only by a rigorous application of the experimental method of the physicochemical sciences.

Bernard's view is remarkably close to that of some scientists of the nineteenth and twentieth centuries who, long after

9. *Physiological Researches upon Life and Death* (Philadelphia, 1809) cited in H. Guerlac, *Selected Readings in the History of Science*, vol. II, sec. 2, 1953.

10. Claude Bernard, *An Introduction to the Study of Experimental Medicine*, pt. II, chap. 1; no. 3.

it had been clearly established that living things are not composed of special organic substances, still believed that living things, though lawfully determined, obey laws which transcend the laws of the inanimate world and, indeed, run counter to them.

Expressions of this view have varied in the degree of independence which they attribute to biological law. In a comparatively recent formulation of the position, Sir James Jeans says:

> Inanimate matter obeys the laws (of entropy) implicitly; what we describe as life succeeds in evading it in varying degrees. In fact it would seem reasonable to define life as being characterized by a capacity for evading this law . . . it seems able to evade the statistical laws of probability. The higher the type of life, the greater its capacity for evasion.[11]

Precisely what is meant by "evasion" is not altogether clear. Does it mean that living things exhibit a positive resistance against natural physical processes? Apparently this is what Bichât had in mind when he characterized life as "the totality of those functions which resist death." [12]

"Evasion" may also be taken more neutrally, simply as failure to comply with the principles governing purely physical nature, but without implying a positive counterforce. Erwin Schrödinger suggests such a view in *What is Life?* where he contrasts living things with ordinary material entities whose natural tendency is toward increased entropy. While he denies that there is a "new force" operative in living things, he declares that they present us with a new state of affairs which is *unprecedented* in physics:

> It needs no poetical imagination but only clear and sober scientific reflection to recognize that we are obviously faced with events whose regular and lawful unfolding is guided by a "mechanism" entirely different from the "probability mechanism" of physics . . . the situation is unprecedented, it is unknown anywhere else except in living matter. The

11. Sir James Jeans, *The New Background of Science* (London, 1933), p. 276.

12. On any other interpretation, the definition is circular; but Bichât seems to have meant that organisms, while possessing vital properties, have the capacity to carry on vital activities, which capacity deteriorates as the organism advances through the natural cycle from maturity to decay. A dead organism, then, differs from an inanimate object only in its history, but, like an inanimate object, it is wholly determined by ordinary physical processes. Bichât, *Physiological Researches*, X.

> physicist and the chemist investigating inanimate matter have never witnessed phenomena which they had to interpret in this way. The case did not arise and so our theory does not cover it.[13]

It remains an open question whether a whole new order of law must be introduced in order to account for living phenomena, but what is clear is that in terms of our experience and the current understanding, a radical discontinuity does exist between the realm of living and of nonliving beings.

> You would not expect two entirely different mechanisms to bring about the same type of law. You would not expect your latchkey to open your neighbor's door as well . . . We must be prepared to find a new type of physical law prevailing in (living matter). Or are we to term it a non-physical law? [14]

By the beginning of the twentieth century, it was well established that living things were not merely composed of the same substances as ordinary physical objects, but that the principle of conservation of energy applied to them as well. This understanding undermined those remaining doctrines which held that vital forces or energies could direct life activities without themselves drawing upon some energy source. But the tradition of vitalism still retained its vitality. The phenomenological difference between the living and the nonliving is too pronounced and the human investment in it too strong to be lightly dismissed. Vitalism continued to be defended in a new form which stressed structural and organizational differences between the living and the nonliving, rather than the earlier focus upon substantive or energetic differences.[15]

According to this position, the laws which govern living phenomena are not antithetical to those which apply to nonliving matter. Rather, the laws of physics are *incomplete* (i.e. not merely incompletely *known*) and require enrichment by purely biological laws. Biological entities are natural objects;

13. E. Schrödinger, *What is Life?* (New York: Anchor Books, Doubleday, 1956), p. 79.

14. Ibid., p. 80.

15. Wm. Carlo, "Reductionism and Emergence: Mechanism and Vitalism Revisited," *Proceedings of the American Catholic Philosophical Association*, 1966. Carlo's point is that the earlier (platonic) form of vitalism was substantive, hence metaphysically dualistic; while the later doctrine stresses structure and form as the crucial differentia, the vital factor being an organizational principle inseparable ontologically from the object formed. Carlo identifies the later formulation of vitalism with Aristotelianism.

but life involves something "more" than inanimate matter, and this is irreducible to—although compatible with—physical principles. Proponents of this form of vitalism have been identified as emergentists, or holists or organicists. They deny the presence of a substantive or spiritual or energizing life factor, but they affirm that there is an "organizational" principle over and above the constituents of the complex living system, and the explication of this organization is the basis of the autonomous science of biology.

Hans Driesch[16] employs the term "entelechy" to designate the organizational principle, and thereby openly acknowledges his indebtedness to Aristotle, although his own usage of the expression differs from that of Aristotle. For Aristotle, the entelechy is an indwelling final cause, present in the natural object from the point of its inception, which guides its ultimate self-realization in accordance with the ideal pattern of its essence. The entelechy has primary responsibility for the maturation of the organism, for it is the active agent which raises the physical potentialities of the organism to the state of actuality.

Driesch assigns a more modest role to the entelechy. He does not identify it as primary cause and pattern of self-realization, but rather as a regulator governing which of the various potentialities resident in the material system is to be permitted realization and which is to be restrained. Entelechy is thus not the template of organic organization, nor the creative agent which brings it about; but it serves as a kind of insurance which protects the built-in tendencies of the organic system from being disrupted by adverse environmental conditions. Having neither substantive being nor creative energy, it is held to offer no violation of the physical laws of nature. It is nonspatial, nontemporal, and nonpsychic, in all respects nonquantifiable; but it is upon specific portions of matter that it has effect. It neither increases nor decreases the features of the material world but only alters their organization.

Driesch's entelechy, while functioning only as a *unifying* and not a *productive* cause, nonetheless betrays his orientation toward a traditional Aristotelian concept of causality. Since the organism as organized possesses a "wholeness" which is not to be found in the aggregation of the individual constituents, there must be a cause of the "wholeness" which is ontologically prior to the developmental process which leads to

16. H. Driesch, *Science and Philosophy of the Organism* (Aberdeen, London: A. & C. Black, 1908).

its realization. Every effect must have a cause which is prior to it and in which it is implicitly present. This is the rationale behind the introduction of the entelechy, and it denies the occurrence of novelty. The organizational factor must be accounted for as somehow pre-existent and independent of the matter which is organized.

The arch-opponent of Driesch's form of vitalism was Jacques Loeb, who took on the task of proving mechanism with messianic zeal. His experiments with egg fertilization and particularly with embryological development were similar in character to those carried out by Driesch, but Loeb concluded from them that the life activities exhibited by the organisms examined could be completely accounted for as a consequence of physicochemical processes. Rejecting the alleged "whole-making" feature which the organicists regarded as essential to organisms, Loeb said:

> With all due personal respect for the authors of such terms, I am of the opinion that we are dealing here, as in all cases of metaphysics, with a play on words. That a part is so constructed that it serves the "whole" is only an unclear expression for the fact that a species is only able to live —or to use Roux's expression—is only durable, if it is provided with the automatic mechanism for self-preservation and reproduction. If, for instance, warm-blooded animals should originate without a circulation they could not remain alive, and this is the reason why we never find such forms. The phenomena of "adaptation" cause only apparent difficulties since we rarely or never become aware of the numerous faultily constructed organisms which appear in nature.[17]

He went on to describe his own experimental production of "faulty" embryos which lacked adaptive ability and concluded that their deficiencies were purely chemical in nature. He then argued that our failure to find such ill-adapted organisms in the world was no indication that they were not produced or that nature somehow "knew" not to produce such inharmonious systems. On the contrary, he maintained that such disharmonies and faulty attempts are the rule in nature, and the harmonically developed system the rare exception. But since only the latter do survive, we only perceive them, and we get the "erroneous impression that the 'adaptation of the

17. J. Loeb, "The Mechanistic Conception of Life," *The Popular Science Monthly*, January 1912.

parts to the plan of the whole' is a general and specific characteristic of animate nature, whereby the latter differs from inanimate nature." In making this observation, Loeb revealed his orientation toward the prevailing mechanistic thesis that there is no a priori reason to assume that a tendency toward order is any more alien to the nature of matter than a tendency toward disorder. Just as earlier mechanists had regarded vital activity as inherent in matter and not as externally imposed upon it, so here Loeb viewed the "whole-making" features, so puzzling to vitalists, as normal and natural manifestations of matter.

Some opponents of mechanism have been less impressed with "wholeness" as such, or with the particular mode of organization of living things, than with the apparent historical novelty of such organization. These people stress the "new relatedness" which comes into being at the level of vitality. They refer to the emergence of life as a process which takes place in the physical universe whereby a hierarchical arrangement of material organizations produces qualitatively and chronologically new events in the universe. Inspired by the doctrine of evolution and the modern faith in progress, they do not adhere to the Aristotelian conviction that the effect must be implicitly contained in the cause; but rather stress the creative force of evolution as causing something wholly unprecedented. Vital organization is then neither exhumed from that which entails it nor synthesized additively out of component parts; it is generated *de novo,* spontaneously and unpredictably. This is the highly problematic doctrine of "emergent evolution" defended with variations by H. Bergson, Samuel Alexander, and by Lloyd Morgan. Unlike the Drieschian doctrine of entelechies, the doctrine of emergent evolution is fundamentally historical, and therefore has bearing on the question of the origin of life, which is explicitly excluded as "hors de combat" by Driesch.[18]

The historical element of emergent evolutionism introduces new metaphysical issues which cannot be discussed in the present context and which I have dealt with elsewhere.[19] Its

18. Driesch himself dismisses the problem of origins as having less theoretical importance than that of discovering the laws of life. On this matter he professes a remarkably insouciant ignorance. But, as scientific inquiry has proceeded to offer tentative answers to the question of how and why life began, this apparent indifference is revealed as a glaring weakness of Driesch's theory of the nature of life.

19. "Uniformity, Uniformitarianism and Historical Reconstruction." Paper presented at the meeting of the Pacific Division of the American Philosophical Association, Berkeley, California, April 1970.

relevance to the matter before us is the conviction which emergentism shares with all forms of vitalism, contemporary and traditional, that the organization of matter is an attribute which supervenes upon the character of matter as such, and therefore requires special consideration. The view that in the domain of biology the whole is greater than the sum of its parts is represented in current theoretical discussions of biology in the work of Edmund Sinnott,[20] of Ludwig von Bertalanffy,[21] and of Paul Weiss,[22] among others. An essay of Paul Weiss entitled "1 + 1 ≠ 2 (One Plus One Does Not Equal Two)"[23] makes the point succintly.[24] Without maintaining the existence of any nonmaterial substance, vital force or *élan vital;* without even claiming the noncompatibility of the laws governing physical and biological events, contemporary descendants of the vitalistic tradition continue to hold the position that there is an inexplicable jump between biology and physics, and that the former will never be adequately accounted for in the language of the latter.[25]

IV

Mechanism, like vitalism, has undergone historical modifications conforming to alterations in the content of science.

20. *The Problem of Organic Form* (New Haven: Yale University Press, 1963).

21. *Problems of Life* (New York: Harper & Row, 1952).

22. "The Cell as Unit," *Journal of Theoretical Biology* 5, (1963), 389–397.

23. *Interdisciplinary Topics,* (1966), 801.

24. It is noteworthy that at least Weiss and Bertalanffy have taken an interest in the science of systems theory, and have extended their holistic approach to systems of both suborganic and superorganic nature. While this reinforces the claim that organized systems are irreducible to their component elements, it tends to obscure the allegedly basic distinction between biological phenomena and relations among inanimate objects. A propos this point, it has been reported of a recent symposium of scientists discussing the question whether life transcends the laws of physics and chemistry, that one of the participants reached the conclusion that physics and chemistry themselves must be understood as transcending the laws of physics and chemistry. The symposium was held at the 1967 AAAS meeting in New York on the topic, "Does Life Transcend the Laws of Physics and Chemistry?" The participants were Barry Commoner, Ernst Nagel, John Platt, Michael Polanyi, and the moderator Gerald Holton.

25. This is the position of Neils Bohr and of Max Delbruck, both of whom make the analogy between the condition of biology and that of physics in 1913. They maintain that there is a type of complementarity involved such that the physical state of an object can be described only to

As expressed by C. D. Broad, the classical position of "pure mechanism" affirms that there is:

> (a) a single kind of stuff all of whose parts are exactly alike except for differences of position and motion; (b) a single fundamental kind of change, viz. change of position. Imposed on this there may of course be changes of a higher order, e.g. changes of velocity and acceleration, and so on; (c) a single elementary causal law, according to which particles influence each other by pairs; and (d) a single and simple principle of composition, according to which the behavior of any aggregate of particles, or the influence of any one aggregate on any other, follows in a uniform way from the mutual influences of the constituent particles taken by pairs.[26]

This doctrine is as close to Democritus as it is to Descartes and de la Mettrie. Basically it affirms that the course of a process is completely determined by an exhaustive specification of the initial physical conditions of the system under consideration and its environment. These conditions do not include a special "organization-explaining" factor, and they have no need to, for they are sufficient of themselves. In the eighteenth century, the laws of classical mechanics were thought to be adequate for the purpose. Subsequently, physics itself transcended these laws: matter became dematerialized, and the principles explaining its behavior became more complex and more pluralistic.

In the course of its history, mechanism like vitalism became less extreme, and the two positions have drawn closer to one another, both sides having made concessions to the insights of the other, and, more important, to the complexity of the phenomena to be explained. Nonetheless, the difference has always remained that mechanism emphasizes the continuity and likeness between living and nonliving things, while vitalism stresses their discontinuity.[27] Perhaps the contem-

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the exclusion of its description as an organism, and vice-versa. See N. Bohr, *Atomic Physics and Human Knowledge*, (New York: John Wiley, 1958).

26. In fact, as Broad admits, no one has ever held an unadulterated theory of this form. It represents the ideal which the thoroughgoing classical mechanist approximates (C. D. Broad, *Mind and its Place in Nature* [London: Routledge, Kegan, Paul, London, 1923]).

27. It should be noted that the mechanistic stress on continuity does not entail reductionism of the more "advanced" to the less. It is equally plausible to anthropomorphise lower level objects—e.g. to attribute "soul"

porary perpetuation of the disagreement can best be illustrated by a sampling of statements from proponents of the opposing points of view.

Expressing the confidence of the mechanist position, James D. Watson says:

> We see not only that the laws of chemistry are sufficient for understanding protein structure, but also that they are consistent with all known hereditary phenomena. Complete certainty now exists among essentially all bio-chemists that the other characteristics of living organisms . . . will all be completely understood in terms of the coordinative interactions of small and large molecules. Much is already known about the less complex features, enough to give us confidence that further research of the intensity recently given to genetics will eventually provide man with the ability to describe with completeness the essential features that constitute life.[28]

More succinctly, Dean E. Wooldridge says: "Fantastically complicated though a large protein or nucleic acid may be, the problem its structure and properties pose to human understanding is one of degree, not of quality." [29]

On the other hand Edmund Sinnott claims:

> No one can deny the very great advances that have been made by the biochemical method of approach to biological problems or the boundless possibilities that are open before it, but an over-emphasis on the molecular point of view may have unfortunate consequences . . . it will distract attention from the fact that there are fundamental problems of biology that have stubbornly resisted solution by chemical means alone. Conspicuous among these is the problem of form. This is no minor issue that can be swept under the rug and safely ignored in the hopeful belief that further biochemical progress will almost automatically clear it up. It must be kept in the forefront of our thinking and its solution attempted from every possible direction.[30]

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to inanimate entities. But in fact the majority of mechanists have sought to explain the more complex in terms of the simpler, and thus to regard physics as the key to biology rather than the reverse.

28. *The Molecular Biology of the Gene*, (New York: W. A. Benjamin, 1965), p. 67.

29. *The Machinery of Life* (New York, 1966), p. 42.

30. *The Problem of Organic Form.*

Once again, we find a confrontation between the conviction that a thoroughgoing familiarity with the elemental principles of the physical universe will suffice to account even for its living manifestations, and the counterclaim that the phenomena of life can be explained only if these elemental principles are enriched by further principles of organization (the problem of form).

Let us consider the contemporary state of the controversy.

V

Lacking historical perspective, we are bound to be caught up in the polemical nature of the theoretical dispute, and the virulence of its rhetoric is itself a clue to its fundamental nonrationality. Curiously, much of the language employed by both sides is directed not against the contemporary enemy but against a foe long dead and since repudiated by its descendants. Thus, Francis Crick, speaking of vitalism says, "It implies that there is some special force directing the growth or the behavior of living systems which cannot be understood by our ordinary notions of physics and chemistry."[31] In fact, this is not the position of any noteworthy modern vitalist, and certainly not that of the men whom he goes on to criticize. He dismisses vitalism as "mystical," referring to those who endorse it as "a lunatic fringe" and admonishes them:

> There are still people today who believe that the earth is flat, in spite of all the enormous accumulation of scientific evidence to the contrary. And so to those of you who may be vitalists I would make this prophecy: what everyone believed yesterday, and you believe today, only cranks will believe tomorrow.[32]

The organicists on their side are equally hostile toward molecular biologists, accusing them not merely of doing bad science but also of the worst sort of opportunism and anti-intellectualism.[33]

31. *Molecules and Men* (Seattle, University of Washington Press, 1966).
32. Ibid., p. 99.
33. The very titles of the articles opposing molecular biology are antagonistic; e.g., the February 1964 issue of *BioScience* carries an article by Robert Zuck entitled "Molecular Botany—A New Anti-Intellectualism?"—cited in "The Cell and the Organism: a Re-examination," Sister Adrian Marie, O. P., in *Philosophical Problems in Biology,* ed. V. E. Smith, St. John's University Philosophical Series, no. 5 (New York, 1966).

Barry Commoner, in a vice presidential address to the American Association for the Advancement of Science[34] deplores the effect of reductionism upon the enterprise of science itself. Decrying the fact that bright young scientists prefer linking strands of DNA to mating Drosophila, Commoner says:

> As soon as an interesting and important biological problem becomes susceptible to chemical or physical attack, a process of alienation begins, and the question becomes, in the end, lost to biology. But in each case, the purely chemical—or physical—studies run their course and come to the blank wall that still surrounds the intimate events which occur within the *living* cell. The obvious need is to return home to biology. But now the errant science has long forgotten its home, and the mother is too bewildered by its fast-talking offspring to be very happy about welcoming it back into the family.

In the end, Commoner continues, scientific inquiry is stultified:

> So long as this process of alienation affected only the end products of metabolism (such as starch, rubber, or pigments), the parent science suffered some damage, but no really lethal blow. But now biochemistry and biophysics have reached deep into the core of biology—to reproduction and inheritance—and the question arises as to how biology will survive this more penetrating attack.

The major objection which organicists raise against molecular biologists is that the analytic approach of the latter necessarily oversimplifies the complex nature of the subject matter. The solution of small-scale problems *in vitro* is, they argue, no guide to the explication of the large-scale, systemic interactions which are the essence of biology. Biological phenomena, they insist, are dynamic expressions of processes. They cannot be understood in terms of static models, nor can they be segregated from the living context within which they normally take place.

Once again the disagreement between opposing views is focused upon the locus (or status) of organization; for both sides are agreed that there is organization. The question is, where does it come from and how is it maintained? Contemporary mechanists, like mechanists of the past, affirm that the structure of matter, animate as well as inanimate, is the

34. "In Defense of Biology," *Science* 133 (1961), 1745–1748.

consequence of those forces which derive ultimately from the arrangement of electrical charges of the elemental particles. In keeping with this view, Bernal has provisionally defined life as "a partial, continuous, progressive, multiform and conditionally interactive, self-realization of the potentialities of atomic electron states."[35]

The order which is to be found in such complex material combinations as organisms can be explicated without appeal to extrinsic organizational principles; for under any but the most extreme thermal conditions, matter exhibits an inherent tendency toward architectonic stability. There is no reason why the tendency toward order should be less natural than the tendency toward disorder. Bernal ascribes to matter "a geometrical beauty of a type that Plato would have much appreciated: sets of identical particles which hold themselves together by the principles of self-assembly in the most elaborate structures."

There is increasing agreement among mechanistic biologists that the mode of self-assembly is reproduction which takes place at the molecular level just as it has been traditionally associated with the perpetuation of species of organisms. The notion of biological heredity which was once thought to be a unique phenomenon, is now regarded as simply an extension or general expression of the more fundamental replication which takes place at the molecular level. By this process, nucleic acids reproduce themselves and govern the formation of amino acid chains which determine the structure of proteins and hence the whole process of construction of living organisms. Self-assembly of matter as it approaches greater stability also produces greater complexity, advancing at the pre-organic level from atom to molecule, from monomer to polymer, and from polymer to organism. The concept of evolution applies to the pre-organic as well as to the organic domain. Indeed, it is held that "chemical evolution" took place on earth over a period of 4.5 billion years prior to the appearance of the first organism.

The formation of the first organism by this means is a matter of probability, but it is a likelihood which, because of the length of time available to it, is a probability which approaches certainty.

> When we consider the spontaneous origin of a living organism, this is not an event that need happen again and

35. J. D. Bernal, *The Origin of Life* (Cleveland and New York: World Publishing Co., 1967).

> again. It is perhaps enough for it to happen once. The probability with which we are concerned is of a special kind; it is the probability that an event occur *at least once*. To this type of probability a fundamentally important thing happens as one increases the number of trials. However improbable the event in a single trial, it becomes increasingly probable as the trials are multiplied. Eventually the event becomes virtually inevitable . . .
>
> The important point is that, since the origin of life belongs in the category of at-least-once phenomena, time is on its side. However improbable we regard this event, or any of the steps which it involves, given enough time it will almost certainly happen at least once. And for life as we know it, with its capacity for growth and reproduction, once may be enough.[36]

But mechanistic biologists are not restricted to the speculative claim that because it is *possible*, the formation of matter into the complex objects now familiar to us is, in the fullness of time, necessary. While no direct demonstration is possible, stronger evidence may be provided in the form of an analysis of models and experimentation with systems presumed to be analogous to living systems.

The technique of molecular biology is analytic. In order to understand the nature of life, biologists break down complex life activities into presumed subprocesses which may be studied in isolation. Advanced laboratory techniques permit direct access to components of living systems whose existence, to say nothing of their structure, were matters of conjecture in the past. Biologists employ models, which are not intended as mere illustrations, but as conceptual tools whose use will yield additional insights into the nature of the living system.

It is clearly impossible to gather direct evidence concerning the origin of life; but it is meaningful to ask: "What circumstances could, in keeping with known physical laws and conformably with the known historical past, give rise to the

36. G. Wald, "The Origin of Life," *Scientific American*, August 1954. There is, however, no necessity that life did originate only once. It is compatible with mechanism as well as with vitalism to affirm that life had several beginnings. There are, in fact, contemporary theories which affirm that even now life is continuously being created anew, but that the new forms are either destroyed by more advantaged competition or are so similar to the living forms now existing that they are virtually indistinguishable from them and hence remain unnoticed, J. Keosian, *The Origin of Life* [New York, Reinhold, 1964]). See also *Science 131*, (1960), p. 479.

present state of organic life?" It is then possible to replicate these conditions and observe what happens. Even this does not constitute proof of what did take place; for whatever occurs now, it might then have been otherwise. But if, in addition, independent evidence is given regarding the primordial nature of the earth which describes it as conforming to the conditions which would have generated life as we know it, then the case for the story given becomes even stronger. In fact, such evidence has been accumulated over recent decades. The theory first formulated by A. I. Oparin,[37] and then modified by himself and others, contends that life appeared on earth after a long period of chemical evolution in a reducing (non-oxygenic) environment out of primitive inorganic substances, which formed organic compounds under the stimulation of solar radiation or electric discharges. While there is disagreement concerning features of this process—e.g., the temperature of the primordial "soup" of elements, the specific nature of the energy source—there have been model experiments which render any one of the alternatives plausible, and which are also compatible with what is known of the primitive geological conditions of the earth. The most renowned of these experiments, carried out by S. L. Miller in 1953, reveals that amino acids can be formed by passing a spark through a circulating solution of methane, ammonia, hydrogen, and water. Additional experiments showed that amino acids so derived could combine to form proteinoid compounds. Similar experiments were performed, especially by Kornberg,[38] to synthesize nucleic acids.

While all such experimental results must be supplemented with geological and paleontological evidence regarding the actual history of the universe, they do support the claim of mechanistic biologists that elemental matter, left to itself in adequate circumstances, will organize to form compounds of increasingly complex nature, including living organisms.

The vitalistic, or organicist, position denies the principle of self-assembly of matter, and affirms that not only is it necessary to explain the fact of organization, but also that there must be an explication of each level of organization in terms of its place within the hierarchy. In other words, it is not sufficient to describe the constituent parts and their formal

37. A. I. Oparin, *The Origin of Life on Earth*, trans. A. Synge (New York: Academic Press Inc., 1957); *The Origin of Life*, trans. S. Morgulis (New York: Dover Publications, 1953); and *Life, Its Nature, Origin and Development*, trans. A. Synge (New York: Academic Press, 1964).

38. A. Kornberg, *Scientific American 219* (October 1968), p. 64.

relations among themselves. Over and above any such pattern of organization is a principle which organizes the parts in terms of the whole of which they are a part. This marks the difference between an aggregate, which is merely a summation of discrete entities, and an organism, which is a whole whose complex parts are determined by their position within that whole.

Organicists are not in agreement among themselves whether the unit of life is the cell or the entire organism, but they are all convinced that the character of any level of living matter—cell, tissue, organ, organism—is determined from *above*, to at least as great an extent as from below.

In an article entitled "The Cell as Unit,"[39] Paul Weiss objects to describing a cell in terms of its composition of molecules and their component atomic and subatomic units on the ground that this fails to differentiate between a live and a dead cell, or even a dead cell from a homogenate of a physically disintegrated system. He acknowledges recent spectacular successes in synthesizing "higher order" systems from "lower order" elements, but he cautions against undue optimism in this regard since most of it is held "in direct proportion to the lack of first-hand and penetrating acquaintance with the living cell *as a whole* (Weiss' emphasis), which is a unit rather than a sheer summative assemblage or conglomerate." The actions of a cellular system, he says, cannot be understood unless one takes into account the cooperative coexistence of all its features. All of them "contribute to the maintenance and operation of all the others in such a way that collectively they achieve a relatively stable and durable group existence." While the various component activities of cell life can be analyzed in isolation by the scientist, they are in fact carried on by the cell simultaneously by harmoniously coordinated interactions. The macromolecular subunits of the cell which are fitted to carry out these activities (and therefore exert "molecular control of cellular activity") appear to derive their own specific configurations which are the key to their power of control by a kind of "pre-fitting" which is imparted to them "*as members of just such an organized group unit.*" In other words, it is in virtue of their place in the cell that they are qualified with properties permitting them to exert a controlling influence upon the cell.

Similarly, in the case of interaction between cells, the specific character of the action cannot, according to Weiss, be

39. *Interdisciplinary Topics* (1966).

understood simply by analysis of the cells as independent units. Even artificial experiments which replicate *in vivo* conditions reveal by their empirical shortcomings that the full complexity of factors influencing not merely the growth but also the differentiation of cells has not been adequately reproduced.[40]

It is maintained that cells interact with one another in accordance with a functional as well as a genetic determination, and that their function is itself to be understood in terms of the organism as a whole. It may well be that nothing less than an entire embryo or organism is sufficient consistently to provide all of the correct substrates, hormones, and enzymes at the right place and at the right time for a specific and characteristic action to occur. In any case, there is experimental evidence that behavior which is not explicable in terms of an analytic breakdown of its composition is understandable when approached from the point of view of the "meaningfulness" of the action to the whole organism which exhibits it.[41]

In line with these observations, the organicist rejects any account of the nature of life which takes as its model anything less than the entire organism. For this reason, organicists tend to be scornful of the "somewhat fictitious and oversimplified" model systems employed by molecular biologists. Dismissing these as having, at best, a coincidental resemblance to the living systems they are meant to duplicate, the organicist is severely restricted in the type of experimentation which is available to him. Since direct confirmation regarding the origin of life is impossible, and since he rejects inference based upon conceptual models which presume to replicate the circumstances under which life might have originated, he is not in a position to make well-founded judgments concern-

40. The artificial culture of cells in nutrient media is a well established experimentally refined technique. Cells can be made to grow and proliferate *in vitro*, but it has been repeatedly observed that the normal differentiation which takes place in the intact organism does not take place in the artificial culture. Cells *in vitro* tend to dedifferentiate or to revert to a common cell type. This has led histologists to question whether the normal development of the cell actually is genetically encoded in its DNA or whether it is not at least partially determined by its functional role and its adaptation to its environment. Several references are given in Sister Adrian Marie, O.P. "The Cell and the Organism," (n. 33 above).

41. Experimental work on perception by Jerome Lettvin, et al., for example, has been successful when predicated upon the hypothesis that the eye of the frog is responsive to a fly, which is meaningful to the organism; unsuccessful when analyzing perceptual behavior in terms of the effect of light flashes upon the retina. See J. Lettvin, "The Frog's Eye Tells the Frog's Brain."

ing the origin of life. Furthermore, the holistic orientation of organicism imposes the logical dilemma that, if the whole is logically prior to its parts, then we have no way of accounting for the origin of the whole itself. The doctrine of the self-assembly of matter is clearly to be rejected, and so is an evolutionism which stresses the novelty and progressively increasing complexification of later states.

It is not difficult to comprehend how an organicist commitment might induce one to accept some form of absolute idealism in order to solve this historical (or genetic) problem. On such a view, all formation of wholes is but a moment in the ultimate self-realization of that single whole in terms of which all others derive their being and their scientific rationalization.

Alternatively, an organicist may adopt an orthogenetic, or finalist, position with respect to origins. This is essentially the solution of Teilhard de Chardin,[42] who acknowledges a novelty of sorts in the phases of evolutionary development. The development, however, is conceived as linear, heading toward a goal which is "virtually" contained in its antecedents and which exerts a kind of drawing power. The relationship here defined is teleological, the end exercising a persuasive, or erotic, dynamism upon the steps leading to its fulfillment. In this respect it differs from the schematism of absolute idealism in which the parts are prefigured in the whole from the very beginning, and it leaves some scope for understanding the reality of change and development. But the two accounts share the fundamentally Aristotelian conviction that the moving cause must be "richer" than the effect which it brings about, and that, where alteration takes place, it must be due to the imposition of form by an active principle upon something which, relative to it, is passive.

The order which organicists identify as a supra-elemental property of a living system, or what Weiss calls the superordinating principle of regulation, replaces the classic vitalistic principle, or entelechy. No longer substantive or energetic or "contrary to nature," it nonetheless marks a distinct break in the natural order of things, such that the science which deals with living things is and forever must be irreducible to and independent of the science dealing with the inanimate universe.[43] Here, as in all previous forms of vitalism, we

42. T. de Chardin, *The Phenomenon of Man,* (New York: Harper Torch Book, 1961).

43. There are, of course, more traditional expressions of vitalism still current. In a recent article entitled "In Defense of Vitalism" (*Journal of*

find a readiness to accept discontinuity in the universe and, accordingly, to deny the unity of science.

VI

It has been argued against the thesis I have defended that to preserve the terms "mechanism" and "vitalism" to refer to the disputants of modern biology is to introduce historical red herrings which will only obscure the issue by inviting irrelevant emotional and mystical associations. There is no doubt that such associations persist, and I hold no strong brief for the retention of the traditional terminology if in fact it is counterproductive. I do believe, however, that the rhetorical continuity reflects the ideological continuity which it has been my purpose to point out. I do not mean to shower any contemporary doctrine with abuse by labeling it as either mechanistic or vitalistic, but only to show that the philosophical orientations which led to the promotion of a mechanistic or vitalistic doctrine in the past are still with us today and still promote the formulation of theories which come in conflict over the same basic issues.

There is a contemporary movement which seeks to steer a course between the pitfalls of both traditional mechanism and vitalism. This is General Systems Theory, espoused by organicist biologists such as L. von Bertalanffy[44] and Paul Weiss,[45] and by cyberneticists following Norbert Wiener[46] and semanticists following Count Korzybski,[47] among others. According to this doctrine, physicalist reductionism is incorrect, but so is a vitalism which represents life as a phenomenon unique in the universe. General Systems Theory endorses a new concept of the unity of science, one which views the reality of the universe not as flowing from the simple laws holding among simple material particles, but rather as a struc-

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Theoretical Biology, 20 [1968] 338–340) D. Dix, a practicing biochemist, affirms that the relations within nonliving systems can be expressed kinetically and thermodynamically in terms of energy. But this is not the case for living systems whose parts are not exclusively energy-related but are related in terms of survival advantage. This suggests that life has a "nonmolecular goal" and leads Dix to the conclusion that "the force which is the drive toward the maximum benefit be called the vitalistic principle."

44. L. von Bertalanffy, "An Outline of General System Theory," *British Journal for the Philosophy of Science 1:* i, (1950–51), 134.

45. For example, "1 + 1 $\neq$ 2," *Interdisciplinary Topics* (1966).

46. N. Wiener, *Cybernetics* (New York, 1948).

47. A. Korzybski, *Science and Sanity*, 2nd ed. (New York, 1941).

tural unity replicating itself at many levels, where it constitutes a formal isomorphy within phenomenological distinctness.

> 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 organized entities, leading in a super-position of many levels, from physical and chemical to biological and sociological systems. Unity of Science is granted, not by a utopian reduction of all sciences to physics and chemistry, but by the structural uniformities of the different levels of reality.[48]

General Systems Theory agrees with vitalism in declaring the autonomy of biology. Biological concepts do not apply to lower levels of organization, and the phenomena represented by these concepts do exhibit modes of action which are specifically new relative to phenomena and actions at the preceding levels of organization. However, this break in continuity between levels is a common phenomenon, characteristic throughout the natural universe. It therefore does not mark off a singularity of life. The break between the living and the nonliving is no more mysterious than that between the electrons and atom, or atoms and molecules. In all of these instances, the whole is greater than the sum of its parts, and this turns out to be not an unscientific characterization, but a principle which applies to all systems and which is exactly formulatable as a law.

> 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 modern development. Thus, concepts such as whole-ness and sum, mechanisation, centralisation, hierarchical order, stationary and steady states, equifinality, etc. are found in different

48. L. von Bertalanffy (n. 44 above), p. 164.

fields of natural sciences, as well as in psychology and sociology.[49]

The notion of interactive systems, hierarchically arranged, and generally the problem of levels, merits deeper study than I can accord them here. The identification of a nonadditive whole, as opposed to an aggregate of parts seems to presuppose unspecified prior convictions. However, these problems, too, must be explored elsewhere and in a more general context. My purpose in bringing up General Systems Theory at this point is merely to acknowledge that there can be respectable alternatives to mechanism and vitalism. Whether these alternatives can wholly satisfy the historical dilemmas is a matter yet to be resolved.

VII

As a final point, I should like to make some observations regarding a dispute within the ranks of molecular biology itself. Even here, there is disagreement between those who seek explanations of biological phenomena wholly in terms of the configuration of structural parts and those who continue to expect "higher" laws which will account for organization in wholistic, or finalistic, or in some way super-ordinative fashion.

Recently, John Kendrew[50] distinguished between two schools of molecular biology. The first is a British group of structurists, whose work is descended from the crystallographic studies of W. H. and W. L. Bragg. They are primarily concerned with the three-dimensional structure of biological molecules, whose elaboration they believe will prove sufficient to explain the physiological function of cells. They hold that while a mere inventory of the chemical constituents is inadequate to account for the biological features of a gene or cell or organism, these features can be explicated in terms of a complete description of the relations which arise between these constituents as a consequence of their three-dimensional orientation. A complex protein such as hemoglobin or myoglobin, for example, is not simply a chain of amino acids insulated from its environment, but is a chain which curls in upon itself, and thereby produces a whole new set of relations contingent upon the interaction of its structural parts.

49. Ibid.

50. J. Kendrew, Review of *Phage and the Origins of Molecular Biology*, ed. J. C. Cairns, G. S. Stent, and J. D. Watson. (Cold Spring Harbor Laboratory of Quantitave Biology) in *Scientific American*, March 1967.

No appeal need be made to control by "ends" or "wholes," but it is clear that the behavior of every part is conditioned by its place within the whole and cannot be explained apart from it.

The second school of molecular biology, the informationists, grew around the work of Max Delbruck and Salvador Luria. This group denied the sufficiency of structural explanations of life and looked instead for hereditary explanations at the molecular level in the form of a one-dimensional molecular information carrier.

In the introduction to a book of essays dedicated to Max Delbruck on the occasion of his sixtieth birthday, Gunther Stent[51] affirms that the phage workers were in fact motivated by a "romantic idea" that living matter would turn out to be inexplicable in terms of the known laws of physics and would require the discovery of "other laws."

> Thus it was the romantic idea that "other laws of physics" might be discovered by studying the gene that really fascinated the physicists. This search for the physical paradox, this quixotic hope that genetics would prove incomprehensible within the framework of conventional physical knowledge, remained an important element of the psychological infrastructure of the creators of molecular biology.[52]

Rejecting the faith of the (mechanistic) British school that all biological phenomena, no matter what their complexity, could ultimately be accounted for in terms of conventional physical laws, the informationists regarded life as an elementary fact which cannot be explained, but must be accepted as the starting point in biology. According to a later discussion by Stent, the "romantic phase" of the informationists culminated in the discovery by Watson and Crick of the structure of DNA. It was followed by a dogmatic or academic phase in the course of which the practitioners in the field gradually abandoned the expectation that they would reveal the "other laws" of biology. Increasingly, all hope of paradox disappeared, and there remained only the necessity of ironing out the details of heredity.

> The only hope now left the veterans of the first phase was the hope that the central dogma might somehow prove to be untrue after all, in which case quest for the paradox could be resumed. But, as the work of that decade was to

51. G. Stent in *Phage and the Origins of Molecular Biology.*
52. Ibid., p. 4.

> show, the central dogma is essentially correct. No paradoxes had come into focus, no "other laws of physics" had turned up. Making and breaking hydrogen bonds seems to be all there is to the workings of the hereditary substance.[53]

As the prospect for "other laws" receded, many molecular biologists drifted away from the problems of genetics to other areas of investigation which might still offer a barrier between physics and biology. For many the study of the nervous system, evoking the old philosophical puzzles of the interaction of mind and body, represents the new frontier of biological research, and the last stand of vitalistic aspiration.

> The inability of even imagining any reasonable molecular explanation for such manifestations of life as consciousness and memory still offers some hope that biology may yet turn up some "other laws of physics." But it is also possible that study of the higher nervous system is bringing us to the limits of human understanding, in that the brain, being a finite engine, may not be capable, in the last analysis, of providing an explanation for itself. In that case, the paradox will have been found at last: there exist processes which, though they clearly obey the laws of physics, can *never* be understood.[54]

I cannot vouch for the accuracy of Stent's psychological analysis. Nonetheless, the suggestion that he makes seems very much in keeping with the historical evidence for the thesis which I have been arguing, namely, that in every generation, at every stage of scientific inquiry, investigators will divide themselves in accordance with a pattern which I have designated as vitalistic vs. mechanistic. I have argued that such opposing convictions are not the consequence of rational argument or the conclusions of examinations of evidence. They are psychologically prior to these and rather dictate to them in the form of attitudes and prejudices prior to inquiry. While one of these patterns of thought may gain temporary ascendancy within an individual or a civilization, its opponent inevitably arises in a new guise appropriate to contemporary issues. It is my contention that the mechanism–vitalism dispute is but one of a number of such fundamental disagreements which will be perpetuated as long as people ask questions and seek rational answers.

53. G. Stent, "That Was the Molecular Biology that Was," *Science 160* (1968), 390.
54. G. Stent, in *Phage and the Origins of Molecular Biology*, p. 8.