CHANCE, NECESSITY, AND PURPOSE: TOWARD A PHILOSOPHY OF EVOLUTION

by Jeffrey S. Wicken

Evolutionary interpretations of nature are quite ancient, dating back along with virtually everything else in Western thought, to the speculations of the Greek philosophers beginning in the sixth century B.C. But early evolutionary thinking never really went beyond this speculative stage, and evolution never provided a particularly compelling philosophy of biology until the time of Charles Darwin. Even now there are serious conceptual discontinuities in evolutionary theory, where its philosophical mission of unifying organic and inorganic nature is not fully realized. Whereas organic nature is pictured as purposive, self-serving, and, at least in its highest expressions, conscious, inorganic nature is conceived as behaving according to the blind mechanistic principles of chance and necessity. Even if the issue of consciousness is bracketed altogether, it is difficult to conceive of how mechanistic principles, which include no concept of purpose or of self, could ever have led to the evolutionary emergence of organized, self-referential systems.

Jean Lamarck's solution to this problem was a deist one: He assumed that the Creator had endowed matter with certain perfecting or self-organizing principles, beyond those of physics, that operated to generate life from inorganic matter and to evolve it to progressively higher forms.[1] Quite aside from his other, more historically problematic insistence on the inheritability of acquired characteristics, Lamarck's appeal to perfecting principles intrinsic to matter abrogated a fundamental metaphysical principle of the science of both his and our times, namely, that explanations for natural processes always be sought entirely in efficient causes of a demonstrable nature.[2] Since one can never deduce the complex and the organized from the simple and the unorganized without invoking the extra, formative principle of natural selection, Lamarck's program was philosophically unstable from the beginning. With the Darwinian formulation of natural selection, a basis for putting evolutionary explanations on efficient-causal

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[*Zygon*, vol. 16, no. 4 (December 1981).]

footing was provided, at least in principle. But even with this formulation there are serious difficulties in explaining the progressive character of evolution within an overall mechanist framework: Why should organizational complexity tend to increase if it seems to bear no direct relationship to survival and reproduction?[3] More fundamentally, how can one explain the emergence of life without relying, as Lamarck did, on undemonstrable perfecting principles in matter?

In view of the latter problem in particular, it is not surprising that most natural philosophers before Darwin saw creationism as the only philosophically sound way of bridging the conceptual chasm that separated organic and inorganic nature. No less critical a thinker than Immanuel Kant saw in the phenomenon of life the single clear indication of God's hand in nature.[4] Kant defined an organism in operational terms as a natural purpose—at once its own cause and effect.[5] This pithy and insightful definition has considerable utility in the philosophy of evolution. I will return to it later.

Kant considered the possibility of evolutionary change, but he ultimately rejected it because the blind laws of physics, which was the fundamental science of matter in the eighteenth century, seemed utterly powerless to account for the purposive organization of the organic world. With Darwin's careful documentation of evolutionary change and his formulation of the principle of natural selection, and with the subsequent plethora of evolutionary evidence from paleontology, anatomy, and molecular biology, the denial of evolution as a process is no longer a tenable option for most people. But if evolution as a process is now beyond doubt, the Kantian problem of life's origin remains entirely unresolved in modern evolutionary theory and shows quite forcefully its fundamental incompleteness.

Whereas creationism addresses in a forthright way the problem of sufficient cause in nature, modern evolutionary theory sometimes invites us to ignore this problem by its invocation of chance at the crucial juncture between life and nonlife. But creationism and chance share the same explanatory defect of regarding certain phenomena as somehow being beyond the necessary or logical structure of nature. If phenomena are connected only by a thread of chance or by the hand of God, the animate and inanimate worlds cannot be regarded as integrated aspects of a single unified nature. Rather they must be conceived as essentially autonomous domains of a nature that is theoretically fragmented. A coherent theory of evolution must therefore be one that includes life in the dynamic structure of nature in a lawlike way. To do this it must demonstrate that the Kantian natural purpose is a necessary consequence of materialistic principles. Much philosophic import in evolutionary theory therefore hangs on the meanings of chance, necessity, and purpose that it assigns to nature. I will examine the interpretations of these concepts in their earliest and most pristine formulations in Greek thought and then consider the manner in which they are tied together in the thermodynamics of evolution.

Chance and Necessity

Two powerful world views that have battled for Western man's intellectual soul over the past two millennia, mechanism and organicism, have their respective origins in the teachings of Democritus and Aristotle. Democritus was the archmaterialist and the archreductionist, in both respects a true patron saint of modern science. His teaching culminated two brilliant centuries of pre-Socratic thought that, in its distinction between the realms of opinion and knowledge laid the epistemological foundation of theoretical physics as it was to be followed over the centuries. The phenomenal world of change belonged to the realm of opinion, whereas a presumed underlying world of geometric laws and necessary connections belonged to the realm of true knowledge.[6] For Democritus this "true" world of necessary connections involved the blind, mechanistic motions of atoms in the void. In the Democritean view the natural philosopher must be able to make the epistemological plunge from the empirical to the theoretical, from the world of sense and quality to the world of number and geometric form.

In addition to the assumed blindness and lawlike character of atomic motions, the Democritean program acknowledged a certain epistemological meaning of chance in the dynamics of the universe that expresses the statistical nature of these motions.[7] Certainly, if the universe is conceived as being deterministically structured through blind mechanistic laws, chance can have no possible ontological role in its operation (the issue of quantum indeterminacy is bracketed here). Perfect ontological determinacy was in fact the Laplacian claim: If we somehow could know the microcausal configuration of the universe at some point in phase space (i.e., the positions and momenta of each particle), then all past and future configurations could be derived from this configuration in the manner of a geometric demonstration.[8]

But in the Democritean program, which extended its precepts into classical physics, chance was not understood in its ontological sense as a breach of determinism but rather as a problem of epistemological access, of negotiating the gulf separating the macroscopic, experienced world from the microscopic world of necessary connections. This is the point of view elaborated by Jacques Monod in his modern-day Democritean treatise, *Chance and Necessity*: Given the macroscopic information provided by thermodynamic-state specifications, there are vast numbers of alternative microcausal configurations that are equally possible; therefore knowing the former does not allow one to predict (or retrodict) the deterministic microevents involved in the emergence of life and in organic evolution.[9] Here chance means epistemological indeterminability, and its use reflects the need to treat microevents in a statistical way.

Another aspect of the chance-necessity problem concerns the relationship between process and law. The derivation of a physical process requires more than an appropriate mechanistic law; it requires also an independent specification of the initial configuration on which this law will operate but which is itself outside the explanatory power of this law.[10] We cannot, for example, derive the present motions of the planets from the laws of celestial mechanics alone but need also some independent information about an initial state of motion, or phase-space configuration, to which these laws might be applied. In general, these starting points for mechanistic demonstration can be sought in any of three metaphysically independent sources: creation, chance, or law. Of these alternatives, only chance fails to deal in a forthright way with the problem of sufficient cause. Indeed the invocation of chance at crucial junctures between theory and phenomena sidesteps this issue completely. In spite of this serious omission, we are invited by Monod and others of his particular reductionist persuasion to regard the chance-necessity metaphysic as the "light and the way" of objective science.

Monod's position is that life can be regarded essentially as a hereditary mechanism that is able to propagate itself more or less faithfully through the synergistic action of proteins and nucleic acids which catalyze each other's production. The hereditary mechanism is thus a molecular version of Kantian natural purpose, and any explanation of its origin must deal with the problem of causal sufficiency in a clear and nonevasive way. Monod's solution is to attribute the hereditary mechanism to chance, that is, to an incredibly improbable chain of microevents, so improbable as to constitute perhaps an utterly unique occurence in the history not only of Earth but of the entire universe as well. Given this incredible chain of events as a starting point, life is then considered to have elaborated around the hereditary mechanism through the necessity of natural selection: Any randomly appearing structure or mechanism that increases its propagative powers will necessarily accumulate in the biosphere. All biological functions and faculties, including that of consciousness, are thus conceived by Monod to emerge when the right associations of matter by chance occur, according to their contributions to the viability of the hereditary mechanism. Life in this view is essentially alien from the rest of nature, a magnificent accident that follows from the chance appearance of a certain molecular mechanism. The philosophic implications of this metaphysic are profound, and Monod does not shrink from developing them to their full, unhappy conclusions. But because of its unwarranted use of chance as an explanatory category, the Monodian metaphysic is unsound at a fundamental, philosophic level.

The question that must be considered at this point is the legitimacy of chance as an explanatory category in evolution. Where is its use proper, and where is it fraudulent? Chance is central to neo-Darwinian thinking, and within the strict bounds of organic evolution per se it is an entirely legitimate and essential concept. Indeed the concept of random mutation has a firm theoretical basis in statistical thermodynamics, being a necessary consequence of the second law, which forbids error-free replications in the same way that it forbids perfect crystals. Chance in this statistical sense is therefore an essential part of neo-Darwinian theory, which seeks no further reduction to deterministic laws. Chance works within the confines of neo-Darwinian theory because it does not lead to an abrogation of the sufficient cause principle. Given a population of organisms that are already purposively organized into the modern genotype-phenotype dichotomy for survival and reproduction, chance mutational events together with some (weakly specified) mechanism that translates genotypes into phenotypes provide sufficient conditions for the generation of those phenotypic variants on which natural selection operates.

On the other hand, the extrapolation of this principle to the emergence of life does not occur within the guidelines for causal sufficiency. In the neo-Darwinian interpretation of evolution, the flow of variant-producing events is, however loosely, mechanistically understood on the basis of a preexistent translation mechanism that gives genotypic alterations phenotypic expressions. But since the flow of events leading to the evolutionary emergence of the hereditary mechanism itself is unknown, the invocation of chance at this juncture has no statistical meaning whatever; it simply begs further explanation in the same way as would the invocation of creation or of immanent purpose in nature. In any case, the sufficient cause issue in the emergence of life must be dealt with through the formulation of a richer, more comprehensive set of evolutionary laws than the present Democritean metaphysic can deliver.

Purpose in Nature

There has always been an affinity between atomism and evolutionism because of the incommensurability between "blind motions" and fixed forms. If all that exists in nature is due to the blind motions of atoms and their selective patterns of coherence, no given species should have any more claim for continued viability than what is justified by its own powers for self-maintenance. There is therefore a survival-of-the-fittest kind of natural selection implicit in Democritean thinking, which is made more explicit in the later writings of Lucretius, who speaks of species of organisms as continually coming into existence and passing into extinction.[11] Organisms are not of course passive collections of atoms. They are purposively organized for their own survival and reproduction, a fact of which Democritus seems not to have been ignorant.[12] But the concept of purpose in the Democritean program is strictly a derivative and secondary one: It is a teleonomic attribute of life that emerges with the chance appearance of self-regulative properties.

In Monod's treatise this protocybernetic concept of life is identified with the hereditary mechanism. Once this mechanism emerged, natural selection began to preserve those further elaborations of chance that enhanced its propagation in the biosphere. Biological purposes, whether instinctual or conscious, are all selected as aids to the propagation of the hereditary mechanism. The concept of a self as an organizational and valuational center of life, to which purposes are referred and through which they are given meaning, is strictly a cybernetic one, with the hereditary mechanism at the helm. This view of life is deeply unsatisfying to most people of humanistic bent and is responsible for much modern ambivalence toward evolutionary theory.

But, as discussed previously, the chance-necessity doctrine is secured in rather loose philosophical soil. Neo-Darwinism too often supposes the coincidence of objective science with Democritean mechanism and too often insists that we explain all phenomena of organic nature under the latter's metaphysical umbrella. This approach is what Marjorie Grene has referred to as the "faith of Darwinism," its willingness to explain by stipulation or legislation what the demonstrable powers of its own principles cannot.[13]

To provide a less reductionistic basis for evolutionary explanations, inorganic nature must somehow be elevated or vitalized to include, at least in nascent form or potency, the essential categories of life. In particular the concept of purpose must be woven more securely into the ontology of nature than is allowed in the Democritean program. The Aristotelian approach, though quite thoroughly (and, to my mind, excessively) discredited by modern science, frames this issue of purpose in a way that is very germane to the philosophy of evolution.

The methodological development of modern science has been based to a large degree, on the systematic denial of purpose as a fundamental ingredient in the dynamics of nature. This program began in the seventeenth century for very sound reasons: Since purposes are in principle only inferable and are forever beyond the powers of objective science to confirm or dispute, their assumption is at best irrelevant to the enterprise of science and at worst a very serious barrier to its free empirical inquiry into the general laws of nature.[14] Thus Aristotelian teleology, which regarded all natural phenomena as occurring for some final cause or purpose, was antithetical to mechanistic science's aims as they began to be perceived by Galileo, René Descartes, and Francis Bacon. This caveat aside, there are some extremely powerful features of Aristotelian biology that provide excellent antidotes to the excesses of mechanistic thinking that currently abound in evolutionary theory.

In contrast to Democritus, Aristotle insisted always on the non-resolvability of natural phenomena into simpler, materialistic elements or components. Since there was in the Aristotelian program no concept of a mechanistically connected infrastructure in nature to which necessary laws might have applied, no epistemological leaps were required in moving from the sensible to the true. The sensible was the true, and each phenomenon in nature had to be understood as a whole in its full qualitative richness. The tension between holism and reductionism in the philosophy of biology begins here, and the latter has developed ever since within its resultant fissures.

Aristotelian organicism is the metaphysical converse of Democritean mechanism since it begins with the categories of organic nature and applies them to the physical world. Purpose is considered to be that ingredient in nature that is responsible for orderly, end-directed change, as exemplified paradigmatically by biological development: One cannot deduce the epigenetic pattern of the oak's development from the structure and material composition of the acorn without appealing also to some immanent "good" or purpose served by that developmental process, namely, the actualization of a preestablished adult form that existed potentially in the acorn at the time of its germination. For Aristotle all change involved this striving of substances after their proper forms.[15]

Aristotle liked to use analogies from art to illustrate his philosophy of nature. The sculptor begins with a purpose in mind, which he translates into some form he hopes to achieve. Only then does he select tools and materials appropriate to the job. If this logical priority of purpose and form over means and material is evidenced in our own imperfect art, it surely is no less true of nature's.[16] All explanations for natural processes therefore must proceed hierarchically downward from purposes (which may be identical with their forms) to efficient and material causes. Biological wholes are thus logically prior to their anatomical parts, for the parts achieve their meanings only with respect to the operation of the whole. Further, what is essential to the whole must have logical precedence over what is merely accidental or incidental to it. In man the intellect is logically prior to the manipulative digits of his hand; the latter serve the needs of the former, rather than vice versa.

Aristotle used these concepts of wholes and parts and of essences and accidents to muster powerful arguments against the evolutionary speculations of his pre-Socratic predecessors, who regarded new biological properties and functions as emerging when the right combinations of matter had been achieved.[17] How can the logically anterior be ontologically posterior? Only by according infinite generative powers to chance does the neo-Darwinian program escape (or sidestep) this fundamental objection to the emergence of new anatomical parts and abilities. It might be noted parenthetically that such cultural analyses of human evolution as Lewis Mumford's *Myth of the Machine* would seem to support the Aristotelian position that the essential cannot be generated from the secondary, that the evolution of the human mind cannot be explained simply by appealing to the selective premium on handling tools, but that it must involve also the higher demands of language and symbolic representation.[18]

The fact that over two millennia separated Aristotle and Darwin is in part a measure of just how strong and logically comprehensive the Aristotelian philosophy of biology was, and Darwin's own analysis of evolutionary change pays careful attention to Aristotelian principles. Indeed Darwin's rejection of macromutation as a source of evolutionary change is evidence of his own insistence on the priority of the whole (its fitness) over its parts in determining the course of evolution.[19]

Irreversibility and Necessity

Although particular evolutionary pathways meander in all directions according to the opportunities presented by nature, there is nevertheless an overall, large-scale orientation of the evolutionary process that points from the simple and slightly organized to the complex and highly organized. Although progressive evolution is certainly not incommensurable with natural selection as the sole orienting principle in evolution, neo-Darwinism with its Democritean metaphysics is not entirely comfortable with this phenomenon and has not sanctioned it with general explanations.[20] The reason, at least at a philosophical level, has to do with the Democritean perspective on the nature of time. Central to the development of the Democritean world view in classical physics was the elimination of time as a fundamental ingredient in nature by treating it as a kind of spatialized coordinate along which events occurred by virtue of their configurations in phase space.[21] Thus in this perspective time is really a perceptual phenomenon, having to do with the irreversible and cumulative character of biological development and personal experience, a fact that itself tends to separate the organic and inorganic worlds.

In a temporally open-ended Democritean cosmos, time can be assigned its direction only on the basis of biological irreversibility. But with respect to physical changes, this direction is entirely arbitrary. If atomic motions are blind, then given configurations are bound to recur over the infinite stretches of time available to the cosmos. But these sequences of events are not irreversible in any lawlike way; they could be reversed by the conceptually simple expedient of reversing the positions and momenta of all atoms involved.[22] Classical physics deals only with reversible motions; its laws are invariant with respect to time reversal and can be used for retrodiction as well as for prediction. So unless one subscribes to a Newtonian view of time as something "real" independently of the occurrence of actual events in nature, time in a Democritean cosmos has direction only by virtue of the biological irreversibility that we use to order perceptual events.

Neo-Darwinian metaphysics is essentially this timeless one of classical physics, so that the progressive character of evolutionary change must be seen as superimposed on a substratum of in-principle reversible microevents, an understanding that places very heavy demands on natural selection as an orienting principle. Of course natural processes are irreversible, as mandated by the second law of thermodynamics, and a coherent view of nature requires that evolutionary direction be connected in some lawlike way to the irreversible thermodynamic flows occurring through the biosphere. Considerable progress toward a thermodynamic theory of evolution has been made in recent years.[23] However, the philosophic controversy between the second law and evolutionary self-organization is one that runs quite deep and requires additional clarification.[24] It turns out that many of the issues that face a thermodynamic theory of evolution concern the interrelations of chance, necessity and purpose which one sees in nascent, prescientific form in the thought of the pre-Socratic philosopher Empedocles.

The Empedoclean vision did not generate the same level of scientific and philosophic elaboration as did those of Aristotle and Democritus, perhaps because of its treatment of time as an irreducible reality in the cosmos. Ever since Parmenides, this has not been a popular theme in Western thought. However, precisely because of its treatment of time, the Empedoclean world view provides a very suitable philosophic nest in which to locate a thermodynamic theory of evolution.

Empedocles is best known as the originator of the concept of the four "roots of matter" as compositional elements from which the diversity of the world was generated. He is in this sense a materialist, attributing all sensible properties of substances, including those of organisms, to elements combined in certain proportions. But it is necessary to qualify this assessment somewhat: Matter for the Greek philosophers was never dead or inert, as it became later in classical physics, but included all the potencies for life.

The Empedoclean cosmos included a dynamic law that worked at the macroscopic level to give time a fundamental directionality. This macroscopic law, which was a philosophical harbinger of the second law of theremodynamics, resulted from the continually changing mix of two mutually excluding associative and dissociative principles (love and strife) which entered and exited the universe according to a fixed cosmic clock. Love promoted the intermingling of the different elements in certain numerical proportions; strife promoted their segregation.

Balances of love and strife are required for the existence of discrete substances having individualized properties: When the cosmos is saturated with love, all elements bind together homogeneously; when it is saturated by strife, they separate out completely. So the changing mix of these two principles constitutes the creative force in the universe, a macroscopic flow of necessity that provides for a kind of selective chemical affinity between the elements that changes with the passage of time. These elemental combinations are understood in a Pythagorean way, with certain allowable numerical ratios of elements being correlated with particular forms or structures.[25] It follows from this that the problem of generating the various substances of nature, including organisms, was one of combining elements in the proper ratios.

This world view requires evolution as a corollary because as the proportions of love and strife change according to the macroscopic flow of necessity, so too must the kinds of substances or entities that are stable. The evolutionary scheme described below is taken from Giorgio de Santillana's excellent discussion of Empedoclean thought.[26] The cyclic movement of love and strife is represented by the movement of a clock such that at noon love is completely dominant and at midnight strife is completely dominant. At neither of these points do individual substances exist. At noon all elements blend in a homogeneous mixture; at midnight they segregate completely into their own pools. Individual substances require the selective elemental interactions that derive from the opposing tensions of love and strife.

Each half-cycle, from midnight to noon and from noon to midnight, represents an evolutionary period. The period beginning at midnight with love on the ascendancy looks somewhat silly from a post-Aristotelian perspective and provides an instructive parody of excessively mechanistic treatments of evolution. As love begins to enter this strife-saturated cosmos, certain elemental ratios become stabilized and their corresponding structures coalesce from the heretofore segregated elements. These structures include all varieties of disembodied anatomical parts, which combine in haphazard ways to form patchwork monsters of low viability. Those combinations that turn out to work well together are selectively preserved through their fitness advantages. This view, similar to the Democritean view, regards biological functions and purposive organizations as "emergent": They appear when the right combinations of matter are attained.

The second half-cycle is more interesting and more subtle and captures much of the progressive flavor of evolution pointed out by Herbert Spencer as a process that moves from the homogeneous and indefinite toward the complex and differentiated.[27] It also fits quite well with the thermodynamic view of evolution to be discussed presently. As strife enters the world, certain "whole-born," proto-organisms begin to differentiate from the world's homogeneous elemental mix. These structures are not organisms in the modern sense since they require none of the organized survival functions of life. The dominance of love at this point assures the stability of mixed substances of all allowed proportions; the environment is "friendly" and supportive of life, somewhat analogous to the energy-rich organic oceans thought in recent times to have spawned the first organisms. Because of this abundance and easy exchange of matter, there is no need for the high levels of biological organization required to support life's present sophisticated survival functions, just as there is no need for elaborate metabolic pathways in an energy-rich organic soup. Differentiation occurs as a consequence of increasing strife: As strife becomes more influential, the environment becomes less hospitable, less nutritive, and life begins to assume its modern biological character, in which specific kinds of purposive organizations are required to support survival. Organizational complexity comes from environmental scarcity in this view, a view that is commensurable with modern understanding, although such terms as "organization" and "complexity" are admittedly read into Empedocles' work with some metaphorical license.

Nowhere in his teachings does Empedocles speak of "brute matter" in the Cartesian sense; Empedocles saw the biosphere as emerging under the differentiating influence of increasing strife due to the inherent potencies for form of the elements combined in particular numerical ratios. The organic and inorganic realms are thus knit by the irreversible flow of necessity and the informing power of number. This irreversible flow establishes a clear relationship among chance, necessity, and purpose that is formally maintained in the thermodynamic treatment of evolution to be discussed presently.

The Democritean program acknowledged only a mechanical kind of necessity based on deterministic atomic motions. But the processes mediated by these motions occurred by chance in the sense that they depended on "accidental" initial configurations. The Empedoclean program, by contrast, brings evolutionary events into the realm of necessity by connecting in a quasi-statistical manner the macroscopic flow of love and strife to the microscopic combination of elements. Chance still plays a role in the generation of specific substances, including organisms, which must always occur according to the opportunities provided by nature. But the ambient love-strife level determines which elemental ratios, along with their structural correlates, will be stable at any given time. These Pythagorean ratios are built into the formal structure of the cosmos, rather like chemical valences. As strife increases, the number of stable combinations diminishes, and natural selection ensues, leading to the evolution of increasingly differentiated structures. Evolutionary processes, including the emergence of life, are thus consequences of necessity because increasing strife determines the conditions under which the Pythagorean logos can be expressed. Chance is involved in the details of the evolutionary process but not in its overall character from the homogeneous to the differentiated.

The role of purpose in this scheme is intermediate between its role in the Democritean and Aristotelian schemes discussed previously. Teleological processes, in which substances "strive" to fulfill certain purposes immanent in nature, are not acknowledged. Necessity is blind, and love and strife can be regarded as having only the generalized, impersonal purposes of integration and separation. Life emerges as a harmonious expression of the tension between these opposing general purposes in a way that includes it within the overall dynamics of nature. Particular biological purposes that appear during evolution serve the general cosmic ends of necessity by promoting the stabilities of those organisms whose elemental ratios and consequent organizational features are most in tune with prevailing love-strife levels. Those species of organisms that prevail under given love-strife levels must be those that are purposively organized to maintain their proper elemental ratios under those conditions through discriminating interactions with the environment. In de Santillana's analysis, Empedocles conceives of this interaction as a kind of "resonance" of like elemental ratios between organism and environment mediated by the integrating power of love. With love dominant in the world, many elemental ratios are stable and there prevails an intimate, nutritive resonance between organism and environment. But as strife enters more fully, this easy coherence is interfered with, and differentiation and specialization are required to maintain given elemental ratios. Thus biological functions appear as derivative purposes that maintain the integrity of life under inhospitable circumstances. At the same time the organizational correlates of these biological functions are themselves physical expressions of given love-strife levels because their degree of differentiation is proportional to the selectivity of their function.

There is a second dimension to this interweaving of life and necessity in Empedoclean thought. Biological purposes are not only the results of necessity; they also provide means by which its ends are attained by helping mediate the passage of love and strife through the cosmos. De Santillana's example of the particularization of love as Eros illustrates this well: The aim of love is harmony and coherence, but its manifestation must serve not only the transient interests of love but also those of increasing strife. Accordingly Eros's integrative work is accompanied by balances of jealousy and separatedness. So biological purposes are both created and bound by necessity, which though blind in microscopic detail is macroscopically determinate and intolerant of deviations from proper cosmic balances. The inviolability of these balances and their bounding of individual destinies constitute a theme in Greek thought that permeates its literature as well as its philosophy. But the important point here is that the Empedoclean interpretation of life implicitly solves the Kantian problem. Organisms may be understood as natural purposes but in a sufficiently comprehensive way to integrate them with the rest of nature, since organisms are not only their own causes and their own effects in this perspective but also the causes and effects of necessity's impersonal flow. I will return to this idea presently in a thermodynamic context.

To recapitulate, three points of view with respect to the meaning of purpose in nature have been thus far distinguished. The Aristotelian view that nature is itself purposive in all its particular expressions has been quite properly rejected by science as antagonistic to its objective aims. The more prevalent Democritean view regards purposes as emergent consequences of biological self-perpetuation and in its neo-Darwinian incarnation refers to the emergence of teleonomic organization around a replicative mechanism. The third, the Empedoclean point of view, seems to bridge these two positions, with biological purposes being both particular expressions and means of necessity's impersonal flow. Biological purposes thus serve not only individual survival needs but cosmic ends as well.

Necessity and the Second Law

The Empedoclean world view would seem to offer rich soil for the development of a comprehensive philosophy of biology. Its treatment of the inner, perceptual dimension of life is materialistic but never reductivistly so: Matter is never "dumb" for Empedocles, and all nature enjoys a kind of cosmic sentience based on Pythagorean harmonies. Bracketing these suggestive observations, what is of interest here is that Empedocles' treatment of chance, necessity, and purpose is one that readily lends itself to thermodynamic elaboration. The necessity of increasing strife is formally analogous to the necessity of increasing entropy, and the differentiation of the cosmos in response to increasing strife is paralleled by its differentiation in response to increasing entropy. The production of entropy can be regarded as a kind of general purpose in nature, whose end is maximum randomization of matter and energy among available quantum states. The routes for matter-energy randomization are for the most part associative, complexity-generating ones, since it is through such processes that potential energy resulting from the forces of nature can be randomized as heat.[28] The second law of thermodynamics provides for an essentially Empedoclean integration of organic and inorganic nature by establishing the initial conditions under which the microscopic determinacy of atomic-molecular events occur and by providing a solution to the Kantian problem of how natural purposes emerge from blind laws.

As noted previously, the directions of the microscopic processes that contribute to evolutionary change are regarded in the Democritean, neo-Darwinian program as accidental in the sense of depending on some prior phase-space configuration that cannot be derived from mechanistic laws. To bring the evolutionary emergence of life into the realm of law, these initial phase-space configurations or microstates must be shown to be not accidental at all but derivative of the macroscopic, thermodynamic conditions of the biosphere. It is heuristically useful in this argument to consider physicochemical transformations as occurring in a kind of two-dimensional probability space (*W* space) with one coordinate axis representing the thermodynamic macrostates available to a system and the other representing the number of alternative microstates or phase-space configurations available to each macrostate. Provided that their microscopic motions are indeed blind (the stochastic assumption), macroscopic systems are a priori obliged (neglecting statistical fluctuations) to maximize their volumes in this *W* space, to move toward that condition of equilibrium characterized by a maximum spread of matter-energy among its various microstates.

The microevents that contribute to the evolution of a thermodynamic system, including the biosphere, can be attributed to chance only to the extent that they conform to the probability distributions that characterize the equilibrium condition. At equilibrium all microevents occur with the same probabilities as their mirror images in phase space. But the more remote a system is from equilibrium, the more these microevents deviate from their probabilistic distributions. Chance thus gives way to necessity as systems approach their maximum compression in *W* space. The greater a system's compression in *W* space, the greater its potency for irreversible change. What this means on a microscopic level is that the initial conditions for microevents are not arbitrary or accidental at all; they are stacked such that given configurations in phase space are more probable than their mirror images. Hence a system's compression in *W* space gives statistical force to evolutionary microevents. Chance and necessity are thus not mutually exclusive concepts but extreme positions on a continuum of varying statistical force.

The biosphere as a whole is maintained in a condition of high thermodynamic potency or *W*-space compression by its impressed energy gradient resulting from solar radiation influx and the thermal sink of space.[29] This energy gradient establishes the general thermodynamic boundary conditions for evolution by determining what the general channels for entropy production in the biosphere can be. The entire macroscopic character of the evolutionary process can be regarded as an extension of Le Châtelier's principle, whereby a system's internal dynamics must adjust to applied forces or energy gradients.[30] Chemical potential energy is generated continually in the biosphere via photon absorption. The dissipative transformation of this energy to heat transferred to the thermal sink of space is the biosphere's thermodynamic arrow, which serves to propel the evolutionary process in its movement from the simple and unorganized to the complex and highly organized.[31] A principal means for dissipating potential energy in the biosphere is provided by chemical bonding, which links atoms in complex structures. The continual generation of potential energy in the biosphere therefore requires the generation of complexity as a means of relieving the applied energy gradient. As complexity increases, the entropic payoff for additional increases diminishes. Thus the biosphere must evolve toward some stationary state of maximum complexity and minimum specific entropy production.[32] The latter conclusion was demonstrated by Ilya Prigogine for linear thermodynamic systems but would seem to have general applicability to nonlinear systems as well.[33]

The Emergence of Life

We come now to the heart of the connection between the Empedoclean metaphysic and the thermodynamics of evolution, namely, the sense in which the emergence of life is an expression of both chance and necessity. A thermodynamic integration of organic and inorganic nature solves the Kantian problem in the following way. The general cosmic purpose of entropy production or *W*-space expansion required the elaboration of life as stable patterns of entropy production. The concept of an organism as a stable pattern of entropy production is not a usual one and is developed below.

If the biosphere were an isolated thermodynamic system, its evolution would have been determinate since all microscopic routes would have led inevitably toward the equilibrium condition of maximum disorder. Patterns of entropy production are accordingly not stable in isolated systems; they require a supporting energy gradient. By virtue of its applied gradient, the evolution of the biosphere proceeds through entropy-producing patterns or reaction routes of varying stability. Organisms, populations, and societies may all be regarded in a thermodynamic sense as patterns of entropy production whose stabilities are maintained by certain purposive internal organizations. Such organizations are selected according to the stabilities of their entropic patterns.

Entropic patterns occur in the evolution of the biosphere due to the operations of chance: The chance occurrence of one microevent provides a potential starting point for another. Evolutionary microevents are given statistical forces to the extent that they promote entropy production or *W*-space expansion. But to the extent that these events are not strictly necessary, particular chains of evolutionary events must occur according to the chance opportunities provided by nature. As patterns of entropy production maintained by teleonomic internal organizations, organisms are natural purposes in the broad Empedoclean sense, that is, not only their own causes and effects but also the causes and effects of necessity's entropic flow. The propagation of certain patterns over others is the thermodynamic meaning of natural selection.

Natural selection is in fact a necessary consequence of the nature of the biosphere's thermodynamic flows. The biosphere does not passively mediate its flow of energy but transforms it as well through various chemical reaction routes or patterns of entropy production. There are vast numbers of possible reaction routes available to the biosphere, but their occurrences are kinetically limited by the energy barriers to transformational processes. The catalytic lowering of certain of these barriers allows for the selective propagation of particular reaction routes or patterns over others in the biosphere's overall thermodynamic evolution. Those patterns that propagate do so by virtue of enzyme catalysis, which emerges necessarily in the course of the biosphere's evolution toward increasing chemical complexity.

Natural selection is tautological at its core, as many have pointed out in recent years. It remains so in this thermodynamic interpretation: Those patterns of entropy production that propagate will be those that provide the best routes for entropy production, as assessed by their propagation. So, in this sense, natural selection is both a logical and a thermodynamic necessity. The Kantian conception of natural purpose is essential here in bringing the emergence of life into the realm of thermodynamic necessity: To be capable of propagation in the biosphere, certain reaction routes not only must be kinetically facilitated through appropriate enzyme catalysis; the specific catalytic activities involved also must be generated as integral parts of these thermodynamic flow patterns. Reaction routes capable of propagation therefore must be natural purposes themselves, that is, their own causes and effects, in turn requiring their gradual elaboration of the genotype-phenotype dichotomy that is the organizational basis of life. The precise sequence of events involved here is not known and is perhaps ultimately unknowable, although a number of very reasonable scenarios have been suggested.[34]

But the issue here is not the probability of particular scenarios having actually contributed to the emergence of life but rather the sense in which the emergence of natural purposes with genotype-phenotype organizations was as a general phenomenon promoted by the necessity of entropy production in stable patterns. Stable, propagating reaction pathways promote the cosmic end of entropy production and occur therefore as mechanisms in the biosphere's overall thermodynamic evolution. Given the physical and chemical properties of abiotic proteins and nucleic acids, especially their mutually stabilizing interactions and the template-catalytic effects of nucleic acids on amino acid polymerization, the potencies of these molecule types certainly included the generation of a genotype-phenotype replicative mechanism, provided that a thermodynamic, natural-selective mandate for such a mechanism existed.[35] And it did. Those reaction pathways that tended to propagate in the biosphere and to acquire their own autonomous stabilities were those that best exploited these chemical dispositions of proteins and nucleic acids to become synergistically involved in each other's synthesis.

As in the Empedoclean picture, biological purposes arise in this thermodynamic view of evolution both as results of the blind purpose of entropy production or necessity and as the means by which this cosmic purpose is achieved in the biosphere. Entropy production is served by systems that mediate the dissipative transformation of chemical potential energy into heat. There must then be a selective preservation in the biosphere of those reaction systems or pathways according to their abilities to mediate dissipative processes. Thus the overall flow of energy through the biosphere must inevitably increase, barring cataclysmic accidents, toward some maximum value over the course of its evolution, as was pointed out originally by A. J. Lotka.[36] The maximization of total energy flux in turn requires the maximization of energy-transforming units in the biosphere, and in its various ecosystems, to their respective carrying capacities.

It should be noted that maximization of total energy flux is entirely commensurable with the minimization of specific entropy production referred to previously, as has been pointed out also by H. J. Hamilton.[37] Whereas the number of energy-transforming systems in the biosphere tends to a maximum, their mean entropic dissipation tends to a minimum as transformational processes become more efficiently coupled to the generation of the transforming organization itself. Two general thermodynamic ingredients in natural selection emerge from this, which are exploitative power (maximum flux) and efficiency (minimum dissipation). And correspondingly there are two distinct thermodynamic strategies in evolution. The first involves diverting large shares of the biosphere's energy flow into survival and reproduction; the second involves utilizing this flow efficiently for this end. Any new mechanism, species, or technology that increases the biosphere's total energy flux or that reduces its specific dissipation will have found a niche in nature and will be selectively preserved.[38]

Of course, the aptness of one or the other of these strategies depends on prevailing thermodynamic conditions. For ecosystems that are remote from their steady states of maximum flux, exploitation would seem to be the best strategy for genotypic propagation; but once this steady state has been achieved, further evolutionary change must occur through increases in the efficiency with which energy flows are coupled to the generation of its transforming organizational elements. So a given density of energy flow through the biosphere, and through any of its components ecosystems as well, will tend to weave through an organizational network (biological and sociotechnological) of increasing complexity. This idea is implicit also in Harold Morowitz's discussion of the increasing "residence time" of energy in the biosphere as its evolution proceeds.[39] This analysis is germane in a predictive way to the progress of technological evolution. For most of its history, technological evolution has been guided by the "maximum flux" principle, with efficiency being very much a secondary consideration. But with the imminent exhaustion of fossil fuels, steady-state energy flows may soon be upon us, and further technological evolution will then be dominated more and more by the minimum dissipation principle of utilizing the biosphere's natural thermodynamic flow ever more efficiently.

The general point to be made here is that natural selection should not be understood simply as the result of competition among organisms for the biosphere's resources to support their own survival and reproductive ends. It is that of course; but the thermodynamics of the biosphere's overall evolution prescribes the general form this competition must take, and what the thermodynamic ingredients in survival and reproductive strategies must be. These evolutionary strategies are the shapers of specific biological purposes and must be understood not only from the limited, self-referential perspective of particular organisms, species, and societies but also from the cosmic perspective of entropy production.

I should emphasize, as a concluding caveat, that this thermodynamic-Empedoclean integration of organic and inorganic nature through the evolutionary process makes no metaphysical claims whatever about the reducibility of life to the categories of matter, and particularly not to the categories of matter understood in the sciences of physics and chemistry. It claims only that if we understand organisms as natural purposes, whose organizations are both the causes and the effects of certain patterns of entropy production, the emergence of such organisms can be understood to be a necessary consequence of thermodynamic laws and the conditions under which they operate in the biosphere. But there is nothing in this definition that refers to the "inner," perceptual dimension of life and no reason whatever to assume that this inner dimension will ever be reduced to even an expanded set of physical principles available in the future. For the evolutionary process to be a coherent one, these inner dimensions of life must emerge somehow from the various potencies of matter. But we can only speculate as to what these potencies might be.

NOTES

1. R. A. Burkhardt, *The Spirit of System: Lamarck and Evolutionary Biology* (Cambridge, Mass.: Harvard University Press, 1977), pp. 143-85.
2. See, e.g., Bertrand Russell, *Wisdom of the West* (New York: Crescent Books, 1959), p. 88.
3. See, e.g., Ludwig von Bertalanffy, "The Model of Open Systems: Beyond Molecular Biology" in *Biology, History and Natural Philosophy*, ed. A. Breck and W. Yourgrau (New York: Plenum Press, 1972), pp. 17-30.
4. Immanuel Kant, *Critique of Judgement*, ed. R. Hutchins (Chicago: Encyclopedia Britannica Inc., 1952), chap. 65.
5. Ibid., chap. 66; see also C. U. M. Smith, *The Problem of Life* (London: Cambridge University Press, 1976), pp. 223-29.
6. Efforts to reduce laws of nature to laws of mind begin as far back as Pythagoras. For a philosophical discussion see Henri Bergson, *Creative Evolution*, trans. A. Mitchell (New York: Modern Library, 1944), pp. 230-40.
7. See, e.g., Giorgio de Santillana, *The Origins of Scientific Thought* (Chicago: University of Chicago Press, 1970), pp. 141-67.
8. See, e.g., Bergson.
9. Jacques Monod, *Chance and Necessity*, trans. Austryn Wainhouse (New York: Vintage Books, 1971).
10. See, e.g., David Bohm, *Causality and Chance in Modern Physics* (Philadelphia: University of Pennsylvania Press, 1971), pp. 20-25.

11. Lucretius, *On the Nature of the Universe*, trans. R. E. Latham (Baltimore: Penguin Books, 1951), p. 197.
12. De Santillana, p. 155.
13. Marjorie Grene, *The Knower and the Known* (London: Faber & Faber, 1966), pp. 185-201.
14. E. A. Burtt, *The Metaphysical Foundations of Modern Science* (Garden City, N.Y.: Doubleday & Co., 1932), pp. 98-104.
15. Aristotle *Physics* 198a.
16. Aristotle *Metaphysics* 5.2. 1013a 24-1014a 25; see also de Santillana (n. 7 above), pp. 214-16.
17. Aristotle *Physics* 198b.
18. Lewis Mumford, *The Myth of the Machine* (New York: Harcourt, Brace & World, 1967).
19. Soren Lovtrup, "On the Falsifiability of Neo-Darwinism," *Evolutionary Theory* 1 (1976): 267-83.
20. See, e.g., Julian Huxley, *Evolution: The Modern Synthesis* (London: Allen & Unwin, 1942).
21. See, e.g., Milic Capek, *The Philosophical Impact of Contemporary Physics* (New York: Van Nostrand-Reinhold, 1961), pp. 121-34.
22. P. C. W. Davies, "Cosmological Aspects of Irreversibility," in *Entropy and Information in Science and Philosophy*, ed. L. Kubat and J. Zeman (New York: American Elsevier, 1975), p. 13.
23. See, e.g., I. Prigogine, G. Nicolis, and A. Babloyantz, "The Thermo-Dynamics of Evolution," *Physics Today* 25 (1972): 23-28; Simon Black, "On Thermodynamics of Evolution," *Perspectives in Biology and Medicine* 21 (1978): 348-56; Harold Morowitz, "The Physical Foundations of Prebiotic Evolution," *Biology and the Physical Sciences*, ed. S. Devons (New York: Columbia University Press, 1969), pp. 324-34.
24. See my "Entropy and Evolution: A Philosophical Review," *Perspectives in Biology and Medicine* 22 (1979): 285-300.
25. De Santillana (n. 7 above), p. 120.
26. Ibid., pp. 107-28.
27. Herbert Spencer, *First Principles* (London: Watts & Co., 1937), pp. 291, 438.
28. See my "The Generation of Complexity in Evolution: A Thermodynamic and Information-Theoretical Discussion," in *Journal of Theoretical Biology* 77 (1979): 349-65.
29. Morowitz (n. 23 above).
30. A. Zotin, *Thermodynamics of Developmental Biology* (New York: S. Krager, 1972); H. J. Hamilton, "A Thermodynamic Theory of the Origin and Hierarchical Evolution of Living Systems," *Zygon* 12 (December 1977): 289-335.
31. Wicken (n. 28 above).
32. Hamilton (n. 30 above).
33. Ilya Prigogine, *Introduction to the Thermodynamics of Irreversible Processes* (New York: Wiley & Sons, 1955); Zotin; Hamilton.
34. See, e.g., Hans Kuhn, "Self-Organization of Molecular Systems and the Evolution of the Genetic Apparatus," *Angewandte Chemie, The International Edition in English* 11 (1972): 798-820; Simon Black, "A Theory on the Origin of Life," in *Advances in Enzymology*, vol. 38, ed. A. Meister (New York: Academic Press, 1973), pp. 193-234; Manfred Eigen, "Self-organization of Matter and the Evolution of Biological Macromolecules," *Naturwissenshaften* 58 (1971): 465-523.
35. T. Waehneldt and S. Fox, "The Binding of Basic Proteinoids with Organismic or Thermally Synthesized Polynucleotides," *Biochimica et Biophysica Acta* 160 (1968): 239-45; C. Saxinger and C. Ponnamperuma, "Interactions Between Amino Acids and Nucleotides in the Prebiotic Milieu," *Origins of Life* 5 (1974): 189-200.
36. A. J. Lotka, "Contribution to the Energetics of Evolution," *Proceedings of the National Academy of Sciences* 8 (1922): 147-55.
37. Hamilton (n. 30 above).
38. For a discussion of the general application of this principle to social issues as well see Howard T. Odum, "The Ecosystem, Energy, and Human Values," *Zygon* 12 (June 1977): 109-33.
39. Morowitz (n. 23 above).