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ENERGY AND SEMIOTICS: THE SECOND LAW AND THE ORIGIN OF LIFE

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ABSTRACT: After deconstructing the thermodynamic concepts of work and waste, I take up Howard Odum's idea of energy quality, which tallies the overall amount of energy needed to be dissipated in order to accomplish some work of interest. This was developed from economic considerations that give obvious meaning to the work accomplished. But the energy quality idea can be used to import meaning more generally into Nature. It could be viewed as projecting meaning back from any marked work into preceding energy gradient dissipations that immediately paved the way for it. But any work done by an abiotic dissipative structure, since it would be without positive economic significance, would also be difficult to mark as a starting point for the energy quality calculation. Furthermore, any (for humans) destructive work as by hurricanes or floods, with negative economic significance, would not seem to merit the quality calculation either. But there has been abiotic work of keen interest to us—that which mediated the origin of life. Some kind(s) of abiotic dissipative structures had to have been the framework(s) that fostered this process, regardless of how it might come to be understood in detail. Since all dissipative structures have the same thermodynamic and informational organization in common, any of them might provide the material context for the origin of something. So we can pick any starting point we wish, and calculate backward what sequence of energy usages would have been necessary to set it up. Given such an open ended project, we could not find an obvious place in any sequence to stop and start the forward the calculation, and so we would need to take it right back to an ultimate beginning, like the insolation of some area, or the outpouring of Earth's thermal energy. Any energy dissipation might be the beginning of something of importance, and so Nature is as replete with potential meanings as it is with energy gradients.

KEYWORDS: Dissipative structures; Energy dissipation; Energy quality; Entropy production; Final cause; Meaning; Origin of life; Scale; Semiotics

INTRODUCTION

In this paper I seek a way to import meaning, and therefore the approach of semiotics, into Nature in general. Our most basic scientific understandings of Nature have been constructed within physics, but the aspect of Nature of most interest to most people is biology. In the spirit of the Unity of Science ideology, I attempt to illuminate the physical world with the biological—and sociological—concept of work. Work has been constructed within the physical discipline of thermodynamics, which, then, outlines a possible path from bio-sociology to physics. The work concept can be deconstructed by showing that nothing prevents its importation into purely physical contexts, a viewpoint usually neglected because it seems to be without pragmatic interest. Howard Odum cleared this path with his concept of “energy quality”, which I turn into a tool useful for uniting biology and sociology with physics. Going the other way, bio-sociology is illuminated by the realization that, in the context of the Big Bang model of the Universe, work—because it is always to some degree energy inefficient—can be seen to be entrained by the Second Law of thermodynamics. That is to say, work, for whatever acknowledgeable reasons it is undertaken by organisms or societies, is at bottom one way that the Universe takes in its search to reach thermodynamic equilibrium as quickly as possible. One context within which to convincingly show the mutual exchange of meanings between the physical world and the biological is the problem of the origin of life, which culminates the paper.

I BASIC THERMODYNAMIC BACKGROUND

Energy has no independent ontological status in distinction from anything else. Everything is a form of energy. It is both being and non-being, as well as the fuel for becoming. In the sciences it has been constructed as what are represented by the predicates ‘order’ and ‘disorder’, and these are dubbed, respectively, ‘energy gradient’ and ‘entropy’. Entropy is mostly visualized as undirected motion at molecular scale. Energy gradients can be tapped to do work, which dissipates them in the direction of entropy. The portion that gets used productively is labeled ‘exergy’, but typically about half a gradient gets lost during work (Odum, 1983), by way of getting contaminated by entropy, and the proportion lost increases as the work is done more strenuously—haste makes waste (Carnot, 1824). Potential energy gradients are found at all scales. Any material accumulation is an energy gradient, and represents orderly, or informed, configurations of energy. Even a random lump at our scale is orderly, but at a scale below its perceived ‘lumpiness’.

Completely disordered energy we characterize as being fully contaminated by entropy. Complete disorder is difficult to conceive (fully dispersed, completely symmetrical), but could be characterized as the attractor of the following falling gradient: forms -> random clumps of stuff -> dispersed baryonic (standard) matter -> free hadrons (heavy elementary particles) -> quark-gluon plasma -> an empty sea of fully entropic energy—the so called ‘heat’ or ‘thermal’ energy (which affords the Brownian motion—jiggling—of very small particles viewed in a microscope).

It seems unavoidable to suppose that the reverse, “rising” gradient was instituted by the acceleration of Universal expansion in the Big Bang (Kirshner, 2002), initiating, along with the origin of matter, the effects of gravitation,[1] which then afforded, wherever constraints allowed, the agglomeration of forms and eventually the institution

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[1] (a) Following Einstein’s unification of gravitation with acceleration, the gravitational constant should scale with the magnitude of Universal acceleration. (b) It is unclear what the beginning of this rising gradient was like. One could suppose that it was the opposite, whatever that might be, of the sea of fully entropic energy that is the final stage of the falling gradient.

of systems and organizations (e.g., Chaisson, 2001). The Universal reaction to this up-building sequence was, and remains, the Second Law of thermodynamics—the global tendency for isolated systems to disperse towards an equilibrium distribution of energy, and, entrained by that, for local energy gradients to dissipate (Salthe, 2000a). This latter tendency is exploited by dissipative (energy utilizing) systems, from galaxies to living systems, as the source of exergy for their maintenance. So dissipation (or the tendency toward it) is primary, with exergy being captured from that. Without the Universal tendency toward energy gradient dissipation, work would be impossible, even meaningless.

The derivation of exergy from gradients is never, during effective work in the actual world, better than inefficient, with typically somewhat more of a gradient going toward entropy than into exergy (Odum, 1983). It is for this reason that I have been urging that work entrained by whatever purposes in view of the workers, is most fundamentally entrained by the Second Law of thermodynamics in the role of its ultimate final cause of all activity (Salthe, 1993, 2002b, 20003, 2004). To be sure, energy efficiency can be increased by slowing the work rate, but in the natural world slow work is generally ineffective in building stability and underwriting survival. As well, energy efficiency can certainly be improved by design or by evolution, but that only sets a baseline—the rate of work with the greatest efficiency for a given system. Surviving forms frequently require rapid, therefore relatively inefficient, work. The need to calculate energy efficiency has led to the supposition (the First Law of thermodynamics) that energy is Universally conserved, with entropy then inferred from the measurable, 'heat energy'—energy contaminated by disorder.

Traditionally at our scale we understand potential energy ultimately as order somewhere at about the molecular level, using molecular agitation to assess disordered, or thermal, energy—as temperature. This perspective leads us to suppose that at zero Absolute degrees, molecular disorder (motion) would disappear altogether (the Third Law of thermodynamics). At the limit of natural cooling—at thermodynamic equilibrium—pure energy would be associated with no directed motion at all, and (following the above "falling gradient") since there would as well be nothing to contain internal energy, this would be a 'singularity' we need not be concerned with.[2]

Supposedly, if an organized system were as an experiment to be quickly taken down to zero Kelvin degrees, then all the forms present would be preserved just as they are, in very far-from-equilibrium configurations. The system will have cooled without losing the forms that heat (entropy) production / work had engendered. Of course, here the cooling itself was actually a product of work. Even the formation of ice during a freeze is produced by work—meteorological work—and it makes an orderly gradient

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[2] While rapid cooling in the early Big Bang delivered the energy / matter duality as energy, radically disequilibrated by the tremendous acceleration of Universal expansion, 'precipitated' into the stages of matter production, if the cooling (as I assume must happen—Salthe, 1993) begins to decelerate in the senescing Universe, the dispersal of matter would continue, eventually right through the quark-gluon plasma, in the direction of 'pure' energy.

of ice crystals. In spontaneous cooling, it is dispersion itself that produces the drop in temperature, so that at Universal equilibrium there could be no gradients left at all. That is to say, absolute zero would be attainable naturally only if the decay of order went beyond even the quark-gluon plasma stage.[3]

II REDEPLOYING THE CONCEPT OF ENERGY IN SCALAR HIERARCHY TERMS

While economists and ecologists assess energies (either potential or disordered) ultimately only at the molecular level, work of interest to them takes place at multiple scalar levels, and produces energy gradients of all sizes. Yet such complex organization of work efforts is dealt with in a completely reductionist manner in thermodynamics. Consider a coal seam in a mountain. Only when the coal is burned, breaking its chemical bonds, do we consider its potential energy to have been released. Scraping it out of the mountain is not considered to tap its potential energy, nor does carting it, or crushing it into convenient chunks for furnaces (or, via natural processes, mass wasting of the mountain). These work events are viewed as being afforded by energy released from other gradients deployed by men and machines or by Nature, these too assessed ultimately, again, at the molecular level. For business purposes it is then possible to determine the amounts of energy dissipated in preparing the coal by human agency, and to conceptually deduct this from what can be gained from burning it, giving us a 'net energy yield' that allows pricing to reflect the cost of the preparatory 'externalities'.

From the point of view of the scale hierarchy (Salthe, 1985; 1993, Chapter 2; 2002 c),[4] we could quite reasonably take the stages in deploying the coal to be actual steps in its dissipation, thereby considering a lump of coal in the hopper (or, for that matter, in the rubble at the base of the mountain) to be closer to thermodynamic equilibrium than when it was part of a mountain. This requires the realization that, for example, if the coal were to be burned in situ in the mountain, that would cost at least as much prior

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[3] The problem of energy in a quark-gluon plasma, and therefore in the very early Big Bang is one that cannot be dealt with here. This paper focuses upon energy as the material cause of transactions in the material world, as dealt with in ecology and economics.

[4] The scalar hierarchy models the spatio-temporal and dynamical aspects of the world in a synchronic manner. Larger scale systems change at relatively slower average rates than do smaller scale systems, and thereby provide contextual information on the latter's changes. So larger scale systems regulate, control, and interpret smaller scale ones. "Interpretation" here would involve aggregating smaller scale effects as ensembled information. Smaller scale systems are often nested within larger ones, as can be shown in the format, [megascale [macroscale [microscale]]]. (Note that these brackets are different from the set theory brackets used in the specification hierarchy, as in Note 8 below.) The system cannot be effectively modeled with less than three levels. Dynamically, the microsystem proposes possibilities that might occur at the macro level, while the megasystem disposes by choosing from among these possibilities. An example from biology would be [ecological niche [population [organism [cell [macromolecule]]]]]. This implies, for example, that organisms cannot be taken, as such, to be players at the ecosystem level. They make up populations, which can transact at the ecosystem level. This is because the dynamics at any level are screened off from those at contiguous levels as a result of having order of magnitude differences in rates. (For further details see my 1985 book, listed in the references.)

dissipation of energy to set up as is required for its technological deployment. This cost would be paid by, say, a lightning strike and the immediate work of charge separation that prepared for it, or by a forest fire that gradually engulfed the mountain holding the coal seam. That is to say, the free energy derivable from a lump of coal always depends upon the ancillary, and prior, production of entropy from other gradients, no matter how it is made available to the flames, by the business of man or of Nature. This prior deployment of work occurs at several scalar levels, and so it seems reasonable to scale energy dissipation (or entropy production).

Of course, we need not, and indeed could not, take these prior ancillary dissipations into infinite regress, say, by considering also the energy deployments that were necessary to form the coal and accumulate the mountain, or to generate the thunderstorm, or to build the coal fired plant or to organize the industry entraining it. Effective calculation would require attending only to the proximate activities leading directly up to its combustion. This requires only that we be able in principle to locate and conceptually mark the future lump of coal in the mountain.

It should be emphasized again that dissipation of order takes place at all scales and in all kinds of systems, not just at molecular scale. Order, we soon realize, is not an objective concept. One system's disorder could be another's order. But it seems clear that no orderly setup, at whatever scale it is found, will remain undispersed in the absence of work done to maintain it. That is, any kind of order whatever—even great cities—will, one way or another, spontaneously dissipate eventually. (Spontaneity here is guaranteed at any scale by the principle that the dissipation of energy gradients is primary in the material world.)

It is of interest in this context to consider Howard Odum's concept of energy quality (e.g., Odum, 1983). This is the number of joules of previous dissipations represented by a joule (or erg) of exergy derived by some work claiming our attention. Of course, a joule is a joule, but the point of Odum's idea is that the ancillary dissipations that launched "our" joules were spread out over a much larger area than that occupied by, e.g., our little lump of coal, and so could not, without focusing, have been available for the work in question. And, of course, the joules already in that lump when it was part of the mountain would not have been available for this work without all those prior works. So the quality idea refers to a virtual condensing of energy density. The lump of coal focuses joules garnered from larger scale thunderstorms, forest fires or coal mining activities upon one local work task of interest (not well defined in natural cases of course). So it is a question of energy availability. The energy providable by a slow natural burn of coal in situ in the mountain would flow too slowly to support significant human scale work, while that made available by a lightning strike would flow too fast. The power (energy throughflow: Odum and Pinkerton, 1955) in these cases would be respectively too little or too great for economic or ecological works, which are organized (informed) by particular arrangements of matter that mediate middle levels of power.

So, energy quality for Odum represented a narrative account of the number of steps it takes to focus an energy source at some acknowledged task—or, more precisely, the total amount of dissipation required to launch its further dissipation during some privileged work. Ceteris paribus, high quality energy would have been dissipated by way of more steps than low quality energy. But complete understanding of the idea is not gained until it is seen that these steps move from larger scale landscapes, over which potential energies are dispersed, toward lower scale locales, ending at a point of dissipation at the thermodynamically canonical molecular level.[5] From this consideration, it seems reasonable to reverse our perspective and view all larger scale events as actually being supported by low quality energy, while smaller scale events are always afforded by higher quality energies.

So, in a mountain wasting away in landslides we would have gravitational potential energy being converted to kinetic energy, which might actually do some acknowledgeable work, for example, in helping a marmot open a tunnel. Note here how the work concept requires some locus or system profiting from, or just being modified by, it—here the marmot. The work in this example would be work done by low quality energy because it is relatively large in scale—far away from the canonical molecular bond energies of thermodynamics. Its immediate trigger could also have been by way of dissipation of other low quality energies, say, in an earth tremor. Orogenic and meteorological events (both comparatively large in scale) are all, then, afforded by low quality—large scale or widely dispersed molecular—energy gradients. One might object that evaporation, say, which drives hydrological work, is in detail quite small in scale. But the amount of evaporation required to generate palpable hydrological gradients is quite large. Thus, it is whole forests, not individual leaves or xylem tubes, which generate climatic moisture by way of evapotranspiration. Looking the other way, it is, of course, possible that incident solar radiation might directly drive some microscopic transformation in the soil of use to a particular smaller scale system viewed as important in some context, and in that case the work done would be microscopic (toted up in ergs rather than joules!), and therefore, in the present view, afforded by high quality energy. Insolation might be either large or small in scale depending upon what it effects. We find no objectivity here.

While classical thermodynamics could easily analyze any large scale dissipation by way of the heat given off, it became theoretically founded, after Ludwig Boltzmann, upon microscopic—here, high quality—energy transformations. So, I have taken Odum's energy quality idea, which he calculated as the number of energy transformations after insolation prior to some exergy use in a biological system, and modified it—to the number of such steps required to set up any given molecular scale energy dissipation. In Odum's ecological examples the two versions would give the same value. But the present version allows extension of the idea to any scalar

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[5] Nuclear and other energies animating the submolecular world have not taken part directly in ecological work, and have only recently been tapped by humans, and so will not be referred to herein. Eventually they too will need to be considered in this theoretical framework.

hierarchically organized system without having to count steps to molecular dissipation —any dissipation of relatively large scale with respect to human observation will be taken to be of low quality energy; small scale, of high quality. The privileging of the molecular level in thermodynamics implies that dissipation there must often have been preceded by a concatenation of prior dissipations, many at larger scales. The link between Odum's and the present interpretation is that there would have been no point to Odum's formulation if his low quality energies were not virtually garnered from much larger scale areas or volumes than the locus of a high quality transformation of interest, and if quality did not tend to increase inversely proportionally to scale of the area / volume over / within which some energy gradient's dissipation occurs.

III PRACTICAL THERMODYNAMICS IMPLIES SEMIOTICS

I hope to show that the need in thermodynamics to specify what work is being done implies the need to take a semiotic[6] perspective. Odum's energy quality calculus is inherently semiotic. Here, the 'meaning' of high quality energy dissipation would be the development and support of some particular complex systems. This then gives us at least one meaning as well of all the ancillary energy dissipations that prepared for these privileged events. Note that this does not refer to any other works derived (giving other, antecedent local meanings elsewhere) from these prior dissipation events along the way, but only to the overall energy dissipated (as exergy plus entropy) while increasing the quality of energy supporting a given particular system. Semiotically, the world does not merely 'exist', but embodies meanings in its productions. Put another way, this thread of thought leads us to final causation.[7] Technological dissipation of a mountain of coal, for example, finds it meanings / finalities in the support of human constructed complex systems. By extension, natural dissipation of the energies in fishes low on a food chain finds some of its meaning in the support of, e.g., fishes high on that food chain, which, then, are acting as final causes of the dissipation of those energies.

Finality has been excluded from science discourse until quite recently. It has been revived in connection with studies of systems, and so it is not surprising that its revival occurred early in ecology (e.g., Patten et al, 1976). The classical style of doing science was to take systems apart, examining the parts in isolation in order to discover their potencies. But with the advent of complexity consciousness, it has seemed just as important to examine parts as they function within whatever systems they contribute to. This required some tool for viewing causality itself as complex, and that led to a

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[6] Semiotics is the study of the making/ interpretation of meaning. Pansemiotics is the perspective based on the idea that meaning is present throughout Nature.

[7] Final causation (finality) is one of a diachronic pair of Aristotelian causes: efficient cause / final cause. Efficient cause is the trigger or push that gets something going, final cause is its pull into the future—that *for which* something happens. In this essay I have noted the Second Law of thermodynamics as a general final cause of all events. The other two causal categories are the synchronic ones, material cause and formal cause. Material cause is that which makes something possible, while formal cause is that which defines and mediates the caused events.

revival of the Aristotelian causal analysis [7]. All parts of an organized system are implicated in what is happening at any locale within it (e.g., Ulanowicz, 1986, 1997) . A system would cease to function properly if one of its functions ceased to be influenced as usual by average downstream expectations. That influence from the future can be represented using the grammatical construction, the future progressive (Matsuno and Salthe, 2002) as in: 'I will have been doing', derived from the past progressive, 'I have been doing', in turn derived from the present progressive, 'I am doing'. Any continuing system needs to rely upon the ability of its components to be assured of the continuing validity of their future progressive expectations. These act as final causes; systematicity implies finality.

Meanings may be more, or less, general. The meanings referred to above are quite particular. They are entrained, however, by a much more general—indeed, a completely general—meaning / finality, the Second Law of thermodynamics, as it functions in the system of the Universe. In the context of the Big Bang, this law finds its meaning as the reactive, presumably 'equal and opposite' antithesis to the matter, masses, forms and systems generated by the Universal expansion's tremendous acceleration. The richness of forms in the Universe is the premier sign of its great distance from thermodynamic equilibrium, toward which, if we assume it to be an isolated system, we know that it must be tending. A major piece of evidence for that assumption is found in the instability of energy gradients, all of which require work to be maintained. As well, it is not clear how the Universe could be expanding if it were not isolated. So we have the logical form: {entropy production {exergy use}} (read as {ultimate final cause {proximate final cause}}) as the fundamental thermodynamic relationship at any locale.

We tend to associate meanings with particular systems. The autecology of particular species or populations reveals how they have constructed their meanings, and individuals know these meanings in their Umwelts (of Uexküll, 1926—see Salthe, 2001). Of course, a kind of energy gradient would likely support more than one kind of complex system, and so it would also, for an external observer, afford several meanings —related to any systems supported by it further up the energy quality gradient, or, in biological systems, further up in its dependent food chains. Its final meanings would devolve upon the loci of its molecular dissipation, and would be revealed by the persistence in the world of those systems exploiting its dissipation.

Since one large scale gradient (say, that produced by insolation of a forest) will eventually support many molecular level dissipations in different systems, the steps traversed to increase energy quality can be parsed into stages. This can be shown using a specification hierarchy,[8] wherein the dissipations are allocated to different levels.

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[8] A specification hierarchy can be represented as classes and subclasses in set theory form, as in: {lowest level {middle levels (if any)} highest level}}}, each higher level (to the right here) being a refinement of the previous one. The system is diachronic in spirit, and models the fact that higher levels emerge from lower ones, as in 'biology emerges from chemistry', which would be shown as {chemistry {biology}}. Higher levels also modulate or integrate the information contained in lower ones by adding contextualizing

Thus, with the following gloss: {first stage -> {next stage -> {final stage}}}, the last stage, as a refinement of the prior one, implies (a material implication or conceptual subordination) the next, and that the first. So, for example, you could not have evapotranspiration if you had not first had direct reradiation of heat, as shown in the following specification hierarchy: dissipation {directly into heat over some sunlit acreage, leaving some to be dissipated {by way of evapotranspiration from plants in that area, leaving some to be dissipated {as heat production during ATP regeneration in some particular living system in that area}}}. (Note that these are not supposed to be a complete tally of a chain of dissipations; this hierarchy just shows the precedence of implications.) Since there would be many living systems in any area, a complete view of this hierarchy would show it to be branching from its trunk in the initial direct heating upon insolation, ending at many different last stages in its branch tips, each representing a different species or kind of abiotic dissipative structure consuming local molecular scale gradients.

Each step in the dissipation of energy requires the deployment of information. This is embodied in material arrangements that prevent a gradient's instantaneous (possibly explosive) dissipation. So we see that thermodynamics, in the way it was constructed as focused upon molecular level energies to provide a common evaluation of work and waste for all systems, has itself been semiotic in nature. It has been remarked before that classical thermodynamics is not 'objective' for basically this reason. One system's waste might have been another's exergy. Different kinds of energy consumers deploy different techniques to extract exergy from dissipating gradients. We can represent these techniques as the deployment of information[9]—which I define as constraints on entropy production. After molecular bond energy is converted to thermal energy, it is supposed that no system might utilize it any more. It is, however, unclear to me that this is not due to the merely contingent fact that thermal energy is defined in such a way as to exclude the likelihood of there being any gradient in it that could support work in any particular direction. But, is it really clear that what for us is thermal energy could not have within it small scale gradients relevant to, say, activities in a quark-gluon plasma?

Scale is interesting in this context. A large crane might lift tremendous weights, but its energy use is calculated in joules, which are also conceived to propel an ant. The

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information. For example, the biological level controls physical processes, shown as {physics {biology}}. Thus, we have: {diffusion {biological organization of circulatory systems}}. As in the scale hierarchy (Note 4 above) higher levels regulate, control and interpret lower ones. When used to model change, evolution or development, this hierarchy has the form of a tree, with its trunk in the lowest level and branching into its higher levels.

[9] Information in information theory is defined as a restriction on variety or a decrease in uncertainty, so it is represented as diminishing an entropy (here, information carrying capacity or informational entropy). Serving as constraints on physical entropy production, information also diminishes the rate of entropy production, making that more frictional. Information expresses the system holding / expressing it, revealing a locus of meaning But, what is information materially? I take it to be configurations of matter. All such configurations were established historically and tend to get differentiated over time, individuating along the way.

ultimate in reductionism is constructed in the real numbers. 0.6794 can be distinguished from 0.68100456 (these numbers, of course, have been arbitrarily truncated from the real line), as if this could make a difference somewhere. Yet, while this distinction might be palpable for an ant, it could have no effect at all on the crane. Pragmatically, the crane utilizes liters of diesel fuel, while the ant utilizes millimicroliters of glucose solution—both would be reckoned to be of high quality because they have been focused by several prior dissipations. So, while a crane's work is much larger in scale than that of the ant, its power is held to be fundamentally microscopic—as many multiples of microscopic values, of course.

Consider gravitational potential energy. We can construct it too in joules by calculating how much of some at-hand molecular energy source would be required to be oxidized in lifting something in order to install it. But, wait—this is clearly an 'as if'. It is only 'as if' a teetering boulder were apposed to a molecular energy gradient that could activate it, or be depleted by its fall. Its positioning at the top of a cliff need not be imagined as having been immediately supported by some particular molecular bond energies (as mediated, for example, by a crane). It may have been washed there by a rushing flood from a melting glacier. Was the heat energy that undermined the ice, and/or some aggregate of the chemical scale energies that were broken in the ice, the propellant(s) that sped the boulder on its way? (Surely not the heat energy!) This example—and any involving big stuff moving about, as in meteorology—involves only low quality (widely dispersed molecular) energy. Deny this and we would have the infinite regress rearing its head again. Thermodynamics has been constructed by us to be convenient for comparative calculations at our scale. This is the context of its (pragmatic) meaning in our construct, Nature.[10]

Considering again a crane's work, it is only our economic interest in it that requires us to calculate its energy consumption in high quality molecular joules. It could lift that boulder to the top of the cliff, but we know it would never be so utilized. This consideration again forces us to take into account final causes. We see finality in the desired works the crane achieves, but we acknowledge none in the positioning of the boulder, or in its later plunge. These are conventionally viewed as haphazard events without meaning—well, no particular, proximate meaning (for us). This sequence does, however, serve the Second Law of thermodynamics in its project of Universal equilibration, and would do so to a greater degree if the boulder smashed something or if it broke into pieces on impact. And so we could compare the crane's work: {entropy production {lifting}} with the boulder's: {entropy production { }}. Proximate meanings like the lifting require the identification of systems that are supported by some entropy production. Pansemiotics includes among these the likes of species, organisms and cells along with cities, tribes and countries. I have argued that abiotic dissipative structures, like tornadoes, should be included here as well because they are definable local systems in no formal or physical way different from the living. The stumbling

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[10] I refer to the aggregate of scientifically constructed models of the world as Nature, as distinct from the world itself. This paper, like all scientifically based ones, concerns Nature.

block here is that we find it hard to locate their proximate meanings in assignable aims or goals. A tornado works very hard at smashing houses, but to what proximate effect?

In any case, different kinds of energy consumers employ different techniques to extract exergy with different efficiencies from different kinds of energy gradients invited by different proximate finalities. The world, by way of various evolutionary processes, has constructed almost a plenitude of exergy extractions riding on the dissipation, as mandated by the Second Law of thermodynamics, of a plethora of energy gradients. Evolution in its most general sense is the accumulation of historical information (Salthe, 1993), ranging from changing patterns of rubble on planetoids after asteroid impacts, through alterations of genotype representations in populations of organisms, to the individuation of every material object/system, and, indeed, insofar as the Universe has had a particular history, might reasonably be said to include the establishment of the values of what physicists call universal constants as well.

History institutes particulars—all acting as local configurations of constraints on entropy production. The value of energy quality reflects the lengths of particular pathways of energy dissipation, each guided by informational arrangements derived from various evolutionary processes (cosmic, organic, cultural) and/or events. Energy quality reflects as well the energy efficiencies evolved by each consumer (increasing efficiency at one step might reduce the number of joules required to produce each joule of some privileged energy consumed). Light arriving upon the earth is delayed in its reradiation into space (Lotka, 1922) by being captured in configurations—mountains, eddies, organisms—that impose various degrees of friction upon its dissipation. This institution of frictions is the major physical effect of evolutionary (historical)-semiosic (meaningful) processes.

But we need to return to possible meanings that could be assigned to work done by falling boulders, drainage systems and comets—or Brownian motion. We have of course the ultimate meaning in entropy production. But the dissipation of energy gradients producing this also produces in these cases broken stones, carved out valleys and minute debris—all stuffs that are, compared with a prior situation, closer to thermodynamic equilibrium. Brownian motion has components at two scales (Parisi, 2005)—the canonical smaller scale jiggling to no effect, but also a larger scale wandering through the embedding medium. The same can be said of motion in the Bénard instability,[11] where the larger scale wandering gets organized into directional flows that represent orderliness, and even increase entropy production as well (in these respects differing in no way from organisms!) (e.g., Swenson, 1989; Salthe, 1993). In this case a pansemiotician could assert that the final cause here is to make and support the organized fluid cells. But the wandering of particles in Brownian motion produces no

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[11] The Bénard instability refers to hexagonally packed cells that spontaneously organize in a relatively shallow fluid heated from below after the temperature reaches a critical value. Each has a cooling flow moving up on their outside which flows down again on the inside, making a kind of torus. They are frequently used as examples of the spontaneous formation of organization, the result of which is to speed up entropy production. Cloud formations sometimes are the result of such flows.

order, and does not move the system closer to thermodynamic equilibrium either, since it is already almost there. Here we again confront {entropy production { }}. In view of the fact that life can (presumably) originate only under certain particular abiotic conditions, and that human systems can flourish only under a certain range of configurations of climate and substrata, it seems to me most modest simply to declare ignorance here, rather than to conclude that entropy production is the sole meaning of abiotic work, which would thereby be taken by us to be meaningless.

IV DISCRIMINATING LIFE, AND ITS ORIGIN

I hope to show here that the problem of the origin of life requires the pansemiotic view that meaning can be found throughout Nature. From the present perspective, living systems would be seen as having been interpolated into what were originally abiotic ecologies. An ecology is most generally just a partially regularized flow of energies and materials among locales. In this context we can note Ehrensvärd's (1960) concept of a 'living pond' as a first stage in the origin of life, together with Depew and Weber's (1995) view of the organism as a 'superecosystem', along with Sidney Fox's (1988) demonstrations that artificial proteinoid microspheres can carry out most of the coarser behaviors of cells (like cell division), making these processes generic at a certain scale—these coupled to Cairns-Smith's (1982) idea of the 'genetic takeover' of an abiotic system of microscopic informational template inheritance. These ideas form the framework of my views in this section.

We need to take a scalar hierarchical perspective here [4]. In particular we need to discern a molecular system, the cell, in distinction to a macroscopic one, the organism (or syncytium or microorganismic biofilm), distinguishing these from a surrounding megascopic system, a biome-scale ecosystem. So, we can represent the levels as: [mega [macro [micro]]]. Each of these levels provides energy gradients to support the entities within it, and in so doing also mediates safe energies, screening off the more powerful ones that could disrupt smaller scale systems. In biology the micro system also generates energy gradient in the form of ATP, which, when (as in organisms) it is organized so that large amounts can be dissipated simultaneously, can then support work at the macro level.[12] Logically, these functional levels must pre-exist the origin of biology. For a relevant prebiotic system we can imagine an organized molecular system, perhaps an autocatalytic cycle, located within some larger scale dissipative structure, perhaps an eddy, and this would be found in a landscape that has produced it. Here we have the same three scalar levels.

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[12] Thermodynamically it might be fruitful to view organisms as means by which living systems increased the scale of their dissipative activities, mediated by competition between systems for energy gradients. In this perspective we would see living systems as invading and taking over the abiotic dissipative structures initially nourishing them energetically, gradually converting them to biofilms, syncytia, colonies, organisms and populations.

At the mega level we have landscape openness to provide sunlight, and rugosity to moderate it with shade, as well as alternations of these as the day turns and shadows move, allowing dark reactions with unstable intermediaries to proceed undisrupted. This level also provides a terrain allowing the flow and damming of water, along with some regularity of rainfall. And, of course, the basic chemical materials required must be found on its surface. Within this scene a locale will emerge from energy flows that allows the development and maintenance of an organized abiotic dissipative structure, like an eddy. This provides a directed energy flow, bringing in materials and evacuating end products. The latter, proto-waste products, will be produced by autocatalytic cycles located on surfaces bathed by the eddy. And so we have our basic setup. Then we can consult numerous works showing how the spontaneous origin of proteinoids and amphoteric substances (layers and micelles of surface active liquid crystalline precursors of cell membranes) can have taken place, within which the autocatalytic cycles became protected. We are almost there, but not quite. There is as yet no worked out understanding of how the genetic system, and therefore genuine proteins as well as fidelity in reproduction, can have originated. We must assume that it did somehow—this remains an open empirical question.

Well, here we have the following setup: {local entropy production {prebiotic system survival}}. If pansemioticians are willing to allocate meanings to biotic systems, my point now is that it seems extremely stingy of them to refuse them to the actual prebiotic ones that must have provided their ancestral matrix. Some might say that it is the presence of the genetic system as such that makes the difference with respect to meaning. I admit that this a possible choice, but it makes me uneasy in the context of a lack of knowledge about the origin of the genetic system so profound that it might as well be supposed to have been a supernatural event. This choice effectively removes the origin of life from the purview of science.

Formally, if a model can be constructed of a basic living system, it will be constructed in general enough (logico-mathematical) terms that it could be extended to cover abiotic systems as well, given only that the latter have enough degrees of freedom to support the model.

So, I believe we need to construct a formal argument about the origin of life that will be able to framework knowledge about the origin of genetic representation / replication if and when that might be forthcoming. This argument allocates meaning, however vaguely, to prebiotic systems, and, therefore to abiotic systems generally. The first point will be that, given the mandate of the Second Law of thermodynamics, the origin of life is best viewed as having been a way of increasing the entropy production of the earth's surface—this despite the fact that living systems further delay the reradiation of solar energy. An obvious possibility here is that the origin was fostered by the material cause of considerable energy supplies that were not being dissipated very well, or at all, otherwise. This move allows us to place the origin in the framework: {enhanced entropy production {protobiotic system furtherance}}.

Here we need to confront a common objection to this theoretical orientation—that if a system were to maximize its entropy production rate it would thereby likely disrupt its own organization. The critical point is to distinguish energy supplies making up a system's own material embodiment from the external energy gradients that it is capable of consuming. If a system increases the entropy production of its locale, this does not necessarily mean that it will consume or disrupt itself. The basic thermodynamic fact about living systems is that they consume external energy gradients, thereby (because of generic poor energy efficiency) producing entropy into their immediate environment, and, as well, that they ship outside any entropy produced internally, thereby preserving their own form (Schroedinger, 1956).

Living systems might eventually evolve a degree of energy efficiency, but this would in general be limited by the need to heal insults as rapidly as possible, by the need to compete for energy supplies in the general predicament that, with limited supplies the fastest consumer gets the most, and as well by the need to outreproduce other individuals. That is to say, successful ones tend frequently to be 'pushing the envelope' energetically, and rapid work generally decreases energy efficiency. Increasing efficiency in consuming external gradients could be a successful strategy only in special circumstances, perhaps in locales with very restricted supplies, a situation not conducive to the origin of macroscopic living systems in the first place.

The general situation for any dissipative structure is to originate, develop into senescence and get recycled (Salthe, 1993). They originate as spin-offs from larger scale dissipative structures (eddies from streams, tornadoes from mesocyclonic thunderstorm supercells, eggs or buds from organisms). When immature they generate a rapid per unit mass energy throughput, which supports their growth. In senescence this energy throughput declines (the minimum entropy production principle of Prigogine,1955), but, since the system continues growing,[13] its gross energy throughput continues to increase (the maximum power principle of Odum and Pinkerton, 1955), albeit at a decelerating rate. Given that natural systems need constantly (abiotics) or frequently (biotics) to actively strive for survival, entropy production by them from supporting external energy gradients tends to be maximized (the maximum entropy production principle of Swenson, 1989, or, as a more general maximum energy gradient dissipation rate principle, Schneider and Kay, 1997, as well as the 'entropy principle' of Mauersberger, 1995, and Li, 2000).

These considerations allow us to postulate a [macroscopic [microscopic]] protoliving system awaiting the interpolation of a microscopic genetic system. As microscopic, this latter would indeed occupy the locus of meaning in the thermodynamic perspective of this paper, with the rest of the setup—macro and mega —also deriving its meanings from here using Odum's energy quality concept, as explained above. The microscopic components—metabolic micelles or proteinoid

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[13] Many kinds of dissipative systems continue growing in size, increasingly more slowly, but some may grow, in the same asymptotic pattern, only in power (energy throughput), or in density—perhaps density of chemically active sites.

microspheres, with perhaps the information bearing clays of Cairns-Smith—would occupy the original locus of meaning. But meaning would expand outward from these to all dissipative processes involved in generating the high quality energy used to maintain or modify these microscopic entities, pre-, proto- or bonafide biotic. As meaning expands outward, it becomes increasingly vaguer, since it gets less clear which microscopic systems will actually be supported by the energy dissipations occurring over larger scale sites. And, of course, vagueness increases from biotic to protobiotic, and from there to prebiotic.[14] Looked at this way, any material locale in the universe, since it would necessarily have scalar level structure, might potentially be the locus of living or life-like systems, and so would be meaningful in that sense, as reflected from its potential microscopic components by the energy quality calculus.

SUMMARY

Potential energy exists in orderly forms of many sizes, and work takes place at all scales, but thermodynamic order is calculated at the molecular level. Odum's energy quality can be used to scale energy dissipation. The thermodynamic need to specify work implies semiotics, and energy quality is inherently semiotic. Work requires information, which varies with kinds of energy consumers. The meaning of high quality energy dissipation is the support of particular systems, and this meaning is reflected back to all prior energy dissipations (including abiotic ones) from the same basic gradient that helped to raise its quality. These considerations lead us to final causality. The major physical effect of evolutionary / semiosic processes is delay in the reradiation of solar energy from the earth by its being captured in configurations that impose friction on its dissipation. These frictional activities dissipate energy gradients not otherwise accessible to derogation. A plenitude of exergy extractions have evolved on Earth to dissipate a plethora of energy gradients, thereby furthering the equilibration of the Universe.

The problem of the origin of life requires the pansemiotic view that meaning is present throughout Nature. Life, fostered by macroscopic dissipative structures, was interpolated into prior abiotic ecologies. Since this could occur only under certain conditions, it is premature to conclude that only entropy production in the service of the Second Law can be the final cause of abiotic dissipation. This view allows meaning to be present, however vaguely, in prebiotic systems, and so can be allocated to abiotic systems generally. The origin of life is viewed as having been a way to increase the entropy production of the earth's surface. Since natural systems actively strive for survival, their entropy production tends to be maximized by way of maximizing the

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[14] Earlier I pointed out that, in a given ecosystem, the lower quality energy used by larger scale dissipations would have more general meanings than that used at smaller scales. This is because high quality energy gets deployed among many systems, resulting in a tree of increasingly particular meanings. In the pre- and protobiotic cases, however, we need to replace the basal generality with a more generative vagueness since it could not as yet have been clear what particular systems would emerge in the future. The formal relations here are: {vagueness -> {more definite particularity}} and {generality <- {particulars}}.

rates of dissipation of their energy supplies. We can postulate a protobiotic dissipative system that could accept the interpolation of, and takeover by, a genetic system. As microscopic, this latter would become a locus of meaning, with associated macro and mega levels deriving their meanings from there by way of Odum's energy quality concept. Meaning at these larger scales would have eventually been codified and sharpened by the evolution of biofilms, organisms and populations.

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BIBLIOGRAPHY

A.G. Cairns-Smith, *Genetic Takeover and the Mineral Origins of Life*. Cambridge, UK, Cambridge University Press, 1982.

Carnot, S., 'Reflections on the motive power of fire, and on machines fitted to develop that power.' In E. Mendoza (Editor), *Reflections on the Motive Power of Fire and Other Papers*. Dover Pubs., New York, 1824 / 1960.

E.J. Chaisson, *Cosmic Evolution: The Rise of Complexity in Nature.* Cambridge, MA : Harvard University Press, 2001.

D. Depew and B. Weber, *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*. Cambridge, MA.: MIT Press, 1995.

C. Ehrensvärd, *Life: Origin and Development.* Chicago: University of Chicago Press, 1960.

S. Fox, *The Emergence of Life: Darwinian Evolution From the Inside*. New York: Basic Books, 1988.

R. P. Kirshner, *The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Universe*. Princeton: Princeton University Press, 2002.

Li, B.-L., 'Why is the holistic approach becoming so important in landscape ecology?' *Landscape and Urban Planning*, vol. 50, 2000, pp. 27- 41.

Lotka, A.J., 'Contribution to the energetics of evolution' *Proceedings of the National Academy of Science*, vol. 8, 1922, pp. 147-151.

Matsuno, K. and S.N. Salthe, 'The origin and development of time' *International Journal of General Systems* vol. 31, 2002, pp. 377- 393.

Mauersberger, P., 'Entropy control of complex ecological processes' In B. C. Patten and S. E. Jørgensen (eds.), *Complex Ecology: The Part-Whole Relation in Ecosystems* Englewood Cliffs, NJ, Prentice-Hall, 1995, pp. 130-165.

H.T. Odum, *Systems Ecology: An Introduction*. New York, Wiley Interscience, 1983.

Odum, H.T. and R.C. Pinkerton, 'Time's speed regulator, the optimum efficiency for maximum output in physical and biological systems' *American Scientist*, vol. 43, 1955, pp. 331-343.

Parisi, G., 'Brownian motion' *Nature*, vol. 433, 2005, pp. 221- 225.

Patten, B.C., R.W. Bosserman, J.T. Finn and W.G. Gale, 'Propagation of cause in ecosystems' In B.C. Patten (ed.) *Systems Analysis and Simulation in Ecology* Vol. 4, New York, Academic Press, 1976, pp. 457 - 579.

I. Prigogine, *Introduction to Thermodynamics of Irreversible Processes*. New York, Interscience, 1955/1961.

S.N. Salthe, *Evolving Hierarchical Systems: Their Structure And Representation*. New York: Columbia University Press, 1985

S.N. Salthe, *Development and Evolution: Complexity and Change In Biology*. Cambridge, MA, MIT Press, 1993.

Salthe, S.N., '*Theoretical Biology* as an anticipatory text: the relevance of Uexküll to current issues in evolutionary systems' *Semiotica*, vol. 134, 2001, pp. 359- 380.

Salthe, S.N., 'The natural philosophy of entropy' *SEED* vol. 2, 2002 a, www.library.utoronto.ca/SEE, (click on SEED)

Salthe, S.N., 'An exercise in the natural philosophy of ecology' *Ecological Modelling* vol 158, 2002 b, pp. 167-179.

Salthe, S.N., 'Summary of the principles of hierarchy theory'. *General Systems Bulletin* vol. 31, 2002 c, pp. 13-17.

Salthe, S.N., 'Infodynamics, a developmental framework for ecology / economics' *Conservation Ecology* vol. 7, 2003, www.consecol.org/vol7/iss3/art3.

Salthe, S.N., 'The natural philosophy of ecology: developmental systems ecology' *Ecological Complexity* vol. 2, 2004, pp. 1- 19.

Schneider, E.D. and Kay, J.J., 'Life as a manifestation of the Second Law of thermodynamics' *Mathematical and Computer Modelling*, vol. 19, 1994, pp. 25 - 48.

E. Schroedinger, *What is life?* New York, Macmillan, 1945.

Swenson, R., 'Emergent attractors and the law of maximum entropy production: foundations to a theory of general evolution' *Systems Research,* vol. 6, 1989, pp. 187 -198.

R.E. Ulanowicz, *Growth and Development: Ecosystems Phenomenology*. New York: Springer-Verlag, 1986.

R.E. Ulanowicz, *Ecology, The Ascendent Perspective*. New York: Columbia University Press, 1997.

J. von Uexküll, *Theoretical Biology*. London, Harcourt, Brace, 1926.